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AIR MINISTRY

METEOROLOGICAL OFFICE

Scientific Paper No. 10

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by H. C. SHELLARD, B.Sc.
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LONDON: HER MAJESTY'S STATIONERY OFFICE

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by H. C. Shellard, B.Sc., and R. F. M. Hay, M.A.

SUMMARY

Some statistical information is presented regarding the frequency, strength, height and persistence of temperature inversions and isothermal layers at the ocean weather stations I and J during one year. The relation between the occurrence of inversions, both frontal and non-frontal, and various synoptic features has been investigated and a number of significant relationships found. These are combined to give sets of rules which may be used for forecasting, from prognostic charts, the occurrence or absence of inversions over the ocean. Such forecasts are likely to be of interest mainly in relation to abnormal radio and radar propagation and, as this is most likely when a strong temperature inversion associated with a hydrolapse is present at low levels, special attention is paid to non-frontal inversions of 5°F or more with base below the 750-millibar level. In this connexion it should be mentioned that the temperatures used were measured by radio-sonde and that the radio-sonde, due to its lag, tends to underestimate the strength of temperature inversions. Although the radio-sonde also measures humidity the humidity data have not been used in this paper because of their doubtful reliability.

INTRODUCTION

The main purpose of this investigation is to examine the synoptic situations in which temperature inversions or isothermal layers occur, or are absent, over the north-east Atlantic and, if possible, to lay down some rules for forecasting them on the basis of the routine forecast surface and upper air charts.

The work is based entirely on data for the twelve-month period from March 1949 to February 1950 inclusive, using upper air ascents from the ocean weather stations I (60°N, 20°W) and J (53°50′N, 18°40′W), the 0600 GMT surface charts of the *Daily Weather Report* and the 0300 GMT circumpolar 1000–500-millibar thickness charts drawn at the Central Forecasting Office, Dunstable. This restriction to one year's data arose partly because of the considerable labour involved in classifying synoptic situations in detail over a long period and partly because it seemed that one year provided a sufficiently large number of inversions for study. Moreover the results obtained in this paper are statistical results and, to the extent that the selected period was a fairly typical year on the eastern North Atlantic, they may be regarded as representative of average conditions.

On this question of representativeness, Table I sets out seasonal means of air temperature, sea temperature, sea–air temperature difference and sea-level barometric pressure at the two

TABLE 1. *Seasonal mean values of air and sea temperature, sea–air temperature difference and barometric pressure*

	Spring Mar.–May 1949	Summer June–Aug. 1949	Autumn Sept.–Nov. 1949	Winter Dec. 1949–Feb. 1950	Year Mar. 1949–Feb. 1950
Ocean weather station I					
Air temperature (°F)	44·0 (—1·4)	52·1 (—0·5)	49·5 (0·0)	41·6 (—2·0)	46·8 (—1·0)
Sea temperature (°F)	47·8 (—0·6)	52·9 (—1·0)	52·6 (+0·4)	47·5 (—0·9)	50·2 (—0·5)
Sea–air temperature difference (°F)	3·8 (+0·8)	0·8 (—0·5)	3·1 (+0·4)	5·9 (+1·1)	3·4 (+0·5)
Barometric pressure (mb)	1009·8 (+0·1)	1013·6 (+3·2)	1002·3 (—0·6)	993·5 (—6·4)	1004·8 (—0·9)
Ocean weather station J					
Air temperature (°F)	49·4 (—0·5)	56·3 (—0·5)	53·6 (—0·3)	46·3 (—1·8)	51·4 (—0·8)
Sea temperature (°F)	51·3 (—0·2)	57·1 (—0·5)	56·4 (+0·4)	50·9 (—0·5)	53·9 (—0·2)
Sea–air temperature difference (°F)	1·9 (+0·3)	0·8 (0·0)	2·8 (+0·7)	4·6 (+1·3)	2·5 (+0·6)
Barometric pressure (mb)	1014·5 (+1·9)	1017·6 (+3·0)	1008·9 (—1·5)	1000·9 (—7·9)	1010·5 (—1·1)

The figures in brackets are departures from average values for the years 1948–57.

ocean weather stations during the period March 1949 to February 1950, and also (in brackets) their departures from average, the averages used being provisional ones for the ten-year period 1948–57 for the two stations concerned. Over the year as a whole, mean air and sea temperatures and mean pressures were all a little below average and mean sea–air temperature differences a little greater than average. Mean pressures were about three millibars above average in the summer and between six and eight millibars below average in winter, the spring and autumn anomalies being small. In the present context sea–air temperature difference is probably the most significant parameter, because if this is greater than normal low-level inversions are likely to be less frequent than normal and vice versa. In fact the mean sea–air temperature difference in the period selected was equal to or greater than normal in all seasons except in the summer at station I. The inference is that the inversion frequencies found in this paper are likely to be somewhat lower than in an average year, at least at station J. At station I the summer frequencies may be a little higher than average and may balance or even outweigh the probably lower than normal frequencies in the other seasons because, as will appear later, low-level inversions are more frequent in summer than in the other seasons.

Owing to the large number of synoptic features considered and the fact that each could take on anything from three to fourteen values it was found convenient to code the data and place them on punch cards. This permitted mechanical sorting and listing as desired, so reducing the labour involved.

Mr. H. C. Shellard was responsible for the analysis of the data and for the conclusions presented in this paper, while Mr. R. F. M. Hay extracted the basic data and carried out the considerable task of classifying the numerous synoptic features on the surface and upper air charts that were thought possibly to be relevant. In this latter work valuable assistance was given by Mr. C. V. Smith of the Central Forecasting Office, Dunstable.

OCEAN WEATHER STATION DATA — FREQUENCY, STRENGTH AND HEIGHT OF INVERSIONS

As a preliminary step the temperatures at the bases and tops of all inversions and isothermal layers which occurred at stations I and J during the selected period were tabulated. (For the sake of brevity inversions and isothermal layers, taken together, will be referred to hereafter as "inversions"; that is "inversions" with quotation marks will include isothermal layers, while inversions without quotation marks will, of course, refer to temperature inversions only.) All "inversions" with their bases below the 750-millibar level were included, even if their tops were above that level. Occasions when an "inversion" was present but had its base above the 750-millibar level were noted separately to distinguish them from occasions with no "inversion" at any level below the tropopause.

On the majority of days during the period considered there were four upper air ascents, at 0300, 0900, 1500 and 2100 GMT, but on a number of days one or more of the ascents were missed and on a few days no data were available, usually because no ship was on the station.

Table II gives for each station and observation hour the number of days in each season and the year when "inversions" were present. "Inversions" below 750 millibars are subdivided into isothermal layers and inversions of strength 1–4°, 5–9° and 10°F or more. The

TABLE II. *Seasonal and annual frequency of inversions and isothermal layers at the ocean weather stations I and J*

	Spring Mar.–May 1949 Time GMT				Summer June–Aug. 1949 Time GMT				Autumn Sept.–Nov. 1949 Time GMT				Winter Dec. 1949–Feb. 1950 Time GMT				Year Mar. 1949–Feb. 1950 Time GMT			
	0300	0900	1500	2100	0300	0900	1500	2100	0300	0900	1500	2100	0300	0900	1500	2100	0300	0900	1500	2100
	number of days																			
Ocean weather station I (60°00′N 20°00′W)																				
Isothermal layer, base below 750 mb level	10	14	17	12	19	17	17	16	16	13	16	8	20	11	9	10	65	55	59	46
Inversion, base below 750 mb level, strength 1–4°F	24	34	24	27	26	31	30	24	20	18	21	20	10	12	14	10	80	95	89	81
Inversion, base below 750 mb level, strength 5–9°F	12	7	15	7	21	14	18	22	5	9	4	7	8	5	5	3	46	35	42	39
Inversion, base below 750 mb level, strength ⩾ 10°F	2	0	1	0	2	5	3	2	5	4	5	6	0	0	0	3	9	9	9	11
Total "inversions" below 750 mb level	48	55	57	46	68	67	68	64	46	44	46	41	38	28	28	26	200	194	199	177
No "inversions" below 750 mb level	32	26	24	36	14	15	14	18	41	42	39	45	48	55	58	60	135	138	135	159
No ascent	12	11	11	10	10	10	10	10	4	5	6	5	4	7	4	4	30	33	31	29
No "inversions" below tropopause	16	12	9	12	8	7	9	11	25	26	26	37	22	36	30	34	71	81	74	94
Ocean weather station J (53°50′N 18°40′W)																				
Isothermal layer, base below 750 mb level	18	18	18	15	16	11	6	14	17	9	16	17	16	12	15	12	67	50	55	58
Inversion, base below 750 mb level, strength 1–4°F	27	33	34	39	34	30	33	35	15	18	18	13	17	14	17	25	93	95	102	112
Inversion, base below 750 mb level, strength 5–9°F	17	18	14	10	16	20	23	16	9	15	11	11	11	9	6	7	53	62	54	44
Inversion, base below 750 mb level, strength ⩾ 10°F	2	3	4	3	3	5	1	3	5	3	2	2	1	2	3	1	11	13	10	9
Total "inversions" below 750 mb level	64	72	70	67	69	66	63	68	46	45	47	43	45	37	41	45	224	220	221	223
No "inversions" below 750 mb level	23	18	20	22	14	16	19	14	36	40	34	40	44	52	49	44	117	126	122	120
No ascent	5	2	2	3	9	10	10	10	9	6	10	8	1	1	0	1	24	19	22	22
No "inversions" below tropopause	14	13	6	15	8	8	10	3	24	26	23	23	21	30	34	28	67	77	73	69

numbers of days with no "inversion" below 750 millibars, no "inversion" at any level and with no ascent are also given. At both stations a marked seasonal variation in the occurrence of inversions is shown with frequency greatest in summer and least in winter; this variation is not so apparent for isothermal layers. There is no significant diurnal variation. The more southerly station J shows a slightly higher frequency of inversions than station I but this result might not be repeated in other years. The mean probability of there being an inversion below 750 millibars at any observation hour is given in the following table, in which the figures in brackets are the corresponding probabilities for strong inversions, that is inversions of 5°F or more:

	Spring	Summer	Autumn	Winter	Year
Ocean weather station I	0·47 (0·14)	0·60 (0·27)	0·36 (0·13)	0·31 (0·07)	0·41 (0·15)
Ocean weather station J	0·57 (0·20)	0·67 (0·26)	0·37 (0·18)	0·32 (0·11)	0·48 (0·19)

Thus if it is assumed that the selected year was a fairly typical one, then it may be expected that on the average there will be an inversion below the 750-millibar level on between 60 and 70 per cent of occasions in summer and on about 30 per cent of occasions in winter. For strong inversions the frequencies are about 25 per cent in summer and 10 per cent in winter. If "inversions" at all levels are considered the corresponding frequencies become about 90 per cent in summer and 65 to 70 per cent in winter.

Table III shows, for days with one or more inversions below the 750-millibar level on the 0300 GMT ascent, how the heights of base of the lowest inversions were distributed in each season and the year. The figures in brackets include isothermal layers below 750 millibars, either alone or below an inversion, that is, they are the frequencies of lowest "inversion" below the 750-millibar level arranged according to height of base. The level of greatest frequency of lowest inversions was between 3,000 and 4,000 feet at station I and between 4,000 and 5,000 feet at station J, taking the year as a whole. The same result is obtained even if all inversions, not only the lowest, below 750 millibars are taken into account, the numbers of days with two or more inversions with their bases below this level being relatively small, 26 and 20 at stations I and J respectively. Another point of interest is that "inversions" at low levels (below 3,000 feet) were most frequent in summer and somewhat rare in winter at both stations. This is doubtless due to the sea–air temperature difference usually being small or even negative in summer and large in winter in these areas. In summer, out of 49 days at station I and 53 at station J with lowest inversions below 750 millibars, 21 and 19 inversions respectively had bases below 3,000 feet. In winter the corresponding figures were 18 and 29, of which only 1 and 2 respectively were below 3,000 feet and none at all were below 2,000 feet. Most of the inversions with bases below 1,000 feet were surface inversions occurring in the summer half-year.

RELATION BETWEEN THE INCIDENCE OF "INVERSIONS" AND SYNOPTIC FEATURES

General

In order to study possible relationships between the occurrence of "inversions" and various features on the synoptic charts, it was necessary to make detailed classifications of selected parameters over suitable areas surrounding each station from the daily surface and 1000–500-millibar thickness charts. One surface chart, that for 0600 GMT in the *Daily*

TABLE III. *Frequency of lowest inversions below the 750 mb level at 0300 GMT, arranged according to height of base, at ocean weather stations I and J*

Height range	Spring Mar.–May 1949	Summer June–Aug. 1949	Autumn Sept.–Nov. 1949	Winter Dec. 1949–Feb. 1950	Year Mar. 1949–Feb. 1950
feet			*number of days*		
Ocean weather station I					
Surface	1 (2)	4 (5)	3 (6)	0 (2)	8 (15)
100–300	0 (0)	0 (0)	0 (1)	0 (0)	0 (1)
400–600	0 (0)	1 (1)	0 (1)	0 (0)	1 (2)
700–900	1 (1)	3 (3)	0 (1)	0 (0)	4 (5)
1,000–1,900	3 (4)	4 (5)	2 (5)	0 (2)	9 (16)
2,000–2,900	5 (6)	9 (14)	6 (9)	1 (1)	21 (30)
3,000–3,900	11 (14)	10 (13)	7 (6)	1 (3)	29 (36)
4,000–4,900	1 (2)	11 (15)	5 (8)	4 (8)	21 (33)
5,000–5,900	9 (10)	2 (6)	4 (5)	6 (13)	21 (34)
6,000–6,900	3 (5)	2 (4)	2 (2)	4 (7)	11 (18)
7,000 and above	4 (4)	3 (2)	1 (2)	2 (2)	10 (10)
Totals	38 (48)	49 (68)	30 (46)	18 (38)	135 (200)
Ocean weather station J					
Surface	1 (2)	4 (6)	0 (1)	0 (0)	5 (9)
100–300	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
400–600	0 (2)	0 (1)	0 (0)	0 (0)	0 (3)
700–900	1 (2)	1 (2)	0 (0)	0 (0)	2 (4)
1,000–1,900	6 (8)	9 (16)	1 (4)	0 (1)	16 (29)
2,000–2,900	4 (6)	5 (8)	4 (5)	2 (4)	15 (23)
3,000–3,900	3 (10)	6 (6)	7 (9)	8 (10)	24 (35)
4,000–4,900	7 (9)	13 (14)	9 (11)	3 (8)	32 (42)
5,000–5,900	11 (11)	7 (11)	5 (9)	7 (11)	30 (42)
6,000–6,900	7 (10)	6 (4)	3 (4)	6 (9)	22 (27)
7,000 and above	6 (4)	2 (1)	0 (3)	3 (2)	11 (10)
Totals	46 (64)	53 (69)	29 (46)	29 (45)	157 (224)

The figures in brackets include isothermal layers.

Weather Report, and one upper air chart, the 0300 GMT circumpolar 1000–500-millibar thickness chart prepared at the Central Forecasting Office, Dunstable, were used for each day. The number of parameters used was deliberately made large in the hope that all those which might be relevant would be included. The result was that a very large amount of working data was obtained and it soon became obvious that much laborious cross-referencing would be necessary to examine possible connexions between the occurrence of "inversions" and that of any particular synoptic feature or set of features. In order to reduce the work it was therefore decided to put as many of the data as possible on daily punch cards. Information about the layout of the punch card used, details of the synoptic features and "inversion" data included and the codes adopted are not included in this paper but can be supplied to anyone interested.

Having transferred all the data to punch cards, it was decided first to sort the cards according to whether there were surface fronts within 550 nautical miles or not and also according to whether "inversions" were present or not on the ascents for 0300 GMT. On six days at station I and ten days at station J there was no ascent at 0300 GMT; it would have been possible to use data from the 2100 and 0900 GMT ascents but this was not considered worthwhile because of the relatively small numbers of days involved. Since it is obvious that the mere presence of a front on the surface chart would not necessarily cause an "inversion" it was essential to distinguish between those cases in which the frontal surface was likely to lie over the station below the 750-millibar level and those in which it was not. This was done statistically from the information on the punch card concerning type, distance and movement of the front. It was assumed that "inversions" below the 750-millibar level at the station would be unlikely to be caused by an approaching warm front or occlusion which was at a greater distance than 350 nautical miles (corresponding to a slope of about 1 in 260), a receding cold front or occlusion which was at a greater distance than 150 nautical miles (corresponding to a slope of about 1 in 110) or by a receding warm front or approaching cold front regardless of its distance. For this purpose quasi-stationary fronts were treated as warm fronts if stationary or approaching and as cold fronts if receding. The results are set out in Table IV.

Table IV shows that on the great majority of days, 81 per cent at station I and 87 per cent at station J, there was a surface front of some kind within 550 nautical miles of each station. On such days the frequency of occurrence of "inversions" at any level was somewhat greater than it was on days without fronts, the respective frequencies being about 80 and 70 per cent at either station. For "inversions" below 750 millibars the corresponding frequencies were 63 and 47 per cent at station I and 68 and 52 per cent at station J. Of all the occasions of "inversion" below the 750-millibar level a little less than half are likely to have been of frontal origin. Of those that were probably frontal the majority were associated with warm fronts and occlusions, particularly at station I.

The main conclusion to be drawn from Table IV is that if the expectation of an "inversion" below 750 millibars had been related solely to the presence on the surface chart of a front having the appropriate distance, type and motion with respect to the station, then the expectation would have been realized on 97 days out of 129 (75 per cent) at station I and on 99 days out of 142 (70 per cent) at station J. It is also of interest that at station I the majority of inversions below 750 millibars and also of strong inversions ($\geqslant$ 5°F) below that level were probably of frontal origin but at station J the majority in each case were definitely non-frontal.

Next it was decided to examine the frequency distribution of every parameter punched on the cards for all days falling into each of a number of different categories. These included days with and without "inversions" either at any level or below the 750-millibar level, days with inversions or with strong inversions ($\geqslant$ 5°F) below the 750-millibar level, persistent inversions, strong and persistent low-level inversions and all days together. The two categories, inversion below 750 millibars and strong inversion below 750 millibars, were subdivided according to whether the inversions were probably frontal or definitely non-frontal. Comparison between the various frequency distributions found would be expected to show up any relationships which might be of interest between the occurrence or absence of "inversions" and synoptic features. Persistent inversions were defined as occurring when every ascent over

TABLE IV. *Incidence of "inversions" at ocean weather stations I and J in relation to the presence of surface fronts within 550 nautical miles and the likelihood that the "inversions" are of frontal origin or not*

	Type of front	Station I					Station J				
		Inversion below 750 mb	Isothermal below 750 mb	No "inversion"	"Inversion" above 750 mb	Total	Inversion below 750 mb	Isothermal below 750 mb	No "inversion"	"Inversion" above 750 mb	Total
		number of days					*number of days*				
Surface front within 550 nautical miles of ocean weather station and likely to give "inversion" below 750 mb level over station	Warm	33 (18)	6	1	3	43	22 (11)	12	3	5	42
	Cold	7 (0)	4	3	6	20	10 (3)	8	4	2	24
	Occluded	30 (13)	11	9	8	58	16 (3)	14	16	10	56
	Quasi-stationary	5 (3)	1	1	1	8	14 (6)	3	2	1	20
	Total	75 (34)	22	14	18	129	62 (23)	37	25	18	142
Surface front within 550 nautical miles of ocean weather station but not likely to give "inversion" below 750 mb level over station	Warm	15 (3)	9	3	7	34	29 (12)	5	7	3	44
	Cold	13 (7)	10	7	9	39	32 (12)	13	9	14	68
	Occluded	12 (2)	11	26	14	63	11 (6)	7	12	7	37
	Quasi-stationary	3 (1)	1	2	2	8	3 (3)	2	1	—	6
	Total	43 (13)	31	38	32	144	75 (33)	27	29	24	155
No front within 550 nautical miles	Total	17 (8)	12	19	14	62	20 (8)	3	13	8	44
	Grand Total	135 (55)	65	71	64	335	157 (64)	67	67	50	341

The figures in brackets are the number of days on which strong inversions ($\geqslant$ 5°F) occurred.

a period of 48 hours or longer showed an inversion below the 750-millibar level and when the height of the base of the inversion did not change by more than 2,000 feet between any two consecutive ascents. One or two modifications to this definition were found necessary, for example when only one ascent was missing, interpolated values were used; when there were two or more inversions on the same ascent, either could be used; when an ascent, or two successive ascents, had an isothermal layer which showed continuity with inversions on the previous and subsequent ascents, it was accepted; when an ascent had an inversion above the 750-millibar level this was accepted if the ascents six hours before and after had inversions with bases between 6,000 feet and 750 millibars. Strong persistent low-level inversions were defined as inversions of 3°F or more with their bases below 5,000 feet which appeared on every ascent over a period of 24 hours or more. Here again some slight relaxations of the definition were permitted; an inversion of only 2°F on one ascent and a height of up to 5,300 feet on not more than two successive ascents were accepted.

All the results obtained in this way cannot be reproduced here and most of them are of no particular significance. Those which are of interest and which are thought to have a possible value in forecasting inversions are reproduced in Tables V to VII and are discussed in the following sections.

Relation with synoptic parameters on the 1000–500-*millibar thickness chart*

Table V shows the numbers of days in each of thirteen categories when the circulation pattern on the 1000–500-millibar thickness chart belonged to each of the three groups (i) cold pool, trough or adjacent trough, (ii) warm pool, ridge or adjacent ridge and (iii) straight or irregular isopleths. The circulation pattern is that over an area extending five degrees of latitude north and south of the station and ten degrees of longitude east and west of the station. It was not possible to make any significant deductions from the frequencies of the fourteen individual circulation types originally selected because the number of observations of each type was usually too small. They were therefore grouped, as indicated above, into three main types.

The bottom line of Table V shows that over the year examined the frequencies of the three types were about equal (between 31 and 35 per cent). The first two lines of the table show that the frequency of "inversions" was appreciably greater, and that of their absence appreciably less, on days with a ridge or warm pool than on other days. They occurred on 86 and 89 per cent of the days with a ridge or warm pool at stations I and J respectively compared with their overall frequencies of 79 and 80 per cent respectively. The same tendency is shown rather more strongly by the figures for "inversions" below the 750-millibar level and for inversions alone below that level. Strong inversions and persistent inversions were relatively infrequent on days with a trough or cold pool, being much more frequently associated with a ridge or warm pool. The association of inversions and strong inversions with a ridge or warm pool was appreciably greater for frontal than for non-frontal inversions, particularly at station I. In all cases the association with a trough or cold pool was relatively weak. These results suggest as a possible "rule" that on days when the circulation pattern on the thickness chart consists of a ridge or warm pool an "inversion" is to be expected. It is of interest that the numbers of *periods* of persistent inversion, as defined above, during the year examined were 9 at station I and 20 at station J but the longest of these lasted 13 days at station I but only 6½ days at station J. Corresponding figures for strong and persistent low-level inversions were 11 and 12 with longest periods 5½ and 4¾ days.

TABLE V. *Incidence of "inversions" at the ocean weather stations I and J in relation to the circulation pattern on the 1000–500 mb thickness chart*

	Station I				Station J			
	Trough or cold pool	Ridge or warm pool	Straight or irregular isopleths	Total	Trough or cold pool	Ridge or warm pool	Straight or irregular isopleths	Total
	number of days				*number of days*			
1. "Inversion" at any level	76	101	87	264	83	101	90	274
2. No "inversion" at any level	28	17	26	71	31	12	24	67
3. "Inversion" below 750 mb level	47	92	61	200	59	91	74	224
4. No "inversion" below 750 mb level	57	26	52	135	55	22	40	117
5. Frontal inversion below 750 mb level	10	45	20	75	10	29	23	62
6. Non-frontal inversion below 750 mb level	16	25	19	60	26	38	31	95
7. Inversion below 750 mb level	26	70	39	135	36	67	54	157
8. Strong frontal inversion below 750 mb level	3	28	3	34	3	14	6	23
9. Strong non-frontal inversion below 750 mb level	6	6	9	21	10	16	15	41
10. Strong inversion below 750 mb level	9	34	12	55	13	30	21	64
11. Persistent inversion below 750 mb level	9	22	17	48	14	29	22	65
12. Strong persistent inversion below 5,000 ft	4	15	7	26	5	6	11	22
13. All cases	104	118	113	335	114	113	114	341

A table was also prepared showing the numbers of days, in each of the same 13 categories as used in Table V, when the 1000–500-millibar thickness isopleths were curved cyclonically or anticyclonically, or were straight. The measurements of curvature related to an area within a circle centred on the weather station and having a radius of two degrees of latitude (120 nautical miles). The table is not reproduced here because the results and significance were very similar to those of Table V, that is they suggested that "inversions" are to be expected when the curvature of the isopleths on the thickness chart are anticyclonic.

In Table VI frequencies are presented of days with thermal wind directions within the four quadrants 010–090°, 100–180°, 190–270° and 280–360°. The analysis was carried out separately for thermal wind speeds within the ranges $\leqslant$ 30 knots, 35–55 knots and $\geqslant$ 60 knots, but as no tendency was found for stronger winds to be associated with inversions, or vice versa, only the frequencies for all speeds together are presented. The thermal wind values were based on measurements of the isopleths within a circle of radius two degrees of latitude centred on the station and also on the actual thermal winds as measured over the ocean weather station. Comparison of the figures for categories 1 and 2 and for categories 3 and 4 shows a definite tendency for "inversions" to occur on a very high proportion of the days when the thermal wind direction was within the north-west quadrant. The most common thermal wind direction is south-westerly but it will be noted that in categories 6 and 8 to 12 (non-frontal inversions and strong or persistent inversions) thermal wind directions were just about as frequently in the north-west as in the south-west quadrant. A possible "rule", therefore, is that "inversions" are likely to be associated with north-westerly thermal winds on the 1000–500-millibar thickness chart. The frequencies of thermal winds for each measured direction, estimated to the nearest ten degrees, were also computed and it was found that the "rule" became slightly more effective, especially at station J, if the range 280–030° was used in place of 280–360°. This is shown by the figures on the right-hand side of Table VI.

Relation with parameters on the surface chart

The relation between the occurrence of "inversions" and the presence of fronts on the surface chart has already been discussed on pages 5 to 9. Only one of the other surface parameters considered was found to have any obvious value for predicting the occurrence of "inversions" and this was the main surface-pressure feature within 500 nautical miles of the station. Thirteen types of main surface-pressure feature were used in the original classification but here again the number of observations of each type was in most cases too small to give a reliable indication. They were therefore grouped into three sets of related features, namely cyclonic features, straight isobars and anticyclonic features. The results, set out in Table VII, show that on a large majority of occasions the main surface-pressure feature was cyclonic in nature. On the occasions when it consisted of a ridge or high or of straight isobars, however, there was nearly always an "inversion" present (100 cases out of 106 at station I and 132 cases out of 141 at station J). It will also be noted that strong non-frontal or persistent inversions were much more frequently associated with this type of feature than they were with cyclonic features, which was to be expected. The association between inversions and non-cyclonic surface-pressure features is appreciably stronger for non-frontal than for frontal inversions. A further point is that an absence of "inversions" was nearly always associated with cyclonic surface-pressure features.

TABLE VI. *Incidence of "inversions" at the ocean weather stations I and J in relation to the thermal wind direction on the 1000–500 mb thickness chart*

	Station I						Station J						Station I	Station J
	010° -090°	100° -180°	190° -270°	280° -360°	Calm	Total	010° -090°	100° -180°	190° -270°	280° -360°	Calm	Total	280° -030°	280° -030°
	number of days						*number of days*							
1. "Inversion" at any level	5	41	134	80	4	264	15	19	140	95	5	274	82	106
2. No "inversion" at any level	4	20	40	4	3	71	4	14	43	5	1	67	5	5
3. "Inversion" below 750 mb level	3	27	101	66	3	200	14	16	109	80	5	224	68	90
4. No "inversion" below 750 mb level	6	34	73	18	4	135	5	17	74	20	1	117	19	21
5. Frontal inversion below 750 mb level	0	5	41	28	1	75	4	5	30	23	0	62	28	27
6. Non-frontal inversion below 750 mb level	2	5	26	27	0	60	7	4	39	41	4	95	29	46
7. Inversion below 750 mb level	2	10	67	55	1	135	11	9	69	64	4	157	57	73
8. Strong frontal inversion below 750 mb level	0	1	16	16	1	34	2	1	10	10	0	23	16	12
9. Strong non-frontal inversion below 750 mb level	2	2	8	9	0	21	3	1	16	19	2	41	11	21
10. Strong inversion below 750 mb level	2	3	24	25	1	55	5	2	26	29	2	64	27	33
11. Persistent inversion below 750 mb level	2	4	21	19	2	48	9	5	26	22	3	65	21	29
12. Strong persistent inversion below 5,000 ft	2	2	10	10	2	26	5	0	8	7	2	22	12	11
13. All cases	9	61	174	84	7	335	19	33	183	100	6	341	87	111

TABLE VII. *Incidence of "inversions" at the ocean weather stations I and J in relation to the main surface-pressure feature within 500 nautical miles*

	Station I				Station J			
	Low, trough, wave or col (cyclonic)	Straight isobars	Ridge, high or col (anti-cyclonic)	Total	Low, trough, wave or col (cyclonic)	Straight isobars	Ridge, high or col (anti-cyclonic)	Total
		number of days				*number of days*		
1. "Inversion" at any level	164	32	68	264	142	37	95	274
2. No "inversion" at any level	65	3	3	71	58	6	3	67
3. "Inversion" below 750 mb level	110	27	63	200	104	34	86	224
4. No "inversion" below 750 mb level	119	8	8	135	96	9	12	117
5. Frontal inversion below 750 mb level	38	15	22	75	24	10	28	62
6. Non-frontal inversion below 750 mb level	25	6	29	60	30	14	51	95
7. Inversion below 750 mb level	63	21	51	135	54	24	79	157
8. Strong frontal inversion below 750 mb level	16	7	11	34	7	4	12	23
9. Strong non-frontal inversion below 750 mb level	4	3	14	21	7	6	28	41
10. Strong inversion below 750 mb level	20	10	25	55	14	10	40	64
11. Persistent inversion below 750 mb level	9	11	28	48	16	5	44	65
12. Strong persistent inversion below 5,000 ft	2	4	20	26	2	0	20	22
13. All cases	229	35	71	335	200	43	98	341

COMBINATION OF MAIN RELATIONSHIPS FOUND ABOVE INTO SETS OF "FORECASTING RULES"

Consideration of the relationships discussed in the previous section has suggested five possible rules connecting the occurrence of certain synoptic features (two relating to the surface chart and three to the 1000–500-millibar thickness chart) with the presence of "inversions". They are based on Tables IV to VII and on the table referred to in the first paragraph of page 11, and are set out in Table VIII. Table VIII shows, in the form of contingency tables, the results of applying each of these rules separately to the ocean weather station data. In order to avoid having large numbers of occasions of "no forecast" it has been assumed that if a rule does not apply then an "inversion" is not expected. This procedure permits comparison of the usefulness of the five rules using the "index of usefulness" due to Crossley,[1]* $U=\frac{1}{2}(C+C')$, where C and C' are the proportion of whites and blacks correctly forecast, a white or black in this case being the presence or absence, respectively, of an "inversion". For worthwhile forecasting the value of U must exceed one-half. On this basis it can be seen that most of the rules have some degree of usefulness. On the whole rule 5, the one based on the main pressure feature on the surface chart, has the highest values of U, ranging from 0·61 to 0·76. Rule 1, on the other hand, has the lowest values but this arises partly because the rule cannot be expected to indicate non-frontal inversions and partly because a frontal surface may sometimes be marked by a layer of less than normal lapse rate rather than by an "inversion". It will also be noted that rule 1 is inapplicable to categories 1, 4 and 7 of Table VIII and that it cannot fairly be applied to categories 3 and 6 because frontal inversions have already been defined as those occurring when a frontal surface is likely to lie over the station below the 750-millibar level. The highest values of U mostly occur in the strong-inversion categories in which rule 5 is clearly the most useful for indicating non-frontal inversions, while rules 2 and 3 appear to be rather more useful for frontal inversions, particularly at station I.

The next step was to try the effect of combining these five rules in various ways in order to find the most useful set of rules for forecasting inversions directly from prognostic charts. As such forecasts are likely to be of use mainly in relation to abnormal radio or radar propagation and this is most likely to occur with a strong low-level inversion associated with a hydrolapse, a set of rules for forecasting strong ($\geqslant$ 5°F) non-frontal inversions below the 750-millibar level is likely to be of most value.

Numerous combinations of the five rules were tried and it was found that the most useful for (*a*) non-frontal inversions and (*b*) inversions in general, were as follows:

(*a*) If rule 1 does not apply and either rule 5 or any pair of the three rules 2, 3 and 4 does not apply then a non-frontal inversion is to be expected.

(*b*) If either rule 5 or rules 2, 3 and 4 together apply then an inversion is to be expected.

The results of applying these two sets of rules, called for brevity "set A" and "set B", respectively, are given in Table IX. Since set A was found to be about equally as effective for forecasting frontal inversions provided that "rule 1 applies" was substituted for "rule 1 does not apply", the results of so using it are included in the table. The values of U obtained with set A lie between 0·82 and 0·86 at both stations, while for all types of inversion (set B) they usually exceed 0·70, reaching 0·73 or 0·74 if isothermal layers are excluded. These are

*The superscript figure refers to the bibliography on p. 21.

useful results, particularly the fact that strong non-frontal inversions below the 750-millibar level may be indicated from the synoptic charts with an index of usefulness exceeding 0·80. It will be noted that about 90 per cent of the occurrences of such inversions and over 75 per cent of the non-occurrences are correctly indicated. It should be emphasized that sets of rules might be found giving higher proportions of inversions correctly indicated but the proportions of non-occurrences correctly indicated would be much lower. To take an extreme case, the simple procedure of always forecasting an inversion would give a proportion of occurrences correct (C) of 1·00, but the proportion of non-occurrences correct (C') would be zero and U would therefore be 0·50, a result of no value.

The two sets of rules may be set out in detail as follows:

Set A (i) A non-frontal inversion below the 750-millibar level is likely to occur if no frontal surface is expected below that level over the area concerned and if, in addition, *either* there is no cyclonic feature within 500 nautical miles on the surface chart *or* any two of the following features are present on the 1000–500-millibar thickness chart: (*a*) anticyclonically curved isopleths within about 120 nautical miles, (*b*) a warm pool or a ridge within about 300 nautical miles, (*c*) thermal wind direction within the range 280–030° (through north) inclusive over the immediate area.

(ii) A frontal inversion below the 750-millibar level is likely to occur if a frontal surface is expected to exist below that level over the area concerned and if, in addition, *either* there is no cyclonic feature within 500 nautical miles on the surface chart *or* any two of the following features are present on the 1000–500-millibar thickness chart (*a*) anticyclonically curved isopleths within about 120 nautical miles, (*b*) a warm pool or a ridge within about 300 nautical miles, (*c*) thermal wind direction within the range 280–030° (through north) inclusive over the immediate area.

Set B An inversion below the 750-millibar level is likely to occur if *either* there is no cyclonic feature within 500 nautical miles on the surface chart *or* there is anticyclonic curvature of the isopleths within about 120 nautical miles, a warm pool or a ridge within about 300 nautical miles *and* a thermal wind direction within the range 280–030° (through north) inclusive on the 1000–500-millibar thickness chart.

PRACTICAL APPLICATION OF RULES

Two sets of rules have been found which when applied to the surface and upper air charts give useful indications of the presence or absence of inversions. The set of rules most likely to be of value in practice is set A applied to the prediction of strong non-frontal inversions. In order to provide a forecast it is suggested that these rules should be applied to the prognostic charts, that is the prebaratic and forecast thickness charts. In so far as these forecast charts are inaccurate over the area of application it is of course only to be expected that the index of usefulness will fall below the values, which have been found in this paper, of about 0·83 for non-frontal inversions and about 0·73 for all inversions. Another possibility, however, is that, owing to persistence, application of the rules to the most recent actual surface and upper air charts may give a reasonably useful forecast for a relatively short period ahead. This has been tested by applying them using the data of this investigation. This was possible because each daily punch card included information from the 1500 GMT upper air ascent as well as the synoptic features taken from the 0600 GMT surface and 0300 GMT upper air thickness charts. To simplify matters only set B rules have been tested in this way. To test

TABLE VIII. *Application of five possible rules for indicating from synoptic features the occurrence of "inversions" at ocean weather stations I and J*

	Rule 1								Rule 2								Rule 3							
	Station I				Station J				Station I				Station J				Station I				Station J			
	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness
1. "Inversion" at any level																								
"Inversion"	..	..	..	..	..	..	..	..	107	157	0·41	*0·56*	95	179	0·35	*0·62*	101	163	0·38	*0·57*	101	173	0·37	*0·59*
No "inversion"	..	..	..		..	..	..		51	20	0·72		60	7	0·90		54	17	0·76		55	12	0·82	
2. "Inversion" below 750 mb level																								
"Inversion"	97	103	0·49	*0·62*	99	125	0·44	*0·54*	91	109	0·45	*0·59*	87	137	0·39	*0·63*	92	108	0·46	*0·63*	91	133	0·41	*0·61*
No "inversion"	103	32	0·76		74	43	0·63		99	36	0·73		102	15	0·87		109	26	0·81		95	22	0·81	
3. Frontal inversion below 750 mb level																								
Inversion	..	..	..	..	..	..	..	..	43	32	0·57	*0·63*	22	40	0·35	*0·53*	45	30	0·60	*0·66*	29	33	0·47	*0·58*
No inversion	..	..	..		..	..	..		176	84	0·68		199	80	0·71		187	73	0·72		195	84	0·70	
4. Non-frontal inversion below 750 mb level																								
Inversion	..	..	..	..	..	..	..	..	30	30	0·50	*0·57*	42	53	0·44	*0·60*	25	35	0·42	*0·54*	38	57	0·40	*0·55*
No inversion	..	..	..		..	..	..		178	97	0·65		186	60	0·76		182	93	0·66		171	75	0·69	
5. Inversion below 750 mb level																								
Inversion	75	60	0·56	*0·64*	62	95	0·39	*0·48*	73	62	0·54	*0·64*	64	93	0·41	*0·60*	70	65	0·52	*0·64*	67	90	0·43	*0·59*
No inversion	146	54	0·73		104	80	0·57		146	54	0·73		146	38	0·79		152	48	0·76		138	46	0·75	
6. Strong frontal inversion below 750 mb level																								
Inversion	..	..	..	..	..	..	..	..	27	7	0·79	*0·73*	10	13	0·43	*0·59*	28	6	0·82	*0·76*	14	9	0·61	*0·65*
No inversion	..	..	..		..	..	..		201	100	0·67		236	92	0·74		211	90	0·70		219	99	0·69	
7. Strong non-frontal inversion below 750 mb level																								
Inversion	..	..	..	..	..	..	..	..	7	14	0·33	*0·48*	18	23	0·44	*0·58*	6	15	0·29	*0·46*	16	25	0·39	*0·53*
No inversion	..	..	..		..	..	..		194	120	0·62		216	84	0·72		202	112	0·64		203	97	0·68	
8. Strong inversion below 750 mb level																								
Inversion	34	21	0·62	*0·64*	23	41	0·36	*0·47*	34	21	0·62	*0·64*	28	36	0·44	*0·59*	34	21	0·62	*0·68*	30	34	0·47	*0·58*
No inversion	185	95	0·66		158	119	0·57		187	93	0·67		203	74	0·73		196	84	0·70		194	83	0·70	

TABLE VIII. *Continued*

	Rule 4								Rule 5									
	Station I				Station J				Station I				Station J				Station I	Station J
	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Expected	Not expected	Proportion correct	Index of usefulness	Total no. of days	
1. "Inversion" at any level																		
"Inversion"	82	182	0·31	*0·62*	106	168	0·39	*0·66*	99	165	0·38	*0·65*	132	142	0·48	*0·67*	264	274
No "inversion"	66	5	0·93		62	5	0·93		66	5	0·93		58	9	0·87		71	67
2. "Inversion" below 750 mb level																		
"Inversion"	68	132	0·34	*0·60*	90	134	0·40	*0·61*	89	111	0·45	*0·67*	120	104	0·54	*0·68*	200	224
No "inversion"	116	19	0·86		96	21	0·82		120	15	0·89		96	21	0·82		135	117
3. Frontal inversion below 750 mb level																		
Inversion	28	47	0·37	*0·57*	27	34	0·44	*0·57*	37	38	0·49	*0·61*	38	24	0·61	*0·62*	75	62
No inversion	201	59	0·77		195	84	0·70		191	69	0·73		176	103	0·63		260	279
4. Non-frontal inversion below 750 mb level																		
Inversion	29	31	0·48	*0·64*	46	49	0·48	*0·61*	36	24	0·60	*0·67*	65	30	0·68	*0·69*	60	95
No inversion	217	58	0·79		181	65	0·74		205	70	0·75		170	76	0·69		275	246
5. Inversion below 750 mb level																		
Inversion	57	78	0·42	*0·64*	73	84	0·47	*0·63*	72	63	0·53	*0·69*	103	54	0·66	*0·72*	135	157
No inversion	170	30	0·85		146	38	0·79		168	32	0·84		146	38	0·79		200	184
6. Strong frontal inversion below 750 mb level																		
Inversion	16	18	0·47	*0·62*	12	11	0·52	*0·61*	18	16	0·34	*0·62*	16	7	0·70	*0·65*	34	23
No inversion	230	71	0·76		219	99	0·69		213	88	0·71		193	125	0·61		301	318
7. Strong non-frontal inversion below 750 mb level																		
Inversion	11	10	0·52	*0·64*	21	20	0·51	*0·61*	17	4	0·81	*0·76*	34	7	0·83	*0·74*	21	41
No inversion	238	76	0·76		210	90	0·70		225	89	0·72		193	107	0·64		314	300
8. Strong inversion below 750 mb level																		
Inversion	27	28	0·49	*0·64*	33	31	0·52	*0·62*	35	20	0·64	*0·69*	50	14	0·78	*0·73*	55	64
No inversion	220	60	0·79		199	78	0·72		211	69	0·75		186	91	0·67		280	277

Rule 1. "Inversion" likely if front on surface chart is likely to be associated with frontal surface below 750 mb level over station.
Rule 2. "Inversion" likely if curvature of 1000–500 mb thickness isopleths over station is anticyclonic.
Rule 3. "Inversion" likely if circulation pattern on 1000–500 mb thickness chart shows warm pool or ridge over or near station.
Rule 4. "Inversion" likely if thermal wind direction (1000–500 mb) is within range 280–030° inclusive.
Rule 5. "Inversion" likely if main pressure feature on surface chart within 500 nautical miles is not cyclonic.

TABLE IX. *Application of two sets of rules relating occurrence of synoptic features to that of inversions*

	Station I					Station J				
	Expected	Not expected	Total	Proportion correct	Index of usefulness	Expected	Not expected	Total	Proportion correct	Index of usefulness
Set A										
Non-frontal inversion below 750 mb level										
Inversion	49	11	60	0·82	*0·83*	75	20	95	0·79	*0·82*
No inversion	233	42	275	0·85		211	35	246	0·86	
Strong non-frontal inversion below 750 mb level										
Inversion	19	2	21	0·90	*0·84*	37	4	41	0·90	*0·83*
No inversion	242	72	314	0·77		227	73	300	0·76	
Frontal inversion below 750 mb level										
Inversion	58	17	75	0·77	*0·84*	48	14	62	0·77	*0·83*
No inversion	237	23	260	0·91		248	31	279	0·89	
Strong frontal inversion below 750 mb level										
Inversion	30	4	34	0·88	*0·86*	20	3	23	0·87	*0·84*
No inversion	250	51	301	0·83		259	59	318	0·81	
Set B										
All inversions below 750 mb level										
Inversion	87	48	135	0·64	*0·73*	109	48	157	0·69	*0·73*
No inversion	164	36	200	0·82		140	44	184	0·76	
All strong inversions below 750 mb level										
Inversion	42	13	55	0·76	*0·74*	54	10	64	0·84	*0·74*
No inversion	199	81	280	0·71		178	99	277	0·64	
All "inversions" below 750 mb level										
"Inversion"	106	94	200	0·53	*0·70*	131	93	224	0·58	*0·70*
No "inversion"	118	17	135	0·87		95	22	117	0·81	
All "inversions" at any level										
"Inversion"	118	146	264	0·45	*0·69*	144	130	274	0·53	*0·70*
No "inversion"	66	5	71	0·93		58	9	67	0·87	

Set A: { Non-frontal inversion likely if rule 1 does not apply and if either rule 5 or any pair of the three rules 2, 3 and 4 does apply.
Frontal inversion likely if rule 1 does apply together with either rule 5 or any pair of the three rules 2, 3 and 4.

Set B: Inversion likely if either rule 5 or rules 2, 3 and 4 together apply.

TABLE X. *Application of set B rules to forecasting the occurrence of inversions at 1500 GMT from the 0300 GMT upper air and 0600 GMT surface charts*

	Station I					Station J				
	Expected	Not expected	Total	Proportion correct	Index of usefulness	Expected	Not expected	Total	Proportion correct	Index of usefulness
Inversion below 750 mb level										
Inversion	84	56	140	0·60	*0·69*	105	61	166	0·63	*0·68*
No inversion	152	42	194	0·78		129	148	77	0·73	
Strong inversion below 750 mb level										
Inversion	40	11	51	0·78	*0·74*	44	20	64	0·69	*0·65*
No inversion	197	86	283	0·70		170	109	279	0·61	
"Inversion" below 750 mb level										
"Inversion"	104	95	199	0·52	*0·68*	127	94	221	0·57	*0·68*
No "inversion"	113	22	135	0·84		96	26	122	0·79	
"Inversion" at any level										
"Inversion"	119	141	260	0·46	*0·68*	138	135	273	0·51	*0·65*
No "inversion"	67	7	74	0·91		55	15	70	0·79	

set A would have involved detailed consideration of probable frontal movements in each case. The results are given in Table X, in the same form as those of Table IX. The index of usefulness has values between 0·68 and 0·74 at station I and between 0·65 and 0·68 at station J, the higher values again being obtained when the forecast is related to inversions only with bases below the 750-millibar level. Comparing the results with those given in Table IX, it is seen that the decrease in the value of U, which occurs when the rules are tested against conditions nine to twelve hours ahead instead of against current conditions, is not excessive, especially at station I. This presumably implies that on the whole, over the period considered, conditions tended to change less rapidly at station I than at station J.

CONCLUSIONS

(i) Inversions occur frequently at levels below 750 millibars over the north-east Atlantic, their percentage frequencies during the year examined ranging from 20 to 30 per cent in winter to 60 to 70 per cent in summer. Even strong inversions of 5°F or more occurred on about 10 per cent of occasions in winter and 25 per cent of occasions in summer. If isothermal layers are included the corresponding figures are 35 to 50 per cent in winter and about 80 per cent in summer and if all levels are considered they become 65 to 70 per cent in winter and about 90 per cent in summer.

(ii) Over the year considered the base of the lowest inversion was most frequently between 3,000 and 4,000 feet at station I and between 4,000 and 5,000 feet at station J. Inversions with their bases below 3,000 feet were most frequent in summer and somewhat rare in winter; in the winter examined there were none below 2,000 feet at either station.

(iii) On a large majority of days (between 80 and 90 per cent) there was a surface front somewhere within 550 nautical miles of either ocean weather station, but the number of days when there was likely to have been a frontal surface over the station and below the 750-millibar level was much smaller—about 40 per cent—and on only about 70 to 75 per cent of these was an inversion or isothermal layer actually present.

(iv) The likelihood of inversions or isothermal layers is relatively greater:

(*a*) on days when the curvature of the 1000–500-millibar thickness isopleths within a radius of about 120 nautical miles of the station is anticyclonic,

(*b*) on days when the circulation pattern on the 1000–500-millibar thickness chart within a radius of about 300 nautical miles of the station is a warm pool or ridge,

(*c*) on days when the thermal wind direction (1000–500 millibars), as measured within a radius of 120 nautical miles of the station, is within the range 280–030° (through north) inclusive,

(*d*) on days when the main surface-pressure feature within about 500 nautical miles of the station is not cyclonic in character.

(v) Inversions at the ocean weather stations I and J often persist for quite long periods. During the year examined there were 9 periods at station I and 20 at station J when the same inversion could be traced on every ascent over a period of 48 hours or more, the longest periods being 13 days at station I and 6½ days at station J. Such periods were most often associated with anticyclonic conditions.

(vi) Combination of the relationships found between the occurrence of inversions and isothermal layers and various synoptic features has resulted in two suggested sets of forecasting rules, one applicable to either non-frontal inversions or, with slight modification, to frontal inversions, and the other to inversions in general. Both have been shown to have some degree of usefulness. It is suggested that these rules should be used in conjunction with routine prognostic charts although it has also been shown that they have some value when applied to current charts to give a forecast up to 12 hours ahead. The set of rules applicable to non-frontal inversions is best used for indicating strong inversions ($\geqslant$ 5°F) below the 750-millibar level and may have some value in connexion with the forecasting of anomalous radio and radar propagation conditions at sea.

BIBLIOGRAPHY

1. CROSSLEY, A. F.; Measures of success in forecasting. *Met. Mag., London*, **83**, 1954, p. 66.

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