

METEOROLOGICAL OFFICE

FORECASTING TECHNIQUES MEMORANDUM

Nº 17

FORECASTING THE NIGHT MINIMUM
TEMPERATURE OF A CONCRETE
SURFACE IN WINTER

by

C.M.CLARK

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	<u>Page</u>
Foreword	
1. Introduction	1
2. Data used	1
3. Temperature structure in concrete	1
4. Use of the $\frac{1}{2}$ in. temperature	2
5. Forecasting the surface temperature	4
6. Use of data for earlier initial times	10
7. Time of onset of surface frost	10
8. Conclusions	10
9. Acknowledgement	11
10. References	12
Annexe A. A note on icy roads	13

Foreword

The present paper describes a method of forecasting the night minimum temperature of a concrete surface. Unlike an alternative approach described by Parrey³ and Ritchie⁶, which uses the forecast night minimum air temperature as the starting point, in this method a given amount, varying with time of year and cloud cover, is subtracted from the concrete surface temperature at 1800 GMT (or earlier in some months).

Now that most stations are equipped with concrete slabs and measurements are regularly made of the concrete minimum temperature, a simple investigation can readily be carried out, at any outstation, into the usefulness and accuracy of the two methods.

A suitable procedure would be as follows:

1. Note the following temperatures:
 - a. Concrete surface temperature at 1800 GMT (or earlier in some months);
 - b. Concrete minimum temperature for the following night;
 - c. Minimum air temperature during that night.
2. Plot the daily values of the differences (a-b) and (c-b) on graph paper with date along the x-axis. Separate graphs should be plotted for each range of cloudiness chosen (e.g. 0-2, 3-6, and 7-8 oktas as in the present paper), and a smooth curve drawn through each set of points, using monthly or 10-day averages as a guide in drawing the lines. After data for one winter season have been gathered, the curves can be used to forecast the concrete surface minimum temperature during the following winter, and the errors of the two methods compared.

If any information is available on the occurrence of ice on roads in the area around a station, it may be useful to study such reports in relation to the forecast and actual concrete minimum temperature.

Forecasting the night minimum temperature
of a concrete surface in winter

by C. M. Clark

1. Introduction

The danger caused to transport by the formation of ice on roads and runways is considerable, yet no specific forecasting technique is available.

Before he can issue a warning, the forecaster needs to know two things:

- (a) Whether the surface in question is likely to be damp, and
 - (b) whether the surface temperature is likely to fall below 0 degC.
- (a) is not considered here, (b) is the object of the investigation.

2. Data used

Data from thermocouples buried in concrete slabs were made available by courtesy of the Road Research Laboratory. The thermocouples were of the copper/constantan type, the readings being recorded on two strip charts, one for each slab. The concrete slabs, which were situated at Newark, on grassland about 20 ft from the nearest building, are described as follows:

7 in. slab: 4 ft by 4 ft square, and 7 in. deep.

Thermocouples buried at $\frac{1}{2}$, 2, $3\frac{1}{2}$, 5, and $6\frac{1}{2}$ in. in the slab, and at $10\frac{1}{2}$, $14\frac{1}{2}$, and $18\frac{1}{2}$ in. in the subsoil below the slab.

5 in. slab: 4 ft by 4 ft square, and 5 in. deep.

Thermocouples buried as $\frac{1}{2}$, $1\frac{1}{2}$, $2\frac{1}{2}$, $3\frac{1}{2}$, and $4\frac{1}{2}$ in. in the slab.

Data from both slabs were collected in the period 1962-1968 but throughout this survey, data from the 5 in. block only were used, except for fig. 1. A short comparison of results from the two slabs showed them to be very similar in behaviour.

3. Temperature structure in concrete

Isotherms were plotted on depth-time diagrams of the 7 in. concrete, used in this case because of the extra 2 in. depth, for individual days. A typical pattern of diurnal variation of temperature in concrete is shown in fig. 1, and compared with patterns in other types of ground, shown in figs. 2-4. A good indicator of the differences shown is the decrease of diurnal range with depth for each material, shown in table 1.

/Table 1.

Table 1. Diurnal range of temperature as a percentage of the range at the surface.

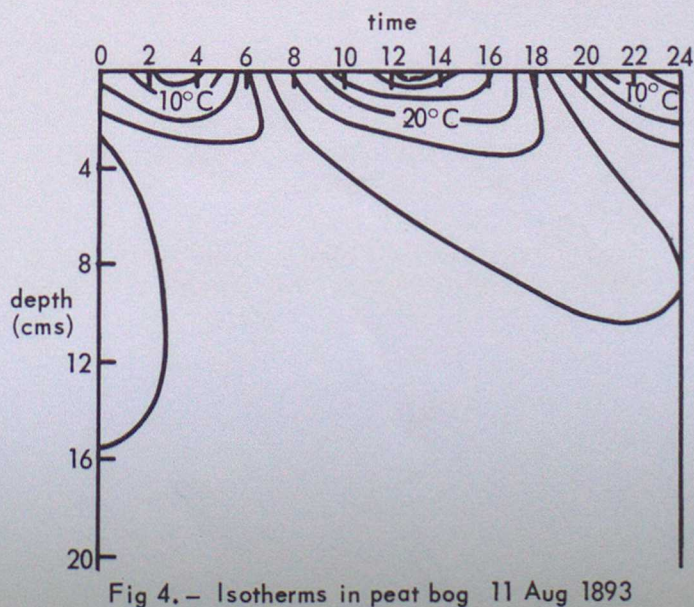
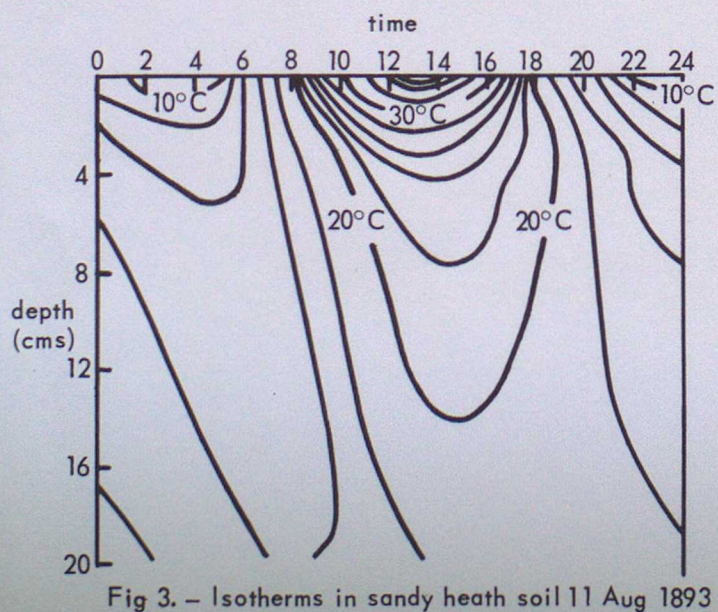
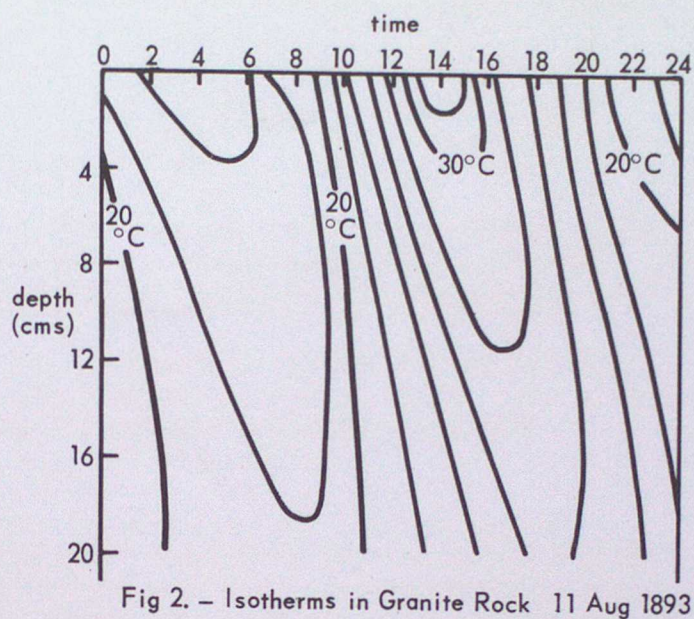
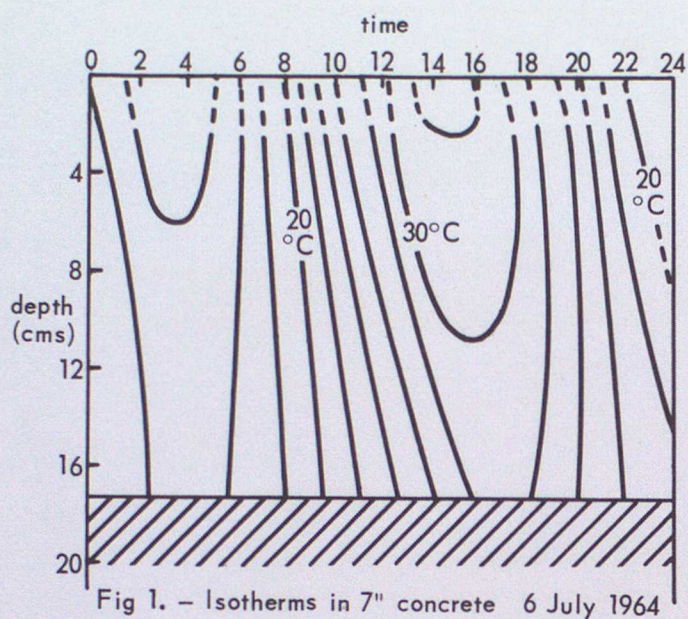
Type Depth	7 in. concrete	Granite rock	Sandy heath	Peat Bog
Surface	100	100	100	100
5 cm	85	79	32	10
10 cm	75	63	23	4.5
15 cm	70	53	13	-
20 cm	-	42	10	2
$a(\text{cm}^2 \text{sec}^{-1})$	0.045	0.021	0.010	0.003

'a' is the thermal diffusivity² of the material and is given by $a = \frac{\lambda}{\rho c}$ where λ is the heat conductivity of the material, ρ is the density of the material, c is the specific heat of the material.

It can be seen that the rate of penetration of heat into the concrete slab is greater than in earth. A 'heat reservoir' is built up during the day, which delays the fall of surface temperature overnight by upward conduction. After a warm, sunny day in July or August, the concrete surface minimum is about 5 degC. higher than the air minimum. The larger heat capacity suggests that concrete surface temperatures will not have a close relationship to earth surface temperatures or grass minima. This is borne out by observations on a concrete surface at Watnall³, which show that there is a much better relationship between concrete surface and screen minimum temperatures than between concrete surface and grass minima. Forecasting techniques have been derived from the screen minimum - concrete surface minimum relationship, but the root mean square deviation of the individual daily values from the mean is about 1.0 degC., and to this has to be added a typical standard deviation of about 1.8 degC in forecasting screen minima⁴. Hence, it seems better to try to derive a forecasting technique from concrete temperature data alone.

4. Use of the $\frac{1}{2}$ in. temperature

As can be seen from section 2, no actual surface temperatures were available in the Newark data, only $\frac{1}{2}$ in. temperatures. The continuity of the isotherms through the concrete was good, and there seems to be no reason to suspect any discontinuity between $\frac{1}{2}$ in. and the surface, so that throughout the following sections the $\frac{1}{2}$ in. temperature is used as the surface temperature, and is referred to as the surface temperature.



5. Forecasting the surface temperature

For any individual night,

$$M_R = T_R - \Delta T_R$$

where T_R is the road surface temperature,

M_R is the road surface minimum temperature.

If a mean value of ΔT_R were found, and T_R were measured, a forecast of M_R could be made, the error of the method depending on the distribution of individual values of ΔT_R about the mean.

Initially, T_R was taken as the measurement at 1800 GMT. A mean ΔT_R was calculated from data for 2-28 March 1967, and applied to data for 3-16 March 1964, in an attempt to forecast M_R over this period. The results were encouraging enough to warrant proceeding with the investigation.

As it seemed reasonable to expect the temperature to fall more on clear nights than on cloudy nights, ΔT_R was recalculated for three ranges of cloud cover, using data from both the previously used periods.

- The three ranges were
- clear (0-2 oktas)
 - part cloudy (3-6 oktas)
 - cloudy (7-8 oktas)

Since no weather observations were available for Newark, the average overnight cloud at Watnall (about 15 miles away) was used. No account was taken of cloud type or height. The investigation of ΔT_R was also extended to other months, and data from the following periods were used to calculate ΔT_R for the three cloud groups each month.

1-22 Nov 1964
11-24 Nov 1963
2-8 Dec and 16-29 Dec 1963

			2-16 Dec 1962		
			5-18 Jan 1968		
			1-26 Jan 1964		
			1-28 Feb 1965		
			10-21 Feb 1964		

Attempts to link ΔT_R with other parameters were not successful. The monthly variation takes the general level of temperature into account, and a more sensitive dependence on temperature within each month could not be found. Wind speed, precipitation, and the previous day's sunshine were not significant, except in their association with cloud cover. Fog was taken as 8 oktas cloud cover if the sky was obscured, and the actual cloud cover was taken if the sky was visible through the fog.

The fairly large monthly variations shown in fig. 5 suggested that ΔT_R would be determined more accurately by using shorter periods. Accordingly, values for ten-day periods were read off from fig. 5. The values so obtained were now applied to a further forecasting test on independent data.

Data from the following periods were used in the test:

1-11 and 25-30 Nov 1962
 1-21 Nov 1966
 8-28 Dec 1967
 12-28 Dec 1966
 1-28 Jan 1965
 4-28 Feb 1963
 14-26 Feb 1968
 1-10 Mar 1963
 6-26 Mar 1968

A few days are missing from some of the periods where the thermograph traces were unusable.

The results of the forecasting test are summarised in tables 2 and 3.

Table 2. Summary of forecast test

Month	Number of forecasts made	Number of forecasts correct to			σ (degC)
		± 1 degC	± 2 degC	± 3 degC	
November	37	22	35	37	1.21
December	38	26	35	38	1.15
January	28	16	26	28	1.26
February	38	17	31	37	1.59
March	38	13	26	33	1.99
TOTAL	179	94	153	173	1.49

/Table 3.

Fig 5. Variation of ΔT_R with month and cloud conditions

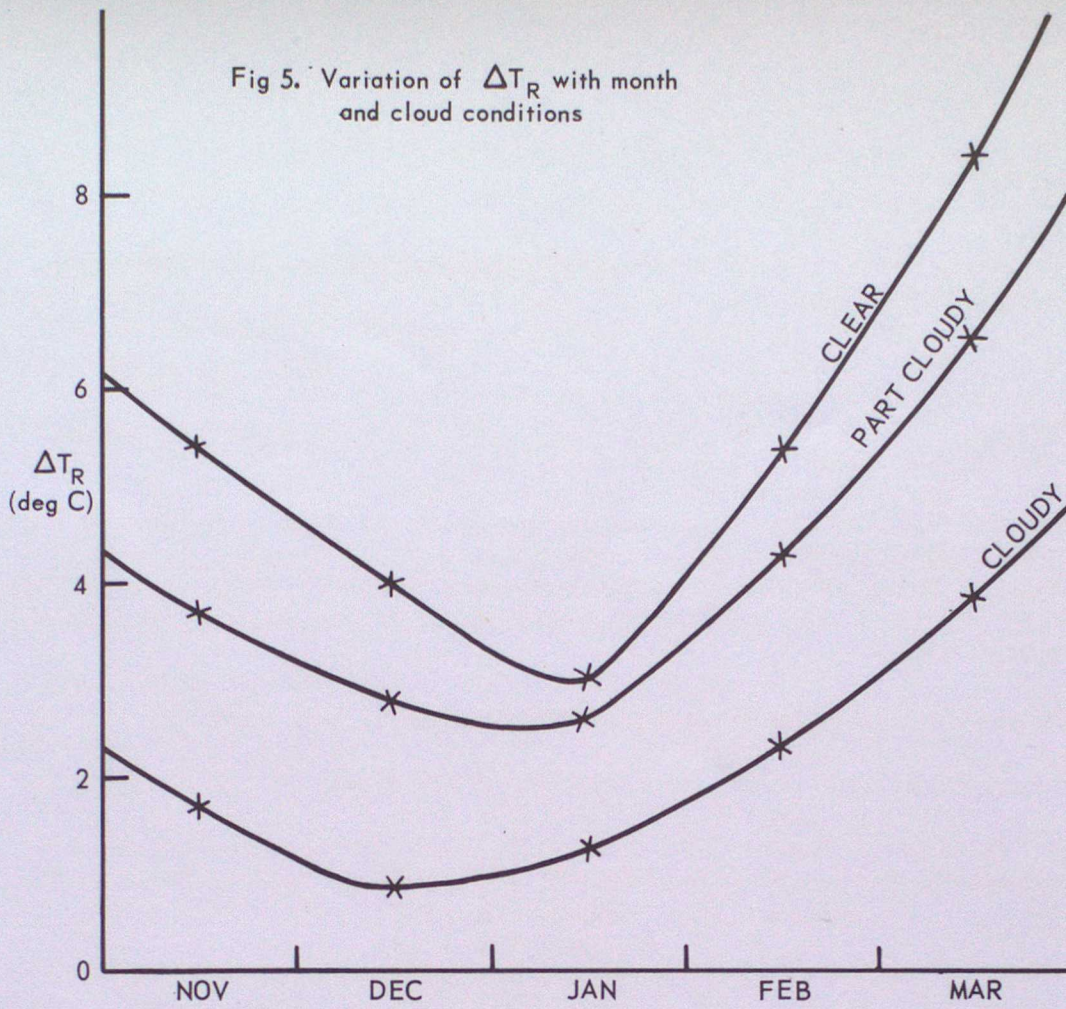


Fig 6. Scale B and solid line are ΔT_R against cloud cover in oktas (for December).

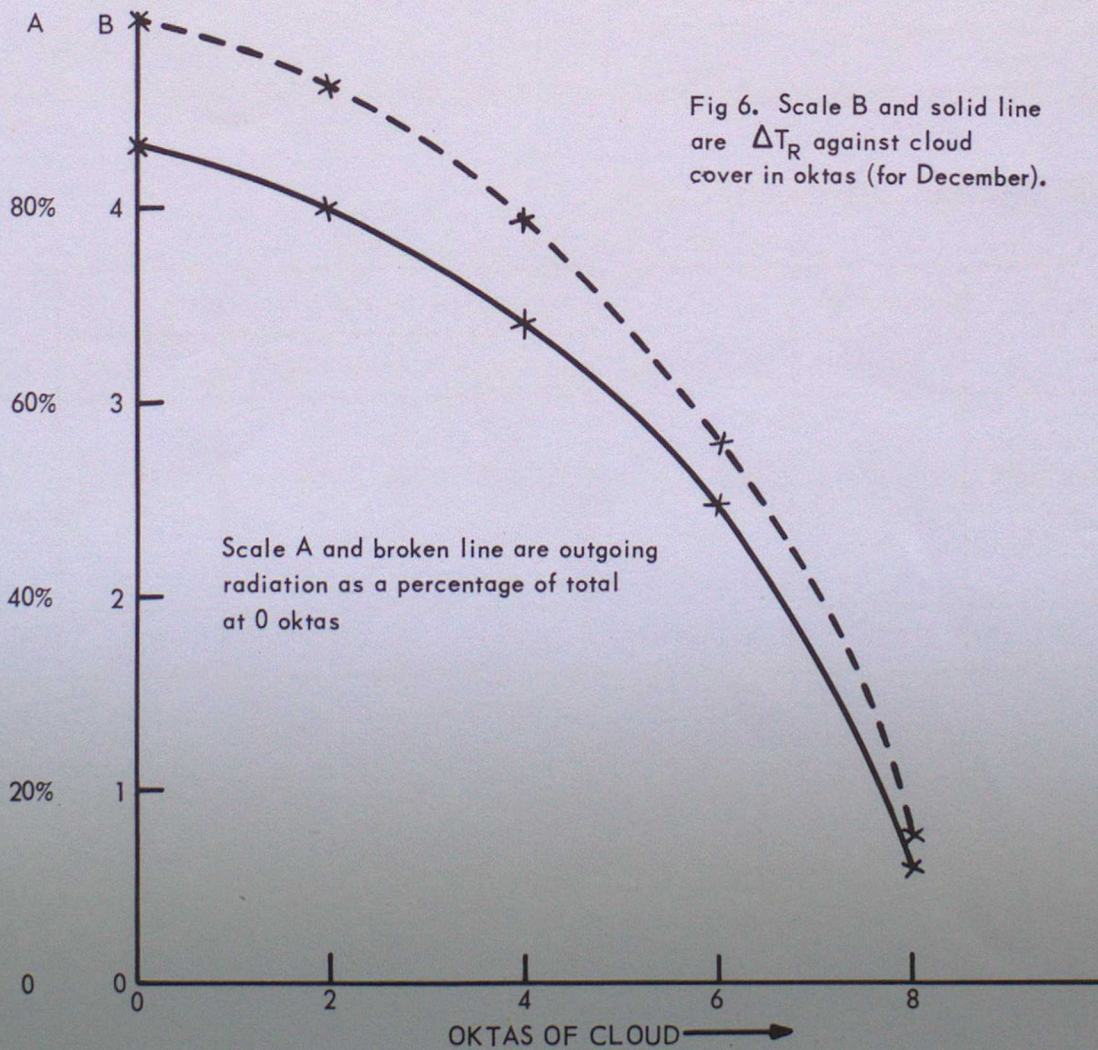


Table 3. Analysis of forecasting frost

a. Frost forecast for expected M_R of 0 degC or below.

	Frost recorded	No frost recorded	TOTALS
Frost forecast	75	10	85
No frost forecast	8	86	94
TOTALS	83	96	179

$$\text{skill score} = \frac{161-90}{179-90} = 0.80$$

b. Frost forecast for expected M_R of 1 degC or below.

	Frost recorded	No frost recorded	TOTALS
Frost forecast	82	20	102
No frost forecast	1	76	77
TOTALS	83	96	179

$$\text{skill score} = \frac{158-94}{179-94} = 0.75$$

A further refinement was to classify ΔT_R by individual oktas of cloud cover, instead of by the three cloud groups used previously. Graphs of ΔT_R against cloud cover were drawn, in order to compute ΔT_R for each okta of cloud. These graphs were interesting, the one for December being reproduced in fig. 6, together with a graph of outgoing radiation against cloud, taken from Geiger³, to which it shows marked similarity. A table of ΔT_R (degC) against cloud and date is reproduced as table 4.

/Table

Table 4. ΔT_R (degC) against cloud and date.

Cloud (Okta)	NOV			DEC			JAN			FEB			MAR		
	1/10	11/20	21/30	1/10	11/20	21/31	1/10	11/20	21/31	1/10	11/20	21/28	1/10	11/20	21/31
0	6.1	5.6	5.1	4.7	4.3	3.9	3.6	3.3	4.0	4.8	5.8	7.0	8.2	9.4	10.6
1	5.8	5.4	5.0	4.6	4.2	3.8	3.5	3.3	3.9	4.7	5.6	6.5	7.5	8.6	9.7
2	5.4	5.0	4.6	4.3	4.0	3.6	3.3	3.1	3.7	4.6	5.4	6.2	7.0	7.8	8.6
3	4.9	4.6	4.3	4.0	3.7	3.3	3.0	2.9	3.5	4.2	5.0	5.7	6.3	7.0	7.7
4	4.5	4.2	3.9	3.6	3.4	3.0	2.7	2.6	3.1	3.8	4.6	5.1	5.6	6.1	6.6
5	3.8	3.6	3.4	3.2	3.0	2.7	2.4	2.3	2.7	3.3	4.0	4.4	4.8	5.2	5.5
6	3.0	2.9	2.8	2.7	2.5	2.2	2.0	1.9	2.3	2.8	3.3	3.6	3.9	4.2	4.5
7	2.4	2.2	2.0	1.8	1.6	1.5	1.4	1.4	1.6	1.9	2.4	2.6	2.8	3.1	3.4
8	1.8	1.4	1.0	0.8	0.6	0.7	0.8	0.8	0.9	1.1	1.3	1.5	1.7	1.9	2.1

Table 4 was then used in a forecast test on the same data as were used to compile the results in tables 2 and 3. The new set of results appears in tables 5 and 6.

Table 5. Result of forecast test using table 4.

Month	Number of forecasts made	Number of forecasts correct to			σ (degC)
		± 1 degC	± 2 degC	± 3 degC	
November	37	21	33	36	1.26
December	38	24	33	38	1.22
January	28	17	24	28	1.22
February	38	23	32	35	1.40
March	38	15	26	33	2.01
TOTAL	179	100	148	170	1.46

Table 6. Analysis of forecasting frost using table 4.

a. Frost forecast for expected M_R of 0 degC or below.

	Frost recorded	No frost recorded	Totals
Frost forecast	76	7	83
No frost forecast	7	89	96
Totals	83	96	179

skill score = 0.84

b. Frost forecast for expected M_R of 1 degC or below.

	Frost recorded	No frost recorded	Totals
Frost forecast	81	17	98
No frost forecast	2	79	81
Totals	83	96	179

skill score = 0.79

The occasions of frost both forecast and recorded include those cases where T_R at 1800 GMT was below 0 degC.

/6.

Table 4 was then used in a test on the same data as were used to compile the results in tables 2 and 3. The new set of results appears in tables 5 and 6.

6. Use of data for earlier initial times.

As 1800 GMT is rather late in the day to make a really useful overnight forecast, an attempt was made to extend the method to earlier hours. Sunset appeared to be a limiting time, and any attempt to forecast minima on the basis of data from more than an hour before sunset was marked by a sharp drop in accuracy. Hence the method worked for 1500 GMT observations in January, but not before 1800 GMT in March. The results of extending the initial time backwards in January are shown in table 7.

Table 7. January

Time	Forecasts made	Number of forecasts correct to		
		± 1 degC	± 2 degC	± 3 degC
1800	39	24	37	39
1700	39	24	33	39
1600	39	23	33	39
1500	39	18	34	37

A new ΔT_R was calculated for each time.

7. Time of onset of surface frost.

The investigation was directly concerned only with forecasting nights when a concrete surface minimum below 0 degC. was likely, not the time of onset of surface frost. However, a brief investigation has suggested that by plotting T_R and forecast M_R on a temperature-time graph, and drawing a slightly concave (upwards) line between them, a reasonable estimate of the time at which the surface falls below 0 degC. is obtained. (The assumption that M_R occurs at 0600 GMT will not usually be far wrong).

8. Conclusions.

The investigation was concerned with temperatures on a 4 ft by 4 ft by 5 in. slab of concrete, which is rather different from a typical road or runway surface. However, there seems good reason to believe that a road or runway would behave in a similar way and it is hoped to collect data from such surfaces for comparison. Although the data used here were thermocouple records, an ordinary grass minimum thermometer, as used by Parrey³ and Ritchie⁶, would probably be adequate for the purpose. Robinson⁵ shows that the mean error (standard deviation not given) of taking a surface temperature, in the dark or in weak sunshine, with such an instrument is 0.6 degC. This inaccuracy, though by no means satisfactory, would be acceptable.

/If

If roads and runways do behave in the same way as the concrete slab, this method could well be a useful tool for the forecaster. Its main disadvantages are:

- a. A years data would be needed to calculate ΔT_R at each particular site before the method could be used.
- b. A thermometer of some sort would be needed on the surface for which the forecast is to be made.
- c. A forecast cannot be made until fairly late in the day.

Its main advantages are:

- a. Its accuracy. It is more accurate than most methods of forecasting night minimum screen temperatures⁴, probably by virtue of disadvantage c.
- b. The only other forecast it depends on is one of cloud cover, with an error in forecast of only about $1\frac{1}{2}$ oktas⁴.

Here it can be said that the forecast would probably be more accurate using only three cloud groups. The marginal improvement in using single oktas would be outweighed by the added inaccuracy in forecasting cloud cover to one okta.

A certain amount of improvement might be introduced by subjective considerations, e.g. if fronts are expected to cross the area, or if a change of air mass is likely.

9. Acknowledgement

Acknowledgement is made to the Road Research Laboratory for the loan of the temperature data, and to Mr. F. Palmer for discovering the existence of the records and bringing them to the author's notice.

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Acknowledgment

Acknowledgment is made to the Road Research Laboratory for the loan of the temperature data, and to Mr. T. Palmer for discovering the existence of the records and bringing them to the author's notice.

Annex A

A Note on Icy Roads in Lancashire on the Night of
25th-26th December 1963

At about 1800 GMT on the night of 25-26 December 1963, widespread icy roads were reported in Lancashire, despite the screen temperature at that time being generally around 3 degC.

A frontal system crossed the area between 0000 GMT 25 December and midday on the same day, marking the end of a lengthy cold spell, which had been quite severe towards its end. The fronts gave a fairly light spell of rain, and a polar maritime airstream of shallow convection, broken cloud, and light wind, followed them across the area during the afternoon.

Data are available for this night from the concrete slab at Newark. Newark experienced a similar sequence of weather, but about 2 hours later. The main difference was that rainfall in the East Midlands (11 mm at Watnall) was heavier.

Date	Time (GMT)	Lancashire Air Temperature (degC)			East Midlands Air Temperature (degC)			Newark Concrete Surface Temperature (degC)
		Ring-way	Squires Gate	Carlisle	Wittering	Watnall	Finningley	
25th	1200	6*	7*	7*	5*	5*	5*	2.3
	1400							2.9
	1600							2.8
	1800	2.7	4*	5*	5*	4*	6*	1.2
	2000	2.9	4.5					-0.2
	2200	2.9	4.0					-0.8
26th	0000	2.9	3*	4*	0*	2*	1*	-1.7
	0200							-2.1
	0400							-1.8
	MIN	2.6	2*	3*	0*	1*	MS 1*	-2.2

* Rounded to nearest degC; data extracted from Daily Weather Reports.

/It

It can immediately be seen that, in the Watnall area, the concrete surface temperature is about 3 degC below the air temperature throughout the period. The surface temperature fell below 0 degC. at about 1945 GMT. Much the same could be expected to happen in Lancashire, causing the concrete surface temperature to fall below 0 degC. at about 1800 GMT as reported.

The ΔT_R forecasting method would have given the following result that night.

$$T_R \text{ at 1800 GMT} = 1.2 \text{ degC.}$$

$$\Delta T_R = 3.0 \text{ degC. (for 4 oktas cloud)}$$

$$\text{Therefore forecast } M_R = -1.8 \text{ degC.}$$

$$\text{actual } M_R = -2.2 \text{ degC.}$$

Date	Time (GMT)	Lancashire Air Temperature (degC)			East Midlands Air Temperature (degC)			Concrete Surface Temperature (degC)
		Ringway	Spurne	Gar- fale	Wittering	Wet- hall	Wittering- ley	
25th	1200	6*	7*	7*	5*	5*	5*	2.3
	1400							2.9
	1600							2.8
	1800	2.7	4*	5*	5*	4*	6*	1.2
	2000	2.3	4.5					-0.2
26th	2200	2.9	4.0					-0.8
	0000	2.9	3*	4*	0*	2*	1*	-1.7
	0200							-2.1
	0400							-1.8
	MTW	2.8	2*	3*	0*	1*	MB 1*	-2.2

* Rounding to nearest degC; data extracted from Daily Weather Reports.

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1. **Forecasting precipitation - methods and techniques in use in the Meteorological Office.** By W.D.S. McCaffery and D.S. Gill. 1964.
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