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AN OBJECTIVE AID FOR MINIMUM TEMPERATURE FORECASTS - ALICE SPRINGS, NORTHERN TERRITORY

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Abstract: The prediction of minimum temperatures at Alice Springs aerodrome, using data for 1800 CST the previous night, is examined by two methods.

Simple linear regression on air temperature yielded useful results on development data, but was unstable on independent data. No improvement was associated with the inclusion of additional parameters.

The second method, based on radiative flux at 1800 CST, gave approximately the same accuracy as the regression technique but was more stable for independent data. It has the added advantage of being more easily adapted to cloudy nights.

1. INTRODUCTION

A requirement exists for a frost warning service for fruit and vegetable growers and also poultry breeders in the Alice Springs district, more particularly in the Heavitree Gap region. Frosts in this region are usually confined to the period May through September.

The provision of a useful service of this nature requires an ability to forecast minimum temperatures, at least in the lower ranges, with an error variance of 16 (degrees F)^2 or less. Such a value permits of the specification of a risk rating, based on predicted values, which leads to an acceptable ratio of frost risk forecasts to frost occurrences while minimising the number of occurrences which will not be predicted.

The users' requirements would be satisfactorily met by frost risk ratings broadcast during the early evening hours, thus enabling full use to be made of the 1800 CST observations from Alice Springs aerodrome, which is located on the plateau south of Heavitree Gap.

The objective of this investigation was to determine whether a suitable objective aid could be provided using the 1800 CST synoptic observations from the aerodrome. At this stage the prediction of aerodrome screen minima has been the target.

2. REGRESSION METHODS

Experience in South Australia has been that useful objective aids (Veitch 1959, 1960) based on 1800 CST data can be obtained using linear regression models with three parameters - air temperature, a function of cloud coverage and surface wind - provided a critical assessment of the synoptic situation indicates that these parameters are representative of the overnight conditions, especially the cloud function.

Six years' records of 1800 CST synoptic observations at the aerodrome were separated at random into two groups, the first (1956, 1957, 1959, 1961) to be used as development data and the second (1958, 1960) for testing any objective aids developed.

To eliminate, as far as possible, any undue variation resulting from the inclusion of nights of non-representative cloudiness which might mask any true relationships, in the first instance only those days which were cloudless at 1800 CST were used. Graphical correlation methods were used to determine whether the relationship between minimum temperature and 1800 CST temperature was linear or curvilinear and to determine whether any reduction in residual error resulted from the inclusion of dewpoint and wind. The 1800 CST air temperature/minimum relationship was reasonably linear and no useful reduction in residual error resulted from the inclusion of the additional parameters, in fact, in some cases the residual error increased.

Calculated regression formulae using 1800 CST temperature gave error variances of 10 to 14 (deg. F)^2, but the regression coefficients and regression constants differed significantly between months, preventing the pooling of data on a seasonal basis. The regression formulae are shown in Table 1.

Table 1. Regression Formulae
(Temperature in °F)

Month	Formula	5% limits of coefficient	
May	$T_{min} = 0.67\ T_{18} - 2.8$	0.56,	0.79
June	$T_{min} = 0.90\ T_{18} - 17.3$	0.77,	1.03
July	$T_{min} = 0.79\ T_{18} - 11.1$	0.64,	0.93
August	$T_{min} = 0.90\ T_{18} - 20.6$	0.79,	1.01
September	$T_{min} = 0.75\ T_{18} - 9.8$	0.64,	0.86

Application of the regression formulae to the test years gave error variances which were considerably larger than the development years - in some months more than doubled. In Table 2 against Method 1 will be found the mean error, mean modulus of the errors and the error variances for each of the individual years, also the pooled values for the development and test years.

This instability suggested that an alternative approach should be tried, especially as the introduction of cloudiness would be expected to increase the residual errors.

3. RADIATIVE FLUX METHOD

A practical approach to the solution of a rather complex theoretical equation for the fall in temperature between sunset and sunrise suggested by Reuter (1951) was applied to the Upper Murray district of South Australia by Mizon (1952) with results which were comparable with those later obtained by other techniques for this area (Veitch 1960).

Assuming, (i) nocturnal radiation constant during the night, (ii) specific heat, density and coefficient of heat conductivity of soil constant with respect to time and depth, (iii) initially linear variation of temperature within soil and air and (iv) constant coefficient of eddy conductivity in the air, the fall in temperature from sunset to sunrise may be expressed as

$$\Delta T = F \left[E + BK_g + (\gamma - \gamma_d)\ C_p A \right] \sqrt{t}$$

where

$$F = \frac{2}{\sqrt{\pi}} \quad \frac{1}{\sqrt{K_g \rho_g C_g} + C_p \sqrt{\rho A}}$$

and

A = coefficient of eddy conductivity of air

B = lapse rate of temperature in the soil

E = net outgoing long wave radiation

K_g = coefficient of heat conductivity of soil

C_g = specific heat of the soil

C_p = specific heat of air at constant pressure

Table 2. Error Analyses
(Error = Observed-Forecast)

(1) = Mean error, °F, Method 1
(4) = Mean error, °F, Method 2
(2) = Mean modulus of errors, °F, Method 1
(5) = Mean modulus of errors, °F, Method 2
(3) = Error Variance $(^{\circ}F)^2$, Method 1
(6) = Error Variance $(^{\circ}F)^2$, Method 2

		Development Years					Test Years		
		1956	1957	1959	1961	Pooled	1958	1960	Pooled
May	No.	3	15	13	20	51	4	12	16
	(1)	+2.3	-1.5	-0.3	+0.9	-0.0	+3.3	+0.9	+1.5
	(2)	2.3	2.9	2.1	2.4	2.5	5.5	2.9	3.6
	(3)	7.1	12.5	6.1	11.5	10.1	41.5	16.8	22.9
	(4)	+0.6	-1.2	-1.3	+1.1	-0.2	-0.9	+0.5	+0.2
	(5)	1.5	2.7	2.8	2.6	2.6	3.3	2.7	2.8
	(6)	2.3	10.3	10.6	11.1	10.2	15.9	12.1	13.1
June	No.	10	10	16	25	61	11	10	21
	(1)	-0.7	+1.6	-0.9	-0.1	-0.1	-2.1	-3.4	-2.7
	(2)	1.9	4.1	1.9	3.3	2.8	4.2	3.5	3.9
	(3)	5.3	21.9	5.1	17.4	13.0	27.0	14.5	21.1
	(4)	+0.3	+0.9	-1.0	+1.0	+0.3	-1.6	-1.1	-1.4
	(5)	1.3	3.8	2.3	3.5	2.9	3.6	2.1	2.9
	(6)	3.8	20.5	8.1	18.3	13.6	17.7	6.9	12.5
July	No.	18	17	15	21	71	13	16	29
	(1)	+1.9	+0.5	-0.4	-1.7	-0.0	+1.4	+0.8	+1.1
	(2)	2.8	2.2	1.6	2.8	2.4	3.6	4.3	4.0
	(3)	11.5	11.3	3.7	15.4	10.9	23.8	31.3	27.9
	(4)	+0.7	+1.1	-0.3	-0.2	+0.3	+0.9	+1.3	+1.1
	(5)	2.7	2.8	2.3	3.0	2.7	3.3	3.9	3.6
	(6)	11.9	19.1	7.2	12.5	12.8	18.0	30.3	24.8
August	No.	20	24	21	25	90	17	25	42
	(1)	-0.3	+0.3	-0.1	+0.2	+0.0	+1.8	-0.4	+0.5
	(2)	1.9	2.7	3.3	2.5	2.6	2.9	2.6	2.7
	(3)	5.6	11.3	14.3	12.8	11.1	12.4	9.5	10.7
	(4)	-1.9	-0.5	-1.4	-0.1	-0.9	+0.7	-1.1	-0.3
	(5)	2.3	2.8	3.3	2.6	2.7	2.7	2.3	2.5
	(6)	7.6	13.0	19.0	12.4	13.0	14.5	7.0	10.1
Sept.	No.	16	21	11	20	68	15	13	28
	(1)	-0.1	-1.2	+1.6	+0.4	-0.0	+1.2	+2.3	1.7
	(2)	2.1	3.5	2.6	2.2	2.7	2.8	3.1	3.0
	(3)	6.0	16.6	23.5	11.5	13.7	13.4	23.5	18.1
	(4)	-0.7	+0.1	-1.0	-0.7	-0.5	+1.8	+1.7	1.8
	(5)	2.0	2.4	3.0	2.3	2.4	2.7	3.8	3.3
	(6)	6.6	11.3	15.4	12.1	11.1	11.8	23.7	17.3

t = duration of the night

γ = lapse rate of temperature in the air

γ_d = dry adiabatic lapse rate

ρ = density of the air

ρ_g = density of the soil

The terms BK_g and $(\gamma - \gamma_d) C_p A$, being an order of magnitude smaller than E are neglected and E is determined from the Brunt relationship

$$E = \sigma T^4 (1-a-b\sqrt{e}) \text{ cals. cm}^{-2}\text{min}^{-1}$$

where

a = 0.526

b = 0.065

e = vapour pressure in mb

σ = 8.132×10^{-11} cal. $\text{cm}^{-2}\,{}^{o}\text{K}^{-4}\,\text{min}^{-1}$ and $T = {}^{o}\text{K}$

Assuming that the soil factors remain constant at a given locality, the term F would be expected to vary with the coefficient of conductivity of the air which should be a function of the wind speed.

At Alice Springs, during the period with which we are concerned, 1800 CST is very close to sunset so the use of these data in lieu of sunset conditions should not invalidate the procedure. There is usually a strong correlation between the overnight range of temperature at the surface and screen level, so application of the technique to screen data is reasonable.

From the data for cloudless nights in the development years, values of F were determined using the observed temperature fall from 1800 CST to minimum. No definite functional relationships between F and wind speed at 1800 CST were revealed and the mean values ($\overline{F}$) for the months were used in subsequent calculations. The products $\overline{F}\sqrt{t}$ for the various months were almost constant, differing by less than 3%. This fact permits a single value of this factor (that for June and July) to be used throughout the season and simplifies the nomogram shown in Fig. 2. The error which is likely to result from this procedure would be less than 1°F in August and September on days of extreme E values.

In Table 2 against Method 2 are shown the mean errors, mean modulus of errors and error variances for each of the months and the pooled values for the development and test years. Comparison of these with the corresponding figures from Method 1 shows little significant difference between the methods on the development years' data, but much more stable results for the test years by the second method. In July 1960 both methods gave larger error variances. The reason for this is not apparent from Table 3 where the normal and actual rainfalls for the various months are shown.

Table 3. Rainfall Alice Springs (points)

	April	May	June	July	August	September
Normal	39	60	52	29	31	28
1956	0	89	147	164	0	80
1957	63	0	170	88	4	0
1958	0	242	61	19	1	8
1959	0	190	6	5	0	1
1960	31	77	4	5	27	12
1961	245	0	0	0	2	1

A check on the working data shows that most of this can be attributed to two days when large overestimates of ΔT occurred, probably due to cloud development during the night. Elimination of these two days would reduce the tabulated values to -0.4, 2.6 and 10.8 respectively.

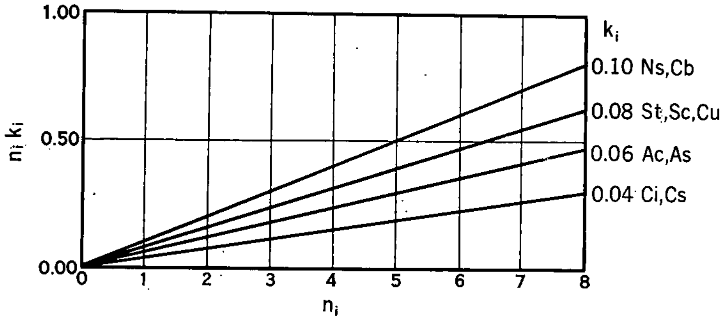

FIG.1 : (a) Values of $n_i k_i$ for various cloud types and amounts.

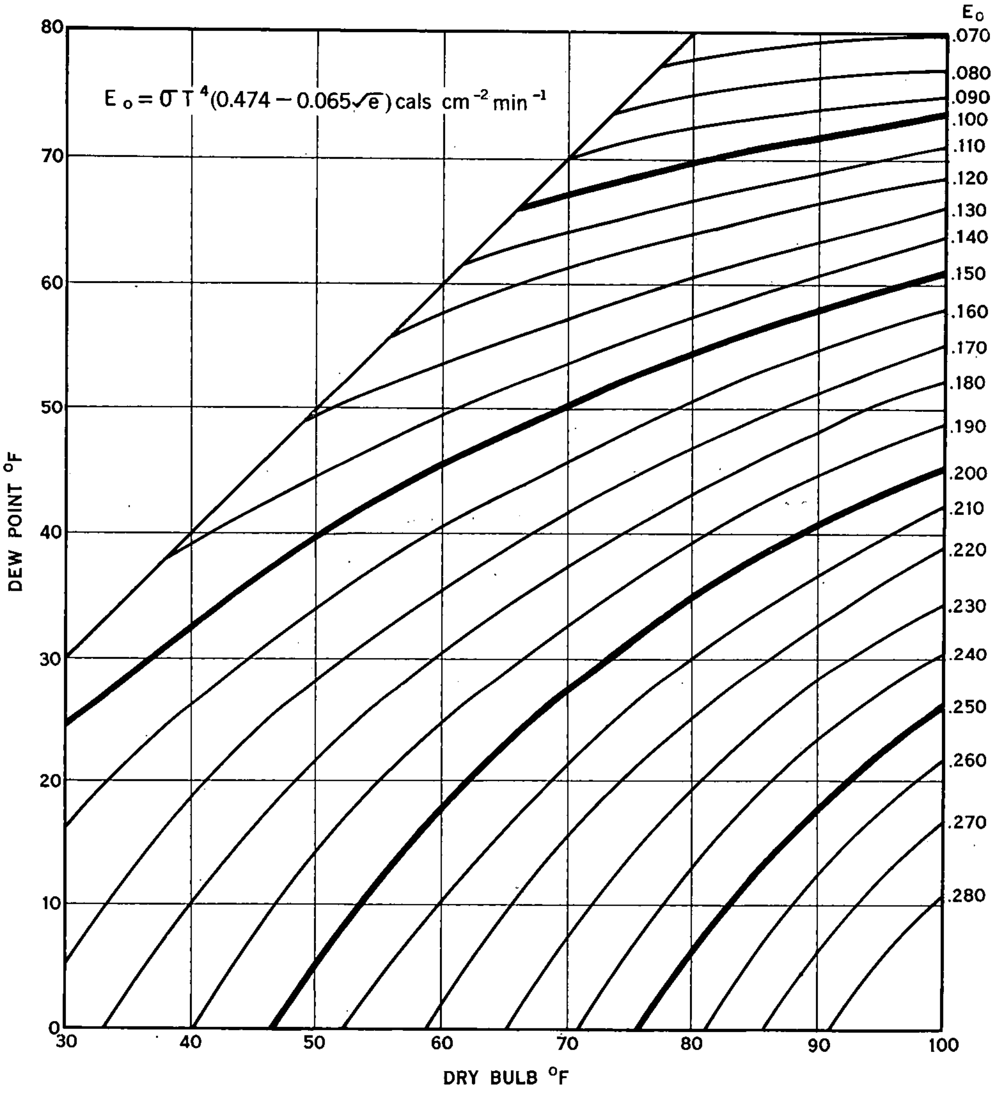

FIG.1 : (b) Values of E_o, given 1800 CST drv bulb and dew point temperatures (°F).
(See text for explanation)

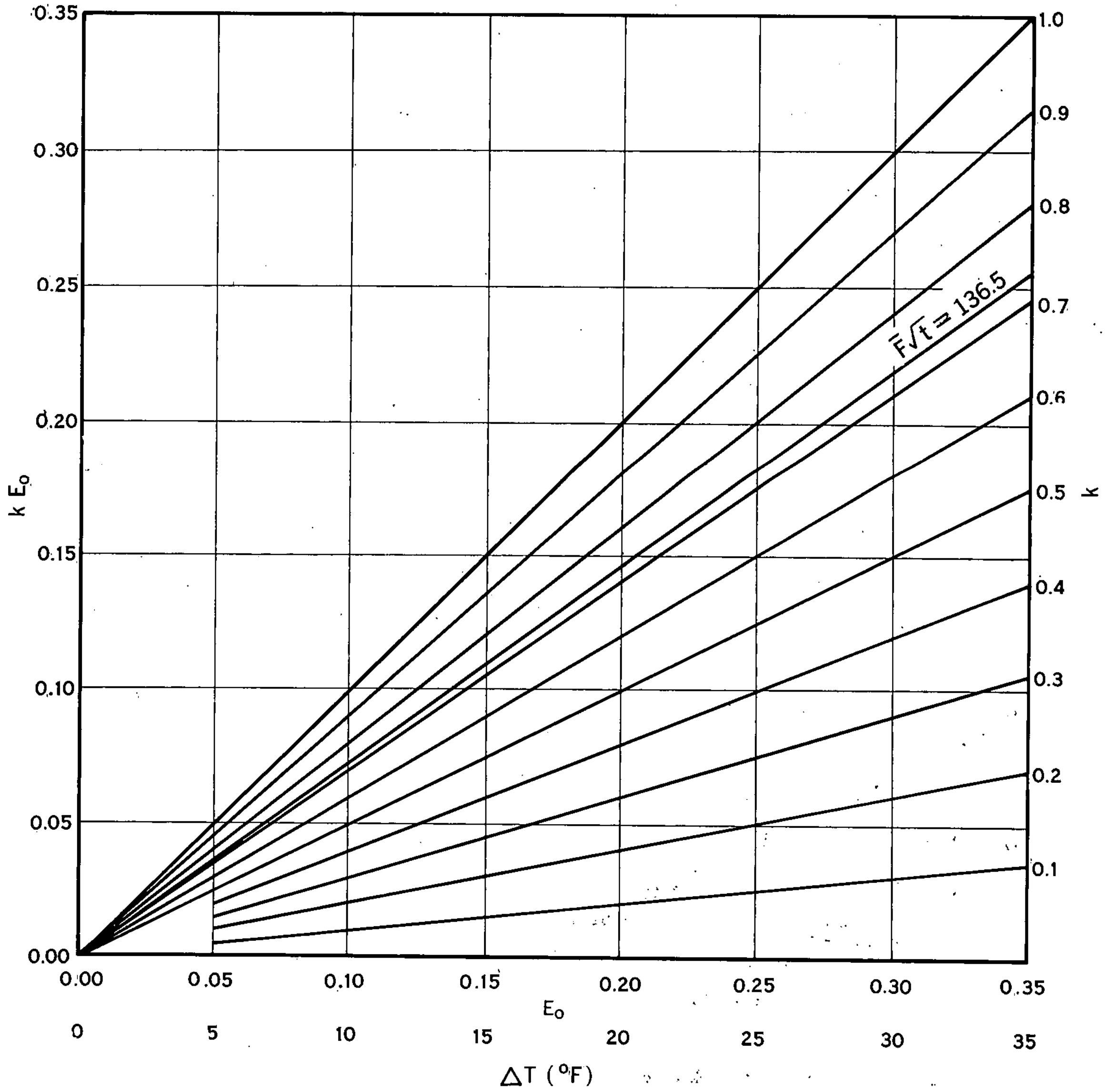

FIG.2 Nomogram for determination of ΔT given E_o and k. (See text for explanation)

4. APPLICATION TO CLOUDED NIGHTS

The net flux at the earth's surface in the presence of cloud has been shown by various workers to be a function of the height of the cloud and to some extent the cloud density. If E_o is the net flux in the absence of cloud then the net flux in the presence of n octas of cloud may be expressed as

$$E_n = E_o (1 - \Sigma n_i k_i) = kE_o$$

where $\Sigma n_i = n \leq 8$, the n_i being the number of octas of the various cloud types present. The average values of k_i for various cloud types are Cirrus 0.04, Altocumulus and Altostratus 0.06, Stratus, Stratocumulus and Cumulus 0.08 and Nimbostratus and Cumulonimbus 0.10.

A rapid evaluation of the estimated temperature fall from 1800 CST to minimum is possible using figures 1 and 2. The procedure is as follows:-

(i) Using the 1800 CST cloud report, modified as indicated below where necessary, from Fig. 1a calculate

$$k = 1 - \Sigma n_i k_i$$

(ii) Enter Fig. 1b with 1800 CST dry bulb and dew point to obtain E_o.

(iii) Enter Fig. 2 with value of E_o on abscissa and move vertically to value of k (thin lines radiating from origin).

(iv) Move horizontally to heavy sloping line labelled $\overline{F}\sqrt{t} = 136.5$. Against this point read off temperature fall on the ΔT scale on the abscissa. Alternatively Fig. 3 may be easier to apply for Alice Springs data. In this the abscissa is E_o, the k values are given by the radiating lines and the values of ΔT corresponding to E_o and k are shown on the ordinate.

If the aid is used at other stations having similar latitudes, e.g. Charleville, a different value of $\overline{F}\sqrt{t}$ may be found applicable. Such reference lines may be easily inserted on figure 2 whereas a new figure 3 would be necessary for each such value.

Examples of the application of the aid under clouded conditions are:-

(i) 8/8 Ac As, Dry bulb 70°F, Dew Point 32°F.
$\Sigma n_i k_i = 0.48$ from Fig. 1 (a), hence $k = 0.52$
$E_o = 0.191$ from Fig. 1 (b)
$\Delta T = 13.5°F$ from Fig. 2 or Fig. 3.
Predicted minimum 56.5°F.

(ii) 4/8 Cs, 3/8 Cu, Dry bulb 56°F, Dew Point 45°F.
$\Sigma n_i k_i = 0.16 + 0.24 = 0.40$. Hence $k = 0.60$
$E_o = 0.145$
$\Delta T = 12.0°F$.
Predicted minimum 44.0°F

In applying the aid the following points should be carefully watched and predicted values modified where necessary.

(a) The soil factors will vary mainly with the moisture content. Discretion should, therefore, be exercised in applying the aid within 24 to 48 hours of appreciable rain. In wet soils the factors Kg, Cg and ρg are all higher than for dry soils and hence F will be decreased and predicted minima likely to be lower than actual minima.

(b) The 1800 CST cloud observations should not be used unmodified unless it is considered that they will be representative of the overnight conditions. If, for instance, in example (ii) above it was apparent that the Cu was rapidly dissipating a more appropriate value for k would probably be 0.84 the value

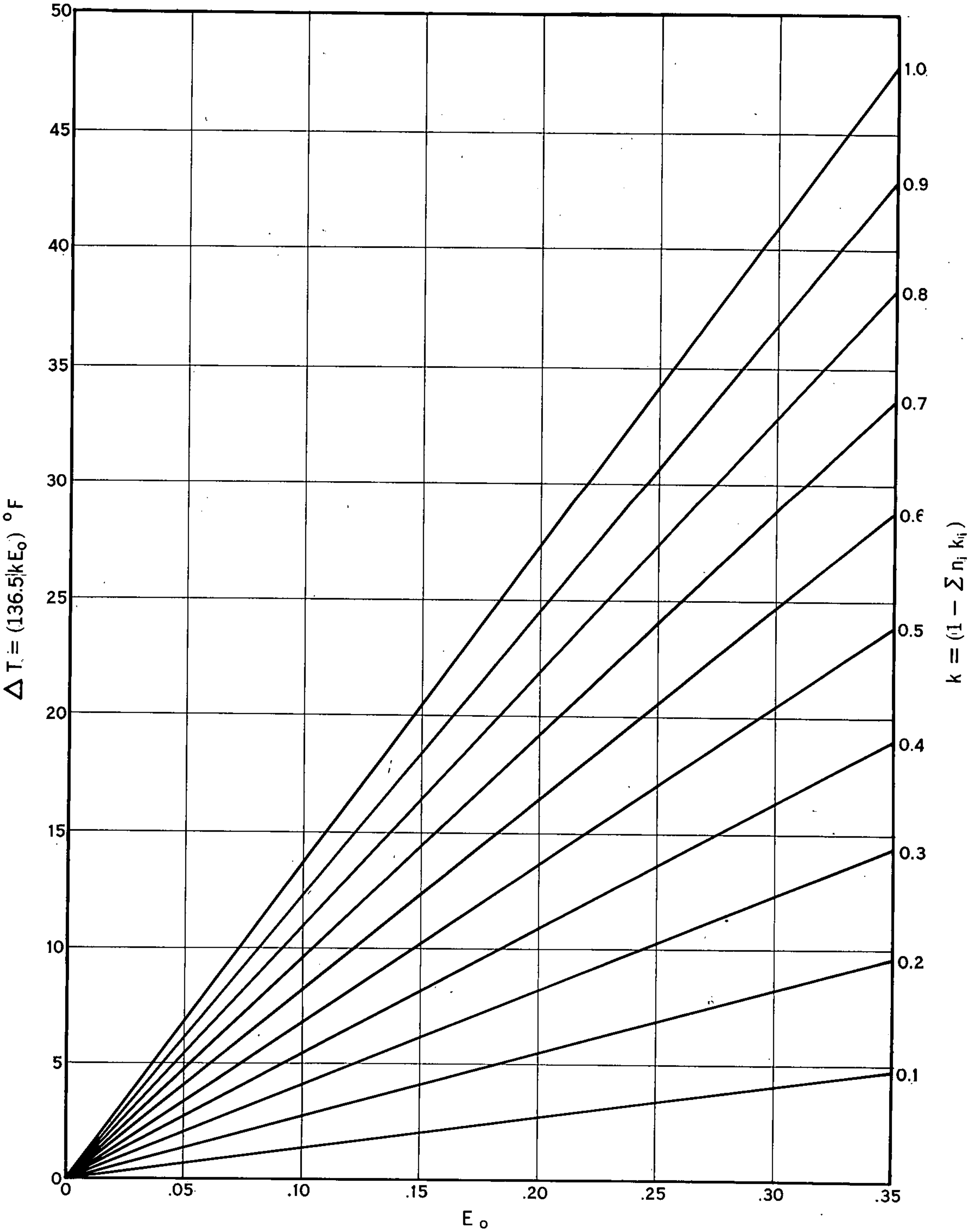

FIG.3 Alternative nomogram for determination of ΔT given E_o and k for Alice Springs only. (See text for explanation)

for no low cloud. Under such conditions Δ T would be 16.6°F and predicted minimum 39.4°F. The forecast value adopted would therefore be somewhere between 39 and 44°F.

(c) The aid should only be used where no major air mass change is expected during the forecast period.

During the May-September period at Alice Springs the factors (a) and (c) will not normally exclude many nights and the use of forecast cloud amounts should reduce errors due to non-representative cloud reports at 1800 CST.

5. DISCUSSION OF TESTS

To assess the value of the objective aids, the following statistics, which are shown in Table 4, were calculated:

(i) The mean, variance and standard deviation of minimum temperature for each of the months considered.

(ii) The mean square of the interdiurnal variation (MSIV) of minimum temperature for each of the months and also for the cloudless day samples. These provide the error variances for persistence forecasts.

(iii) Skill ratings based on persistence forecasts.

$$\text{Skill rating} = S^2 = 1 - \frac{\text{Error Variance}}{\text{MSIV}}$$

For the test years 1958 and 1960, the 1800 CST data were used, without modification from synoptic considerations, to determine the approximate order of the error variance when cloudy situations were included. They would be expected to be greater than the error variances resulting from application of the considerations in the foregoing section. These results and the associated skill ratings are also shown in Table 4.

The variance and the MSIV values show considerable variation, between years, in each of the months May through September. There is no definite correlation between these statistics and mean temperature, although in general the MSIV values for the cloudless day samples are less than those for the whole month.

Although skill ratings are intended to assess the relative values of the aids, they do not achieve this purpose very satisfactorily due to the dependence of the rating on the magnitude of MSIV. The magnitude of the error variances provide the best measure of the usefulness of the aid as a forecasting tool.

Method 2 for days which were cloudless at 1800 CST gave desirable results (error variance $\leqslant 16$) in three out of every four months tested while in only 10 percent of the months tested did the error variance exceed 20, and these were characterised by moderate to high skill ratings. Without examination of the individual synoptic situations and/or the synoptic reports for the overnight period to assess the representativeness of the 1800 CST cloud data during 1958 and 1960, the significance of the whole month error variances cannot be assessed.

6. CONCLUSIONS

(i) The radiative flux technique is highly suited for application under cloudless conditions.

(ii) Some further testing of the aid on cloudy nights is desirable to confirm the cloud factors k_i or determine modified values.

(iii) The specification of a frost risk rating scale for the Heavitree Gap area, based on forecast screen minima at the aerodrome, must wait the determination of the magnitude of the differences between the two areas, particularly on typical frost nights.

Table 4. Error Variances and Skill Ratings

MSIV = Mean square interdiurnal variation.

E_1^2 = Error variance - Method 1; E_2^2 = Error variance - Method 2.

$S_1^2 = 1 - \frac{E_1^2}{MSIV}$ = Skill rating Method 1; $S_2^2 = 1 - \frac{E_2^2}{MSIV}$ = Skill rating Method 2.

N = No. of days in cloudless sample.

		All days						Cloudless Days Only					
		$\overline{T}$	Var.	S.D.	MSIV	E_2^2	S_2^2	N	E_1^2	E_2^2	MSIV	S_1^2	S_2^2
May	1956	49.1	29.6	5.45	26.8			3	7.1	2.3	0.5	-12.1	-3.3
	1957	45.8	48.4	6.96	34.2			15	12.5	10.3	16.3	+ 0.24	+0.37
	1959	47.4	49.2	7.02	12.6			13	6.1	10.6	10.5	+ 0.42	-0.01
	1961	45.8	25.6	5.06	28.4			20	11.5	11.1	20.2	+ 0.43	+0.45
	Development yrs. pooled							51	10.1	10.2	15.4	+ 0.34	+0.34
	1958	55.2	53.7	7.33	18.3	40.9	-1.24	4	41.5	15.9	12.1	- 2.4	-0.31
	1960	45.0	73.7	8.58	52.0	19.0	+0.64	12	16.8	12.1	29.9	+ 0.44	+0.60
	Test yrs. pooled				35.13	30.3	+0.14	16	22.9	13.1	25.5	+ 0.10	+0.49
June	1956	41.8	57.2	7.56	52.6			10	5.3	3.8	53.8	+ 0.90	+0.93
	1957	49.6	24.5	4.95	39.6			10	21.9	20.5	36.0	+ 0.39	+0.43
	1959	41.3	39.2	6.26	26.2			16	5.1	8.1	15.9	+ 0.68	+0.49
	1961	41.9	66.7	8.17	43.0			25	17.4	18.3	46.6	+ 0.63	+0.61
	Development yrs. pooled							61	13.0	13.6	44.7	+ 0.71	+0.70
	1958	40.7	46.3	6.81	20.2	20.2	0.00	11	27.0	17.7	16.3	- 0.67	-0.09
	1960	41.0	75.9	8.71	40.4	17.1	+0.58	10	14.5	6.9	31.3	+ 0.54	+0.78
	Test yrs. pooled				30.3	18.6	+0.39	21	21.1	12.5	23.5	+ 0.10	+0.46
July	1956	43.8	30.4	5.51	43.6			18	11.5	11.9	30.8	+ 0.63	+0.62
	1957	37.5	20.8	4.56	29.6			17	11.3	19.1	15.9	+ 0.29	-0.20
	1959	41.9	49.7	7.05	50.5			15	3.7	7.2	39.5	+ 0.91	+0.82
	1961	36.2	32.6	5.71	22.7			21	15.4	12.5	17.5	+ 0.12	+0.28
	Development yrs. pooled							71	10.9	12.8	25.1	+ 0.57	+0.49
	1958	45.1	65.4	8.09	60.6	37.5	+0.38	13	23.8	18.0	59.4	+ 0.60	+0.69
	1960	43.9	67.8	8.23	52.7	37.3	+0.29	16	31.3	30.3	56.8	+ 0.45	+0.47
	Test yrs. pooled				56.7	37.4	+0.34	29	27.9	24.8	57.9	+ 0.52	+0.57

Table 4 (contd)

		All days						Cloudless Days Only					
		$\bar{T}$	Var.	S. D.	MSIV	E^2_2	S^2_2	N	E^2_1	E^2_2	MSIV	S^2_1	S^2_2
August	1956	38. 8	28. 9	5. 38	25. 2			20	5. 6	7. 6	18. 6	+0. 70	+0. 59
	1957	43. 9	38. 4	6. 20	33. 5			24	11. 3	13. 0	22. 3	+0. 45	+0. 42
	1959	44. 4	49. 1	7. 01	23. 1			21	14. 3	19. 0	23. 3	+0. 39	+0. 18
	1961	40. 4	59. 7	7. 73	52. 2			25	12. 8	12. 4	51. 1	+0. 75	+0. 76
	Development yrs. pooled							90	11. 1	13. 0	29. 7	+0. 63	+0. 56
	1958	46. 6	72. 7	8. 53	62. 2	32. 2	+0. 48	17	12. 4	14. 5	27. 9	+0. 56	+0. 48
	1960	38. 5	29. 7	5. 45	18. 6	10. 5	+0. 44	25	9. 5	7. 0	13. 7	+0. 30	+0. 49
	Test yrs. pooled				40. 4	21. 3	+0. 47	42	10. 7	10. 1	19. 4	+0. 45	+0. 48
Sept.	1956	45. 6	56. 6	7. 52	37. 3			16	6. 0	6. 6	24. 1	+0. 75	+0. 72
	1957	48. 5	51. 3	7. 16	62. 1			21	16. 6	11. 3	40. 3	+0. 59	+0. 72
	1959	51. 6	53. 2	7. 30	55. 2			11	23. 5	15. 4	66. 7	+0. 65	+0. 77
	1961	53. 0	48. 7	6. 98	47. 2			20	11. 5	12. 1	45. 9	+0. 75	+0. 74
	Development yrs. pooled							68	13. 7	11. 1	42. 3	+0. 67	+0. 74
	1958	47. 0	81. 2	9. 01	51. 6	29. 5	+0. 43	15	13. 4	11. 8	51. 3	+0. 74	+0. 77
	1960	53. 3	71. 1	8. 43	73. 7	30. 6	+0. 58	13	23. 5	23. 7	77. 5	+0. 70	+0. 69
	Test yrs. pooled				62. 6	30. 0	+0. 52	28	18. 1	17. 3	63. 5	+0. 71	+0. 73

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