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AN EVALUATION OF THUNDERSTORM FORECASTING METHODS AND ATTEMPTS TO EXTEND COX'S METHOD

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ABSTRACT

Cox's method of thunderstorm forecasting and the use of Showalter and Lifted Indices as alerting aids were tested for most of the following stations: Darwin, Eagle Farm, Guildford, Port Hedland, Adelaide Airport, Mascot (using Williamtown soundings), Laverton and Townsville. Tests were also made of parameters used in the slice method (Beers 1945) assessment of atmospheric stability.

The Cox method was investigated fully at Darwin and Eagle Farm where it was used in combination with an estimate of the thermal advection in the lower half of the troposphere.

Another method was developed for Darwin in which an estimate of the conditional instability was made.

Skill scores based on persistence were used to evaluate the success of the methods.

1. INTRODUCTION

In connection with the Bureau's Seminar on Aerodrome Forecasting in August 1963, the staffs of various aerodrome Meteorological Offices extracted data relating to methods of thunderstorm forecasting.

On the basis of this data tests of Cox's (1961) method of thunderstorm forecasting and the use of the Showalter (1953) Index and the Lifted Index (Galway 1956) as alerting aids are discussed in Section 2. Modifications of the Cox method and the development of other methods were also attempted for several stations. The results of these investigations are discussed in Section 3 and in the conclusions. In all methods, forecasts based on 2300 GMT data were assessed according to the occurrence or non-occurrence of thunder or lightning within a 30 mile radius of the station in the following 24 hours.

The stations considered in this investigation and their station numbers and positions are listed below.

Station	Number	Lat. S.	Long. E.
Darwin	120	12°26'	130°52'
Townsville	294	19°15'	146°46'
Port Hedland	312	20°23'	118°37'
Eagle Farm	578	27°26'	153°05'
Guildford	610	31°56'	115°57'
Adelaide Airport	672	34°57'	138°32'
Mascot	767	33°57'	151°01'
Laverton	865	37°52'	114°45'

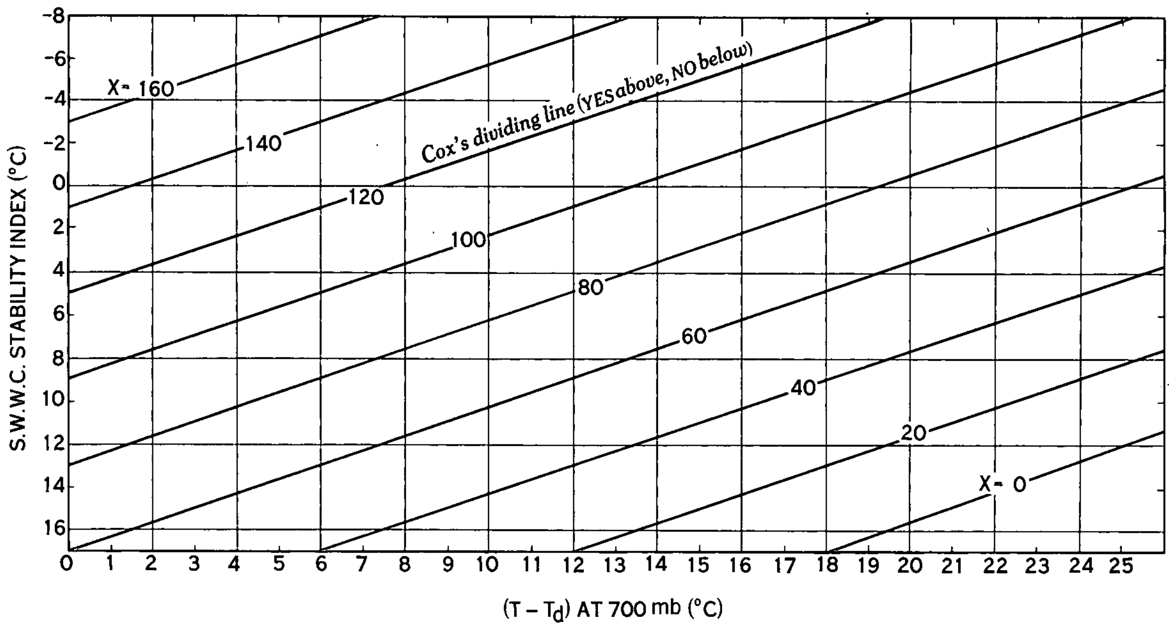

Fig. 1 Cox's (1961) first diagram for thunderstorm forecasting.

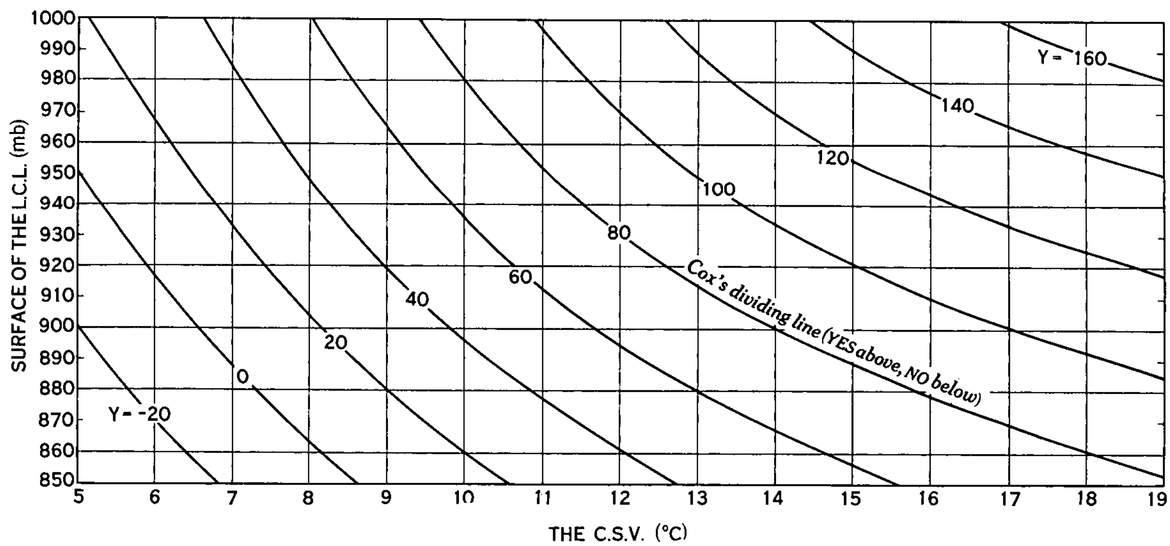

Fig. 2 Cox's (1961) second diagram for thunderstorm forecasting.

2. EVALUATION OF COX'S METHOD AND ALERTING INDICES

(a) Cox's Method

Cox (1961) has developed a method whereby four parameters are combined into a thunderstorm forecasting technique. The four parameters are:-

(i) Severe Weather Warning Centre's (SWWC) stability index in ^{o}C is found by moving adiabatically from the mean wet bulb temperature of the first 100 mb layer up to 500 mb, and then subtracting the temperature thus found from the reported 500 mb temperature.

(ii) The temperature dewpoint difference ($T-T_d$) at 700 mb in ^{o}C. This is used as a quantitative index of the available middle level moisture (when the relative humidity was too low to be recorded its value was taken as 15 per cent. T_d was then calculated using this value and T).

(iii) The "C" stability value (C.S.V.). Descending dry adiabatically from 850 mb to 1000 mb and then ascending moist adiabatically to 600 mb, the C.S.V. is the difference (^{o}C) in the temperature thus found and the reported 600 mb temperature.

(iv) The lifting condensation level (L.C.L.). The L.C.L. (mb) is found at the intersection of the surface mixing ratio curve with the dry adiabatic curve through the surface temperature.

The four parameters are combined into two graphs (Figures 1 and 2). If both graphs indicate "yes", thunderstorms are forecast. If both graphs indicate "no", no thunderstorms are forecast. If one graph indicates "yes" and the other "no", thunderstorms are forecast only if there is cyclonic curvature within the area. The results of tests of this method at seven stations are given in Table 1.

Table 1. Results of test of Cox's method for period Feb.-June 1963 or part thereof, except Laverton where period Oct.-Nov. 1958. (T=thunderstorm).

	Darwin Forecast		Eagle Farm Forecast		Guildford Forecast		Laverton Forecast		Pt. Hedland Forecast		Adelaide Airport Forecast		Mascot Forecast	
	T	No T	T	No T	T	No T	T	No T	T	No T	T	No T	T	No T
Observed T	47	2	9	9	15	6	5	14	18	1	4	0	11	7
Observed No T	19	70	8	124	24	105	4	38	34	24	3	80	21	109

(b) Showalter Index

The Showalter Index (Showalter 1953) assumes that if all or some of the following are present thunderstorms are likely to form.

(i) Convergence which can cause convective exchange of potentially unstable air between the 850 and 500 mb levels.

(ii) Condensation takes place in clouds which have penetrated the freezing level, at temperatures above 0^{o}C.

(iii) The rising air reaches the level of free convection below 500 mb.

(iv) There is cooling aloft or heating below with moisture advection at low levels.

To obtain the value of the index a parcel at 850 mb is lifted dry adiabatically to saturation level and then along the saturation adiabat to 500 mb. The lifted 500 mb temperature is then subtracted from the observed 500 mb temperature. In general a negative index denotes instability and a positive index denotes stability. The occurrence of thunderstorms against Showalter Index for seven stations is given in Table 2.

Table 2. Showalter Index and the occurrence or non-occurrence of thunderstorms (T) for the period Feb.- June 1963 or part thereof.

Index Value / Station		-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Darwin	T				2	5	6	8	16	5	7	2	3	2				1											
	No T					2	1	4	3	3	10	4	11	3	7	4	8	6	6	1	3	7	3				1		1
Eagle Farm	T						2	2	5		3		4			1				1									
	No T						1	3	6	7	14	25	12	10	4	8	12	14	5	5		2	1	1					
Guildford	T	1		1	1	1	2	3	2	3	1	1	3	1		1													
	No T				2	1	2	4	6	9	9	9	15	8	11	10	4	10	8	5	6	5	1	2					
Port Hedland	T				1	1		2	7	2	2	3	1																
	No T	1	1			5	3	3	5	10	8	6	6	6	3	5	9	12	4	7	5	10	4	2	1				
Adelaide Airport	T						1			2			1																
	No T						1		1	3	3	3	1	8	5	4	2	5	6	5	8	10	2	5	2	6	5		
Mascot	T						1		2	1	4	4	4		2														
	No T					1	1	4	6	7	14	18	19	10	9	12	6	5	1	8	4	3				2			
Townsville	T					1	2	2			1	1																	
	No T				1	4	4	5	8	10	11	9	5	11	18	14	6	6	7	4	5	4	1	3			1	1	

Petterssen (1956) says "Experience shows that when the index is less than 3°C, showers are possible; when the index falls below 0°C, thunderstorms may occur, and when it is below -3°C, heavy thunderstorms are probable; areas within which the index is less than -6°C are suspect of tornadoes."

Showalter (1953) states "Experience has indicated that any positive index of +3° or less is very likely to be associated with showers and quite likely to produce thunderstorms. Thunderstorms have increasing probability as the index falls from +1° to -2°".

To test these two opinions thunderstorm forecasts based on index values equal to or less than both +3°C and 0°C have been considered. The results are presented in Table 3.

Table 3. Results of test of Showalter Index for period Feb.- June 1963 or part thereof.

(i) Thunderstorms forecast when index value is $\leq 3°C$ (Showalter (1))

		Darwin Forecast T	Darwin Forecast No T	Eagle Farm Forecast T	Eagle Farm Forecast No T	Guildford Forecast T	Guildford Forecast No T	Townsville Forecast T	Townsville Forecast No T
Observed	T	49	8	12	6	15	6	6	1
	No T	23	65	31	99	33	94	43	95

		Port Hedland Forecast T	Port Hedland Forecast No T	Adelaide Airport Forecast T	Adelaide Airport Forecast No T	Mascot Forecast T	Mascot Forecast No T
Observed	T	15	4	3	1	8	10
	No T	36	81	8	77	33	97

(ii) Thunderstorms forecast when the index value is ≤ 0°C (Showalter (2))

		Darwin Forecast T	Darwin Forecast No T	Eagle Farm Forecast T	Eagle Farm Forecast No T	Guildford Forecast T	Guildford Forecast No T	Townsville Forecast T	Townsville Forecast No T
Observed	T	21	36	4	14	9	12	5	2
	No T	7	81	4	126	9	118	14	124

		Port Hedland Forecast T	Port Hedland Forecast No T	Adelaide Airport Forecast T	Adelaide Airport Forecast No T	Mascot Forecast T	Mascot Forecast No T
Observed	T	4	15	1	3	1	17
	No T	13	104	1	84	6	124

(c) Lifted Index

The Lifted Index (Galway 1956, Wilkie 1960) is very similar to the Showalter Index. In this test the average dewpoint between the surface and 850 mb, and the maximum surface temperature were used to obtain the condensation level. From this level the parcel was moved moist adiabatically to 500 mb. The lifted temperature at 500 mb was then subtracted from the observed value. The occurrence of thunderstorms against the Lifted Index is shown in Table 4. (see page 14).

An index value of +2 or less has been taken as a thunderstorm forecast. The results of forecasts on this basis are presented in Table 5.

Table 5. Results of test of Lifted Index for period Feb.-June 1963 or part thereof.

		Darwin Forecast T	Darwin Forecast No T	Eagle Farm Forecast T	Eagle Farm Forecast No T	Guildford Forecast T	Guildford Forecast No T	Townsville Forecast T	Townsville Forecast No T
Observed	T	54	3	13	5	13	8	7	0
	No T	34	55	68	62	38	91	54	84

		Port Hedland Forecast T	Port Hedland Forecast No T	Adelaide Airport Forecast T	Adelaide Airport Forecast No T	Mascot Forecast T	Mascot Forecast No T
Observed	T	19	0	3	1	12	6
	No T	46	15	8	77	47	83

(d) Skill scores and discussion of above results

Persistence was used as a basis for assessing the skill of the above methods. The occurrence (or non-occurrence) of a thunderstorm in two successive periods of 24 hours from 2300 GMT was regarded as a correct forecast on the basis of persistence. The results of such persistence forecasts are given in Table 6.

Table 4. Lifted Index and the occurrence and non-occurrence of thunderstorms for the period Feb.- June 1963 or part thereof.

Index Value / Station		-9	-8	-7	-6	-5	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	.....	25
Darwin	T	1		1		3	7	7	11	13	7	4		3																				
	No T					1		7	2	4	4	12	4	9	4	9	5	7	4	4	1	2	2	3			1	1	1	1				1
Eagle Farm	T							3	4	2	1	2	1	3			1	1																
	No T								4	6	13	18	27	15	9	7	9	7	2	8	3	1					1							
Guildford	T					1			2	1	4	4	1	5		2	1																	
	No T			2			4	5	3	7	5	3	9	7	13	14	12	9	12	8	6	1	2	3		3	1							
Port Hedland	T					1	3	1	3	4	3	1	3																					
	No T					4	3	1	6	11	5	6	10	6	6		2			1														
Adelaide Airport	T									1			2		1																			
	No T										2	2	4	2	4	2	4	9	6	6	8	9	8	4	2	2	5	2	3		1			
Mascot	T									3	4		5	1	3	1		1																
	No T							2	2	6	14	9	14	17	13	17	11	4	5	8	2	3	1	1		1								
Townsville	T						2	2	1		1	1																						
	No T					1	3	4	7	5	9	8	17	10	14	15	9	8	7	4	8	3	2	1	1	1			1					

Table 6. Results of forecast based on persistence of thunderstorms from one day to the next for the period Feb.- June 1963 or part thereof, except Laverton where period Oct.- Nov. 1958.

Second Day	Darwin First Day T	Darwin First Day No T	Eagle Farm First Day T	Eagle Farm First Day No T	Guildford First Day T	Guildford First Day No T	Townsville First Day T	Townsville First Day No T
T	46	11	7	11	8	13	1	6
No T	11	79	11	120	13	116	6	136

Second Day	Pt. Hedland First Day T	Pt. Hedland First Day No T	Adelaide Airport First Day T	Adelaide Airport First Day No T	Mascot First Day T	Mascot First Day No T	Laverton First Day T	Laverton First Day No T
T	9	10	2	2	3	14	9	10
No T	11	119	2	83	15	117	10	31

Table 7 gives for all methods including persistence, the ratios of the number of correct forecasts to the total number of forecasts and Table 8 the skill scores based on persistence according to the formula

$$S = \frac{R-E}{T-E}$$

where S is the skill score,

R is the number of correct forecasts (adjusted for the ratio of the total number of persistence forecasts to the number actually made),

E is the number of forecasts expected to be correct using persistence as a reference,

T is the total number of forecasts.

Table 7. Ratios of the number of correct forecasts of thunderstorms or no thunderstorms to the total number of forecasts.

	Darwin	Eagle Farm	Guildford	Port Hedland	Adelaide Airport	Mascot	Townsville	Laverton
Persistence	0.85	0.85	0.83	0.86	0.96	0.81	0.92	0.67
Cox	0.85	0.87	0.80	0.55	0.97	0.81	-	0.71
Showalter (1)	0.79	0.75	0.74	0.71	0.90	0.71	0.70	-
Showalter (2)	0.70	0.90	0.86	0.79	0.96	0.85	0.89	-
Lifted	0.75	0.51	0.69	0.43	0.90	0.64	0.63	-

Table 8. Skill scores based on persistence

	Darwin	Eagle Farm	Guildford	Port Hedland	Adelaide Airport	Mascot	Townsville	Laverton
Cox	0.00	+0.14	-0.15	-2.24	+0.25	+0.03	-	+0.12
Showalter (1)	-0.45	-0.77	-0.54	-1.09	-1.25	-0.48	-2.92	-
Showalter (2)	-1.00	+0.09	+0.21	-0.48	0.00	+0.20	-0.39	-
Lifted	-0.68	-2.36	-0.77	-3.09	-1.25	-0.83	-3.67	-

Except for Port Hedland the Cox method is superior to both the Showalter (1) and Lifted Indices. (On many occasions at Port Hedland a Cox method forecast was not made during the later months when there were no thunderstorms. These thunderstorm free days would have probably been forecast using Cox's method and hence the proportion of correct forecasts would have increased.)

The skill scores given in Table 8 show that the Showalter (1) and Lifted Indices are worse than persistence for all stations studied. The Cox method, however, is better than persistence at Eagle Farm, Adelaide Airport and Laverton, and approximately the same at Darwin and Mascot. Results for Adelaide Airport may be misleading due to the small number of thunderstorms.

With both the Showalter (1) and Lifted Indices, for all stations except Darwin, the number of forecasts of thunderstorms greatly exceeded the number of occurrences and consequently the number of thunderstorms that were not forecast was relatively small. This tendency was greatest for the Lifted Index and least for the Cox method where the ratio of the number of thunderstorms correctly forecast to the total number forecast was less than 0.5 at only Guildford, Port Hedland and Mascot.

Except at Darwin, Showalter Index (2) gives better skill scores than Showalter Index (1) and, in three out of six comparisons, better skill scores than Cox's method, but from Tables 1 and 3 it is seen that Showalter Index (2) fails to forecast a higher percentage of actual thunderstorms than either the Showalter (1) or Cox's method. The same applies to persistence as a forecast method compared with Showalter Index (1) and Cox's method. Therefore, from an operational viewpoint, in spite of the skill score indications, Cox's method, overall, is probably a better method than the Indices or persistence "forecasting".

However, the Showalter Index is recognized as an alerting device rather than a definite forecasting method. Except for Mascot, where ten out of eighteen thunderstorms were not indicated (and for which radiosonde data for Williamtown about 80 miles away was used), Showalter Index (1) was fairly successful for this purpose. It is also notable that on many occasions when a negative index was found no thunderstorm occurred. This tendency was more pronounced for the Lifted Index. On occasions when a large positive value was found for the indices and a thunderstorm occurred, a front had passed during the 24 hour period. An exception was a Showalter Index value of +10 at Darwin (where there were no fronts in the periods under consideration).

Tests were also made of parameters used in the slice method (Beers 1945) assessment of atmospheric stability. These included (i) the total depth, above the lifting condensation level, of layers in which the lapse rate was greater than the saturated adiabatic with, at the same time, a relative humidity of at least 70 per cent and (ii) the depth as in (i) in conjunction with the depth of such layers above the freezing level. No separation of thunderstorm and non-thunderstorm cases was achieved.

The circulation acceleration (Beers 1945) itself was calculated for a month at Darwin when thunderstorms were observed on about 50 per cent of the days, but again no separation was evident.

3. INVESTIGATIONS INCLUDING MODIFICATIONS OF COX'S METHOD

(a) Modification of Cox's Method

(i) Darwin: For February, March, April 1963 Cox's parameters (i) to (iv) were calculated and plotted in Cox diagrams, weighting lines X and Y were then drawn in the Cox diagrams (Figures 1 and 2 respectively) with weights increasing from the low to high thunderstorm probability regions. The values for each day were then plotted against each other and weighted according to the Z lines in Figure 3.

Used on its own the line separating non-thunderstorm cases from a mixture of cases of thunderstorms and non-thunderstorms in Figure 3 gave almost the same results as the use of Cox's line in Figure 2.

Browning (1963) has indicated that, in an atmosphere favourable for convection, warm air advection is usually present in the lower atmosphere. Although Darwin is outside the region where strong geostrophic control exists, the product of the magnitude of the wind shear between 3000 and 25000 feet at 2300 GMT and the wind component normal to the shear ($knots^2$) was used as a rough measure of the thermal advection in the lower half of the troposphere. Thermal advection was then tested in combination with the "Z" values from Figure 3. Figure 4 shows the line of best separation for this combination, the thunderstorm area being to the right and the non-thunderstorm area to the left of the line. The separation obtained at Darwin by Cox's lines in Figures 1 and 2, and by the lines in Figures 3 and 4 is given in Table 9.

The results of a test of each of Figures 1 to 4 and Cox's method based on independent data for January, February and March 1964 are given in Table 10 and skill scores using persistence as a base are given in Table 11.

Table 9 - Separation of thunderstorms and non-thunderstorms in Figures 1, 2, 3 and 4 at Darwin for February, March and April 1963.

	Figure 1		Figure 2		Figure 3		Figure 4	
	Points in T area	Points in No T area	Points in T area	Points in No T area	Points in T area	Points in No T area	Points in T area	Points in No T area
Actual T	44	13	55	2	54	3	52	5
Actual No T	12	17	18	11	14	15	10	19

Table 10 - Test of Figures 1, 2, 3 and 4 for thunderstorm forecasting at Darwin for January, February and March 1964. Values based on Cox's method and persistence are also shown.

	Figure 1 Forecast		Figure 2 Forecast		Figure 3 Forecast		Figure 4 Forecast	
	T	No T	T	No T	T	No T	T	No T
Observed T	48	11	58	1	56	3	56	3
Observed No T	18	13	24	7	23	8	23	8

	Cox's Method Forecast	
	T	No T
Observed T	54	5
Observed No T	23	8

	Persistence First Day	
	T	No T
Second Day T	43	16
Second Day No T	16	15

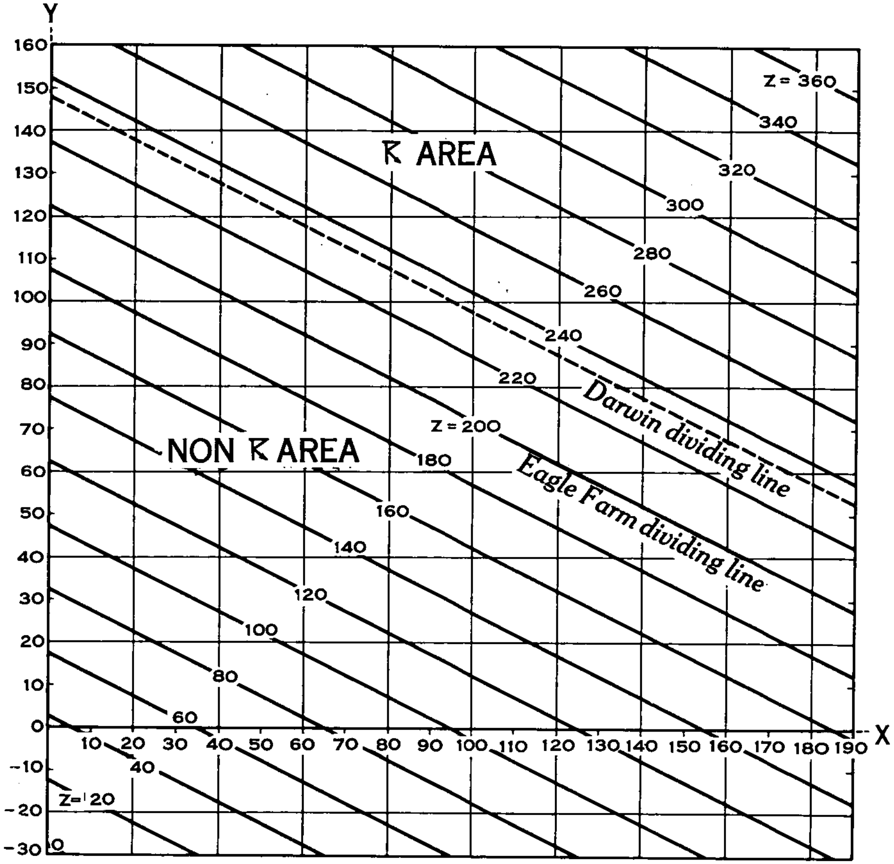

Fig. 3 Darwin and Eagle Farm thunderstorm and non-thunderstorm areas for combination of parameters X from Fig. 1 and Y from Fig. 2.

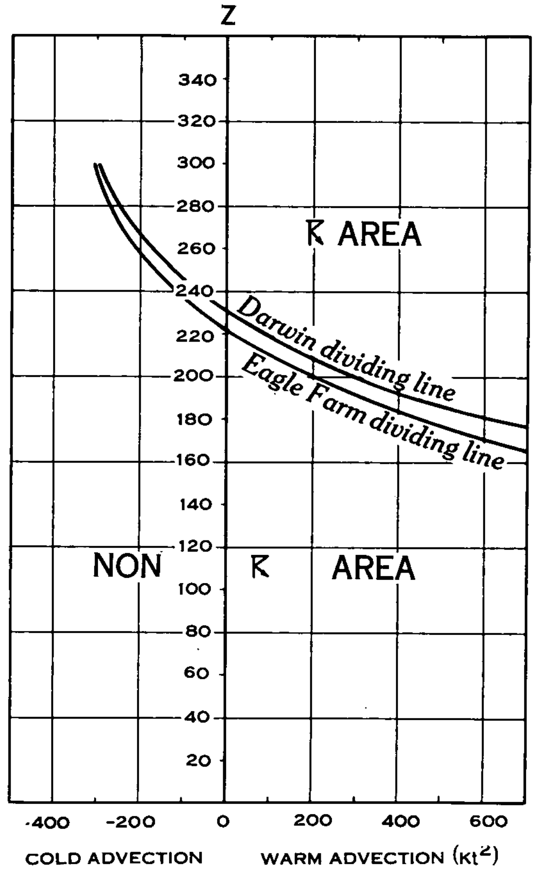

Fig. 4 Thunderstorm and non-thunderstorm areas for combination of parameter Z and thermal advection (in terms of wind shear and wind normal to shear) between 3000 and 25000 feet for Darwin and Eagle Farm.

Table 11 - Skill scores for January, February and March 1964 data using persistence as a base.

Method	Figure 1	Figure 2	Figure 3	Figure 4	Cox's Method
Skill Score	+0.09	+0.22	+0.19	+0.19	+0.13

(ii) Eagle Farm: The same investigation as outlined under (i) above for Darwin was undertaken for Eagle Farm (Brisbane) for January to March 1964. In Figure 3 the line of best separation differed from that for Darwin; this was also the case in Figure 4.

The separation achieved in Figures 1 to 4 is given in Table 12. The results of a test on independent data (January, February and March, 1963) are given in Table 13 and skill scores against persistence as a base in Table 14.

Table 12 - Separation of thunderstorms and non-thunderstorms in Figures 1, 2, 3 and 4 at Eagle Farm for January, February and March, 1964.

		Figure 1		Figure 2		Figure 3		Figure 4	
		Points in T area	Points in No T area	Points in T area	Points in No T area	Points in T area	Points in No T area	Points in T area	Points in No T area
Actual	T	3	12	11	4	14	1	14	1
	No T	13	63	26	50	34	42	20	56

Table 13 - Test of Figures 1, 2, 3 and 4 for thunderstorm forecasting at Eagle Farm for January, February and March, 1963. Values based on Cox's method and persistence are also shown.

		Figure 1 Forecast		Figure 2 Forecast		Figure 3 Forecast		Figure 4 Forecast	
		T	No T	T	No T	T	No T	T	No T
Observed	T	11	2	9	4	12	1	10	3
	No T	15	61	22	54	28	48	17	59

		Cox's Method Forecast	
		T	No T
Observed	T	10	3
	No T	21	55

		Persistence First Day	
		T	No T
Second Day	T	7	6
	No T	6	70

Table 14 - Skill scores for January, February and March, 1963, data using persistence as a base.

Method	Figure 1	Figure 2	Figure 3	Figure 4	Cox's Method
Skill Score	-0.42	-1.17	-1.42	-0.67	-1.00

As a combination of warm air advection in the low levels and cold air advection aloft will produce instability, the use of a differential parameter based on the thermal advection between 3000 and 15,000ft against that between 15,000 and 25,000ft was tested as a replacement for the thermal advection parameter in the layer between 3000ft and 25,000ft as used above. The thermal advection parameter for the layer 3000ft to 15,000ft on its own was also tested as a replacement for the 3000 to 25,000ft advection parameter. Neither of these alternatives used in conjunction with the Cox parameters gave a separation as good as the 3000 to 25,000ft parameter.

Also, as it was thought that the surface conditions reported in radiosonde observations at 2300 GMT would often be unrepresentative of conditions later in the day, the substitution of other data for the near surface data used in Cox's method was investigated. The equivalent of the SWWC stability Index was calculated using the 900 mb wet bulb temperature and the LCL was calculated from 900 mb data.

However, in tests over several months for Eagle Farm and Laverton no improvement over the use of Cox's original parameters was effected by this change.

(b) Conditional Stability - Thermal Advection Investigation

Investigations of individual cases when Cox's method was unsuccessful indicated that this was often due to the inadequacy of the dew point depression at 700 mb and the difference between the environment temperature of a lifted parcel at 500 mb as the respective indicators of the moisture and stability below 500 mb.

Therefore two parameters thought to be more representative were tested for the three months February, March and April, 1963, at Darwin. These were:

(i) The sum of the dewpoint depressions at 50 mb intervals between 900 and 600 mb, and

(ii) A measure of the conditional instability obtained from the area between the moist adiabat drawn from the mean pseudo wet bulb temperature from the surface to 900 mb and the environment temperature sounding from 900 to 400 mb. The area was measured on a skew T - log p aerological diagram using the spacing between whole $^{\circ}C$ isotherms at constant pressure as the unit of length in the horizontal and vertical. Areas are negative if the environment temperatures are greater than those on the moist adiabats.

These parameters were plotted against each other and weighting lines drawn. Taking the line of best separation with the thunderstorm area to the right and the non-thunderstorm area to the left, the separation indicated in Table 15 was obtained.

Table 15 - Separation of Darwin thunderstorms and non-thunderstorms by line of best separation in the first diagram for February, March and April, 1963.

		Plots in T area	Plots in No T area
Actual	T	56	0
	No T	20	10

The values from the first diagram were then plotted against the thermal advection parameter outlined in Section 3(a) above. A line of best separation was drawn and the cases of thunderstorms and non-thunderstorms in each area are given in Table 16.

Table 16 - Separation of Darwin thunderstorms and non-thunderstorms using the second diagram

		Plots in T area	Plots in No T area
Actual	T	55	1
	No T	15	15

The results of a test of the two diagrams on independent data (February 1964) are given in Table 17 and skill scores against persistence as a base in Table 18. Figures 3 and 4 gave results practically the same as the second diagram and Cox's method, the only difference being values of 16 and 0 in the top line.

Table 17 - Tests of the first and second diagrams for February 1964. Values based on Cox's method and persistence are also shown.

		First Diagram Forecast		Second Diagram Forecast		Cox Method Forecast		Persistence First Day	
		T	No T	T	No T	T	No T	T	No T
Actual	T	16	0	15	1	15	1	11	5
	No T	12	0	11	1	11	1	5	7

Table 18 - Skill scores for February 1964 using persistence as a base.

Method	First Diagram	Second Diagram	Cox Method	Figure 3	Figure 4
Skill Score	-0.2	-0.2	-0.2	-0.1	-0.1

4. CONCLUSIONS

The study of the Cox method, Showalter Index and Lifted Index showed that generally Cox method gave the best results. The Showalter Index was an effective alerting device when an index of $\leqslant +3$ was taken as a thunderstorm forecast.

The skill scores in Table 11 show that at Darwin Figure 2 gave the best thunderstorm forecasting results, although the skill scores do not vary significantly. This is not the case at Eagle Farm where in Table 14 Figure 1 has the best skill score. All of the scores at Eagle Farm are negative. Although the skill score for Figure 3 was lower than Figures 1 and 2 it forecasts more thunderstorms correctly. The use of a thermal advection parameter in combination with Figure 3 does not lead to better results at Darwin. However at Eagle Farm, where in the six months studied only three thunderstorms occurred on days of cold air advection, the use of advection with Figure 3 leads to a greatly improved skill score in Figure 4. In Figure 4 lines of equal probability of thunderstorms would have been more appropriate than a single line of separation but the number of cases studied was insufficient to warrant this refinement.

The use of the Cox parameters with both the differential thermal advection parameter and the thermal advection parameter between 3,000 and 15,000ft at Eagle Farm were less successful than Figure 4.

The Conditional Instability method studied at Darwin, gives similar results to Figures 3 and 4 (see Table 18). Because of this and the additional work required to make a forecast by this method in comparison with Figures 3 and 4, the diagrams connected with this method have not been reproduced.

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