

M.O. 307 f

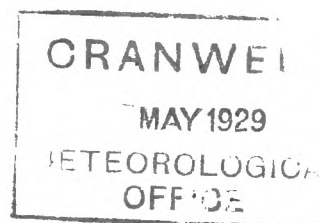
FOR OFFICIAL USE

AIR MINISTRY

METEOROLOGICAL OFFICE

GEOPHYSICAL MEMOIRS No. 46

(Sixth Number of Volume V.)



A Study
of the
Vertical Gradient of Temperature
in the
Atmosphere near the Ground

By N. K. JOHNSON, M.Sc., A.R.C.S.

Published by Authority of the Meteorological Committee.



LONDON :

PUBLISHED BY HIS MAJESTY'S STATIONERY OFFICE

To be purchased directly from H.M. STATIONERY OFFICE at the following addresses :
Adastral House, Kingsway, London, W.C. 2 ; 120, George Street, Edinburgh ;
York Street, Manchester ; 1, St. Andrew's Crescent, Cardiff ;
15, Donegall Square West, Belfast ;
or through any Bookseller.

1929

Price 3s. 6d. Net.

TABLE OF CONTENTS

Section	PAGE
1 INTRODUCTORY	3
2 SCOPE OF THE PRESENT INVESTIGATION	3
3 INSTRUMENTAL :—	
(a) The Site	3
(b) The Temperature-measuring Elements	4
(c) The Housing for the Thermometer Elements	5
(d) The Steel Tower	6
(e) The Aspirating Unit	6
(f) The Electrical Circuits	6
(g) Recording Instruments	7
(h) Possible errors due to Aspiration, etc.	7
(j) Calibration	9
4 MEAN HOURLY VALUES OF TEMPERATURE GRADIENT :—	
(a) Method of analysing Charts	11
(b) Mean Diurnal Curves for each Month	12
(c) Mean monthly and yearly Values	14
5 MEAN TEMPERATURE GRADIENTS FOR CLEAR AND OVERCAST DAYS	14
6 EXTREME VALUES OF THE TEMPERATURE GRADIENT	15
7 FREQUENCY OF OCCURRENCE OF TEMPERATURE GRADIENTS OF VARIOUS MAGNITUDES	22
8 MEAN DIURNAL TEMPERATURE VARIATION AT THREE HEIGHTS :—	
(a) Three-year means.	23
(b) Means for clear and overcast Days	26
9 TEMPERATURE CHANGES DURING EARLY MORNING	26
10 A STUDY OF SOME CHARACTERISTIC CHARTS	30

LIST OF ILLUSTRATIONS

Figure	PAGE
1 ALL-METAL RESISTANCE ELEMENT	4
2 COMPARISON OF LAGS OF RESISTANCE ELEMENTS	4
3 ORIGINAL TYPE OF HOUSING FOR RESISTANCE ELEMENTS	4
(a) External Appearance	
(b) Sectional View	
4 MODIFIED DESIGN OF HOUSING	4
5 TOWER CARRYING TEMPERATURE GRADIENT APPARATUS	5
6 ELECTRICAL CIRCUIT FOR DRY AND WET BULB THERMOMETERS	6
7 DIFFERENTIAL CIRCUIT SHOWING METHOD OF OBTAINING COMPENSATION OF EXTERNAL CONNECTIONS	7
8 HEATING EFFECT OF RESISTANCE ELEMENTS	8
9 HEATING OF RESISTANCE ELEMENT WITH INTERMITTENT CURRENT	9
10 MEAN DIURNAL CURVES SHOWING DIFFERENCES IN AIR TEMPERATURE BETWEEN HEIGHTS OF 1·2 M. AND 7·1 M., AND BETWEEN 1·2 M. AND 17·1 M.	12
11 SHOWING MEAN DIFFERENCES OF TEMPERATURE BETWEEN HEIGHTS OF 1·2 M. AND 7·1 M., AND BETWEEN 1·2 M. AND 17·1 M. FOR CLEAR AND OVERCAST DAYS IN JUNE. <i>facing</i>	13
12 SHOWING MEAN DIFFERENCES OF TEMPERATURE BETWEEN HEIGHTS OF 1·2 M. AND 7·1 M., AND BETWEEN 1·2 M. AND 17·1 M. FOR CLEAR AND OVERCAST DAYS IN DECEMBER	13
13 FREQUENCY OF OCCURRENCE OF VARIOUS TEMPERATURE GRADIENTS	23
14 MEAN HOURLY TEMPERATURE AT THREE HEIGHTS FOR EACH MONTH	26
15 MEAN HOURLY TEMPERATURE AT THREE HEIGHTS	28
(a) June—Clear Sky	
(b) June—Overcast Sky	
(c) December—Clear Sky	
(d) December—Overcast Sky	
16 EARLY MORNING TEMPERATURE CHANGES AT VARIOUS HEIGHTS	29
17 TEMPERATURE CHANGES AT VARIOUS HEIGHTS ON THE MORNING OF JUNE 4TH, 1927. <i>facing</i>	29
18 TEMPERATURE GRADIENT CHART FOR JUNE 29TH/30TH, 1923	
19 TEMPERATURE GRADIENT CHART FOR MARCH 15TH/16TH, 1923	
20 TEMPERATURE GRADIENT CHART FOR JUNE 20TH/21ST, 1923	
21 TEMPERATURE VARIATIONS AT THREE HEIGHTS DURING THE NIGHT OF JUNE 20TH/21ST, 1923	
<i>between 30 and 31</i>	

A STUDY OF THE VERTICAL GRADIENT OF TEMPERATURE IN THE ATMOSPHERE NEAR THE GROUND

§ 1—INTRODUCTORY

In the free atmosphere the vertical temperature gradient normally varies between comparatively narrow limits. On the one hand the gradient rarely exceeds the dry adiabatic lapse rate, and on the other hand inversions are usually of the order of one or two degrees Fahrenheit per hundred metres. In contrast with this, it is well known that much larger gradients of both signs are to be found near the ground, although, as far as is known, no systematic study of their magnitudes and variations has hitherto been made.

Observations of this nature are of importance from various points of view, but chiefly so in connexion with problems of atmospheric turbulence since the whole question of atmospheric stability is bound up in the vertical gradient of temperature.

§ 2—SCOPE OF THE PRESENT INVESTIGATIONS

In the present paper a description is given of a piece of apparatus which was constructed for the purpose of investigating the variations of the vertical temperature gradient in the lowest seventeen metres of the atmosphere, and an account is given of the results which have been obtained from the autographic records given by the instrument during the three years 1923/4/5. The data in question include continuous records of the air temperature at a height of 1.2m. (4 feet) and also of the difference in temperature over the intervals of height 1.2m. to 7.1m. and again from 1.2m. to 17.1m. The temperature-measuring elements consisted of platinum resistance thermometers, all of which were mounted in special anti-radiation housings and kept continuously aspirated.

In the results presented below, detailed consideration is given to the diurnal variation of the temperature gradient and the manner in which this varies throughout the year.

The differences are also shown between the results found with a clear sky as opposed to an overcast sky for both day and night, and for both summer and winter.

A study is also made of a number of individual charts which contain either representative or noteworthy features.

No complete attempt is made to discuss the observational data in terms of atmospheric turbulence.

A preliminary account of the apparatus and the results obtained from it during the first two years was given by the author to the British Association meeting at Southampton in 1925.

§ 3—INSTRUMENTAL

It has already been stated that the temperature measurements were obtained by means of platinum resistance elements mounted at various heights and kept continuously aspirated. A detailed account will now be given of the various features of the apparatus.

(a) *The Site*.—The site of the instrument is near the village of Porton on the south-eastern edge of Salisbury Plain. The temperature-gradient recorder is situated on the top of a horizontal ridge which runs WNW—ESE. for about a kilometre on either side of the instrument. The top of the ridge is at a height of 111m. (364 feet) above mean sea level. The ground to the south slopes away for 700m. at a mean slope of about one in thirty. On the north side of the ridge the ground falls away at about the same slope for some 250m. and then becomes roughly horizontal.

The site of the instrument has an excellent open exposure between SSW. and NNW. Between NNW. and NNE., at a distance of about 500m., lie a number of

single-storied buildings. The horizon between NNE. through E. to SSW. is formed by a ridge of downs which run roughly SW.—NE. at about a kilometre to the east of the instrument, and which rise to a mean elevation of about 40m. (130 feet) above it.

(b) *The Temperature-measuring Elements.*—For the accurate measurement of the temperature of the air it is necessary to protect the measuring device adequately from radiation, and also to cause the air to flow continuously over it.

The original platinum resistance elements consisted of 55 turns of No. 50 S.W.G. platinum wire wound in a fine spiral groove on a porcelain tube 60mm. long and 9mm. diameter, the whole being glazed after the wire had been wound on. At the beginning of 1925 these elements were replaced by all-metal units which possessed greater mechanical strength and better protection against moisture. The construction of this type of element is shown in Fig. 1. The resistance winding is contained in

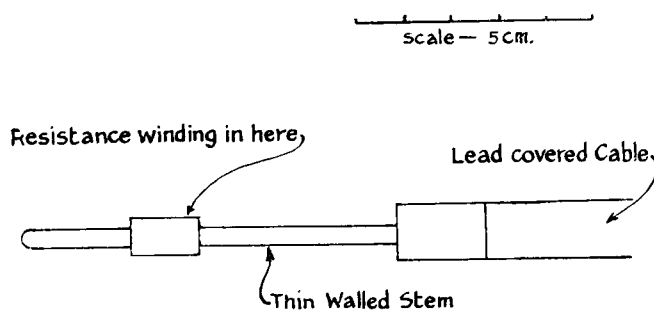


FIG. 1.—ALL-METAL RESISTANCE ELEMENT.

the "bulb" which is carried at the end of the thin-walled stem in order to reduce conduction of heat from the more massive parts of the apparatus. The two types of element are similar in that they both have a fundamental interval of forty ohms, their resistance being about 108 ohms at 40°F.

The similarity in the thermal features of the two types can be seen from Fig. 2, for which I am indebted to Mr. L. G. Hemens. To obtain each curve an element was mounted in the laboratory in a tube and kept aspirated. Initially, the air was taken in through a copper coil immersed in a bath. The element was connected in a Wheatstone bridge circuit so that its temperature could be followed. When its temperature

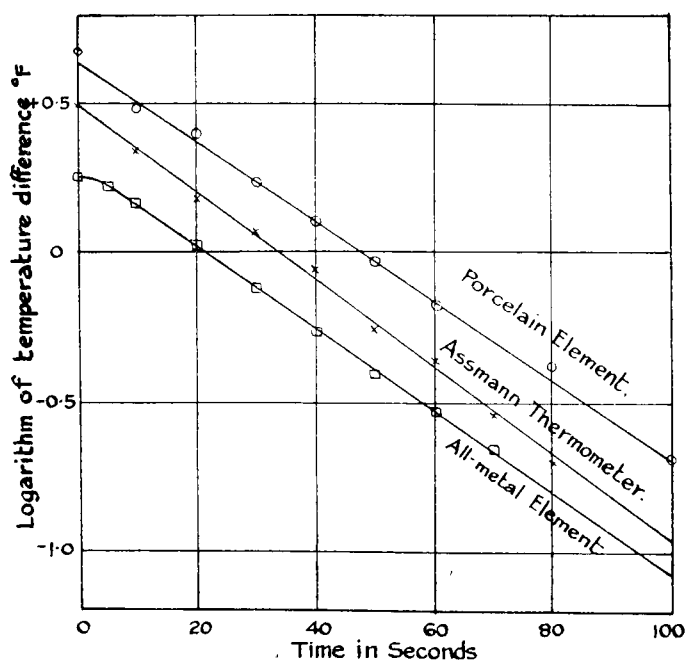
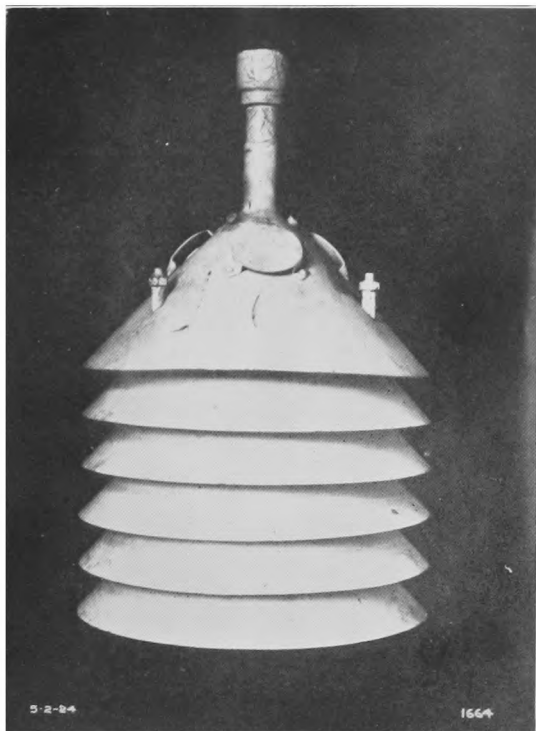
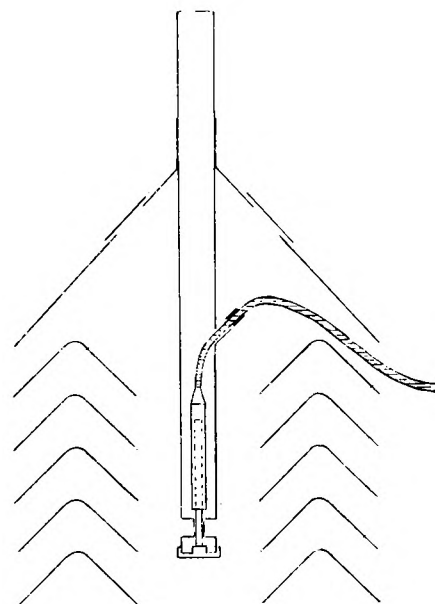


FIG. 2.—COMPARISON OF LAGS OF RESISTANCE ELEMENTS.



a. EXTERNAL APPEARANCE.



b. SECTIONAL VIEW.

FIG. 3.—ORIGINAL TYPE OF HOUSING FOR RESISTANCE ELEMENTS.

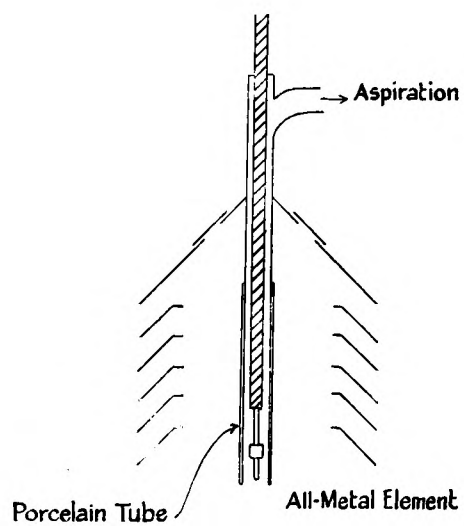


FIG. 4.—MODIFIED DESIGN OF HOUSING.

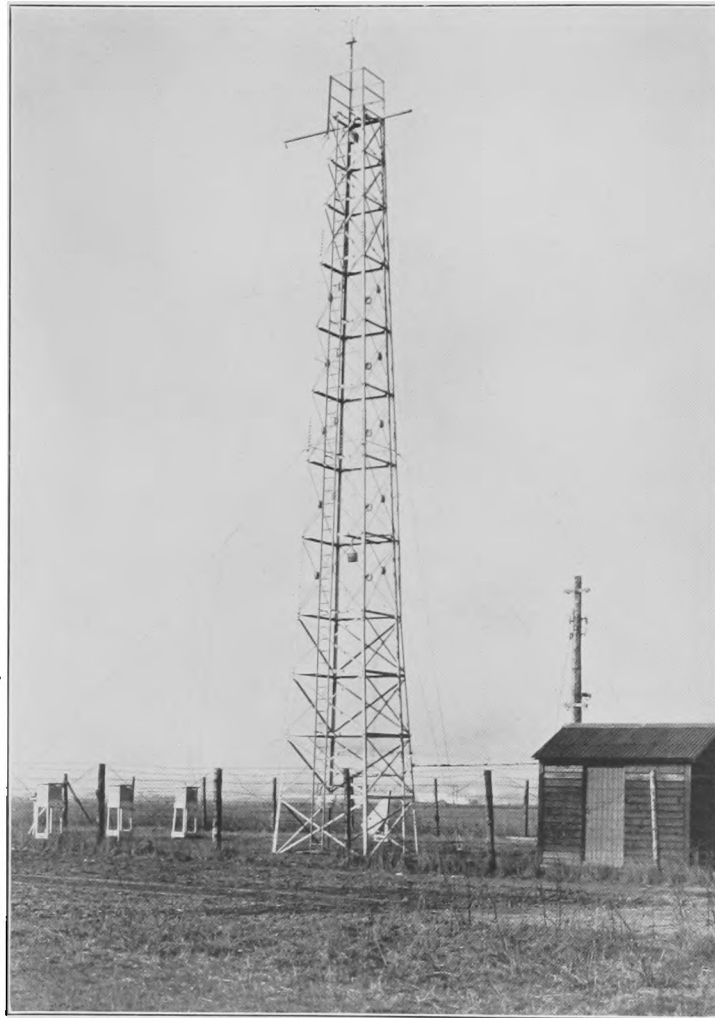


FIG. 5.—TOWER CARRYING TEMPERATURE GRADIENT APPARATUS.

had become steady the air supply was changed over and the resulting temperature changes of the element recorded. This was done with both types of element, and also, for purposes of comparison, with a thermometer of an Assmann psychrometer. In Fig. 2, the logarithm of the temperature is plotted against time, so that the similarity of the elements is to be judged by comparing the slopes of the three lines. Stated numerically, we may regard the recorded temperature difference Δ at any time t as given in terms of the initial temperature difference Δ_0 by

$$\Delta = \Delta_0 e^{-\alpha t}$$

in which α is the coefficient of lag.

The values of α found experimentally are as follows :—

Porcelain element	...	...	...	...	0.0286
All-metal element	...	...	...	...	0.0313
Assmann thermometer	...	...	...	...	0.0334

These results may also be expressed in terms of the fractions of the initial temperature change which are recorded after one and two minutes respectively.

Element	Fraction of temperature change recorded after	
	60 secs.	120 secs.
Porcelain	0.82	0.97
All-metal	0.81	0.96
Assmann thermometer	0.87	0.98

In these experiments it was found that the all-metal elements hesitated for some five or six seconds before commencing to respond to the applied temperature change. The subsequent behaviour agreed closely with the exponential expression given above, and the value of α refers to this part of the graph. In the table just given, however, the intervals of one and two minutes were reckoned from the instant at which the external temperature was changed.

The values for the fractions found by the two methods differ by very small amounts.

(c) *The Housings for the Thermometer Elements.*—Each of the five elements was contained in a separate housing, one such housing being illustrated in Fig. 3 (a) and (b). The former figure is a photograph showing the external appearance, and the latter a diagrammatic central section of the housing. It will be seen that the element is situated inside a central tube of 25mm. diameter, the electric leads being brought out of a short branch tube. The sides of the central tube are cut away at the bottom to allow inflow of the air, and its upper end is connected to the pipe system which runs to the aspirating unit. The central tube containing the element is surrounded by a louvred structure consisting of five copper rings surmounted by a cone. The rings and cone are all spun from No. 22 S.W.G. copper. The entire housing was stove-enamelled white and supported from the top of the central tube.

The above type of housing was employed during the period covered by the present paper. Subsequently the housing has been modified to the form shown in Fig. 4. In this form the central tube is made of white glazed porcelain and is provided with a brass union at the top which enables it to be removed with ease for examining the element or replacing muslin and wick. The connecting lead to the element is now carried straight out through a packing gland at the top of the housing, whilst aspiration is effected through a branch formed by a pitcher-T. The copper spinnings constituting the outer housing have also had their inner portion cut away. The modified form is considered to give a freer air flow round the inner tube, and also to be less liable to deflect contaminated air into the open end of the central tube.

The above account of recent modifications is given for the benefit of any other investigators who may be undertaking similar work.

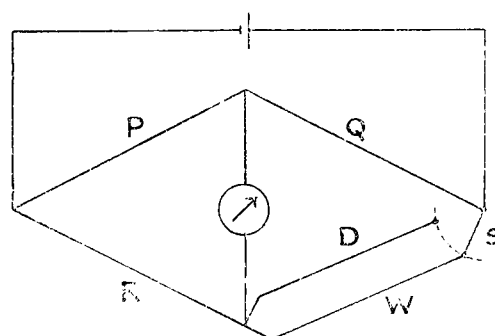
(d) *The Steel Tower*.—The five housings were mounted at the heights previously given on a skeleton steel tower, a photograph of which is given in Fig. 5. With a view to minimising radiation effects, the whole of the tower is painted white. A short distance away on the north side of the tower are situated the small huts containing the aspirating unit and the recording instruments. With northerly winds, therefore, one might expect the records to be affected by the proximity of these huts. Actually, however, no great differences have been detected in the traces on these occasions.

Standing on the ground behind the tower can be seen the external housing of the night-sky camera. Use is made of its records in classifying the temperature gradient at night according to the state of the sky.

(e) *The Aspirating Unit*.—The aspiration of the resistance elements was performed for two and a half years by means of a one eleventh horse-power Heinrici hot-air engine and rotary blower. A pipe of 5cm. internal diameter runs from the suction side of the blower to the top of the tower, and branch pipes of 2.5cm. internal diameter are led off with easy bends to each of the housings. A drain cock is fitted at the lowest point in this pipe system to run off accumulated water periodically. The hot-air engine has now been replaced by an electric motor.

When the aspiration is stopped the records of temperature gradient are totally erroneous. And since the electric power is by no means infallible, a recording instrument is provided which registers the pressure on the suction side of the blower. Failure of the electric current is thus detected, and it becomes possible to prevent the analysis of erroneous traces.

(f) *The Electrical Circuits*.—The electrical circuit employed for recording the dry and wet bulb temperatures is shown in Fig. 6. It is a simple Wheatstone bridge circuit with three fixed arms, P, Q and R. In the fourth arm are connected alternately



P, Q, R—FIXED COILS.
D — DRY BULB RESISTANCE ELEMENT.
W — WET BULB " "
S — AUTOMATIC SWITCH.

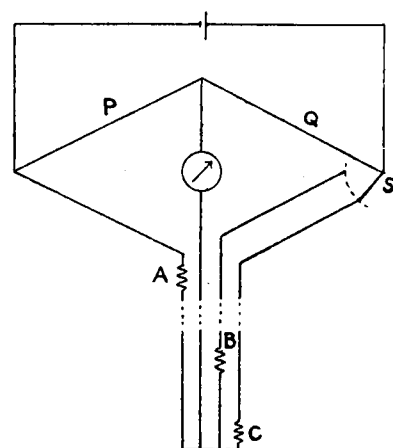
FIG. 6.—DRY AND WET BULB CIRCUIT.

the dry and wet bulb elements. The temperature changes of the resistance elements are given by the departure from balance as indicated on a moving coil galvanometer.

The wet bulb element is mounted in its own housing and in a similar manner to the dry bulb, with the exception that its bulb is covered with muslin and provided with wick feeds which run to a water reservoir. In Fig. 5 can be seen the three housings at 1.2m. (4 feet), *i.e.*, dry bulb, wet bulb and differential element. Single housings can also be seen at the heights of 7.1m. and 17.1m.

Some difficulty was experienced in keeping the wet bulb properly moistened, as it was found that the wick became dried up by the air stream. The trouble has been overcome in the more recent type of housing (Fig. 4) by drilling two holes through the side of the porcelain tube and feeding the wicks in level with the top of the element.

The temperature gradient or differential traces are obtained by a similar circuit (Fig. 7), the only difference being that the fixed arm R of Fig. 6 is replaced by the



P, Q —FIXED RATIO COILS.
S —AUTOMATIC SWITCH.
A, B, C—RESISTANCE ELEMENTS AT HEIGHTS
OF 1·2 m., 7·1 m. AND 17·1 m.

FIG. 7.—DIFFERENTIAL CIRCUIT SHOWING METHOD OF OBTAINING
COMPENSATION OF EXTERNAL CONNECTIONS.

resistance element at 1·2m. and the elements at the other two heights are now connected alternately across the fourth arm of the bridge. The external circuits of this differential system are compensated by being arranged in the manner shown in Fig. 7.

(g) *The Recording Instrument.*—The actual temperature traces are recorded on a thread recorder made by the Cambridge Instrument Company. This instrument comprises the Wheatstone bridge circuits just described, together with the galvanometers. A most important feature consists in the fact that the galvanometers are swinging free and thus take up their correct positions without any errors due to friction between pen and chart.

In the Porton instrument each galvanometer yields two traces consisting of a series of dots made at intervals of one minute. The traces are coloured black and red, and a dot of each colour is made alternately. The interval between successive dots of one colour is therefore two minutes.

It will be seen that the traces thus possess the equivalent of a very extended time scale which is of very great value in investigating phenomena which involve rapid variations of the temperature of the air.

The two galvanometers are mounted side by side and record the four traces on a single chart. The latter has a time scale of 12·75mm. to the hour. At right angles to the time scale the chart is divided into two parts (see Figs. 18, 19, 20). On one part the dry and wet bulb temperatures are recorded in black and red respectively on rulings from 0 to 100 °F., the mean scale being 0·95mm. per degree F. On the other half of the chart the difference between the air temperatures at heights of 1·2m. and 7·1m. is recorded in red, and the difference between 1·2m. and 17·1m. in black. The range available is 10°F. either side of zero, and the mean scale is 4·75m. per °F. The convention adopted for the differential side has been that a negative sign indicates a decrease of temperature with increasing height. Thus a positive value for the temperature gradient signifies a temperature inversion. The sign of the gradient is therefore the same as the sign of $d\theta/dz$ in which θ is temperature and z is height measured upwards from the ground.

(h) *Possible Errors due to Aspiration, etc.*—The velocity of the air past the elements with the earlier form of housing and aspiration was not measured. With the modified housing and electrical aspiration the air flow has been determined experimentally.

In the annular space between the element bulb and the porcelain tube the velocity was found to be about 8m./s. in all the housings in each of the positions on the tower. Errors due to different rates of aspiration are therefore likely to be small.

The pressure reduction in the air just past the bulbs of the elements has also been measured and found to be about 3mm. of water. The adiabatic cooling corresponding with this pressure reduction is one twentieth of a degree Fahrenheit. Level with the bulb the cooling will be less, and since it occurs approximately equally with each element it may be neglected.

In the earlier form of housing it is estimated that the air velocity was about one half of its present value, so that the two sources of error just considered may be regarded as negligible in that case also, particularly as the aspirating pipe system was not altered in any way.

Another possible cause of error in the temperature measuring which has also been investigated is the heating of the resistance elements by the current passing through them. Reference to Fig. 7 will show that the heating effect is not the same in all the elements, for whereas the common element is in circuit continuously the other two elements are only heated intermittently, the current passing for one minute and being stopped for the next minute.

Fig. 8 shows the results of laboratory determination of this heating effect for both types of resistance element. In all cases the current flowing through the element was 10 milli-amperes, which is also the value of the current through the elements in the temperature recording circuit. The elements were aspirated by an air flow which was estimated to be intermediate between that given by the hot-air engine and that provided by the electric motor in the outdoor arrangement.

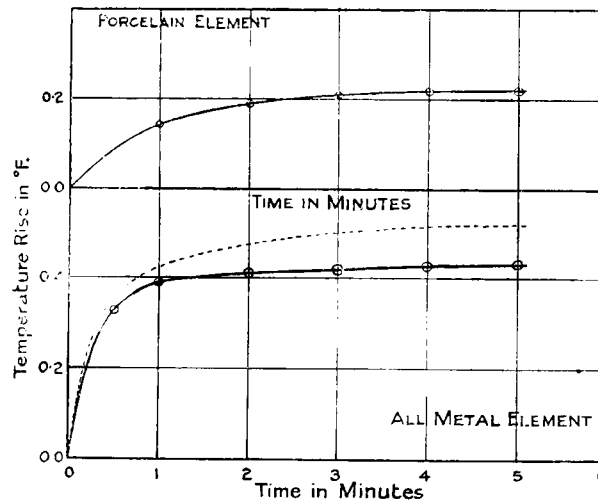


FIG. 8.—HEATING EFFECT OF RESISTANCE ELEMENTS.

It will be seen that the porcelain element heats up to the extent of 0.14°F. in the first minute and attains a constant temperature of 0.22°F. above its initial value after three to four minutes. An element which is continuously in circuit will acquire a temperature, therefore, not more than 0.08°F. above that of an element which is alternately heated and allowed to cool for intervals of one minute.

In the case of the all-metal elements the heating effect is about twice as large, and it also takes place more rapidly. Thus the rise of temperature after one minute is 0.39°F. and the steady value reached in two-and-a-half minutes is 0.43°F. The difference between the one-minute value and the steady value in this case is 0.04°F.

As a check upon this result an actual experiment was carried out in which the circuit was alternately made and broken at one minute intervals, and then finally kept closed in order to obtain the steady value. The result is shown in Fig. 9.

The final steady value is seen to be 0.05°F. above the temperature attained after each minute of closed circuit.

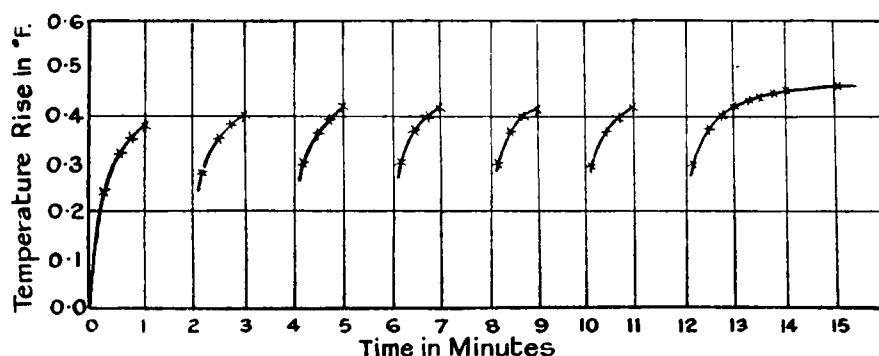


FIG. 9.—HEATING OF RESISTANCE ELEMENT WITH INTERMITTENT CURRENT.

The effect upon this heating of varying the aspiration was also examined. The dotted curve in Fig. 8 shows the effect of reducing the aspiration of the all-metal element to approximately one half its previous value. The rise in the temperature in the first minute is increased to 0.42°F. and the steady value becomes 0.52°F. The difference between these two values is now 0.10°F. as compared with 0.04°F. found with the more vigorous aspiration.

From the above experiments it is seen that the resistance elements in our temperature gradient recorder will be at temperatures above the actual air temperature by amounts depending upon :—

- (i) The type of element.
- (ii) The velocity of aspiration.
- (iii) Whether the element is in circuit continuously or intermittently.

Account has to be taken of these three factors when calibrating the recorder.

A further possible source of error arises from conduction down the metal casing and the electrical leads which communicate with the resistance winding. The lead-covered cable fitted to each element is exposed to sunshine after it leaves the housing, and some experiments have been carried out to ascertain the amount of heating of the resistance winding which is likely to result from this cause. I am again indebted to Mr. L. G. Hemens for the following result. It was found that if the lead-covered cable up to a point distant 19 cm. from the element were maintained at a temperature 100°F. above the air temperature, then conduction raised the temperature of the resistance winding by 0.4°F. The form of housing already described protects the lead-covered cable to a distance of about 48 cm. from the element. Moreover, sunshine is not likely to raise the temperature of the exposed portion of cable to more than about 60°F. above air temperature. It would appear, therefore, that the heating of the resistance element by conduction in actual practice is unlikely to exceed 0.1°F. If the first foot of cable after leaving the housing is either shielded from sunshine or painted white, the conduction error will be still further reduced.

(j) *Calibration.*—From what has been shown in the previous section, it is clear that the recording instruments must be calibrated and the zeros checked when the resistance elements are functioning in their normal manner. For example, the ice point of the dry bulb trace cannot be checked by immersing the dry-bulb element in an ice bath, because the resultant heating effect in the element will then be quite different from what it is when the element is aspirated. Similarly the zeros of the differential temperature traces cannot be checked by immersing all three differential elements in ice baths.

Calibration of the apparatus has therefore always been carried out by direct comparison between the recorder traces and simultaneous readings taken on Assmann psychrometers. An overcast day with a fairly strong wind is required in order to obtain the necessary steadiness of conditions.

Whereas it has been found possible to adjust the dry and wet bulb traces to read correctly to within 0.2° F., this accuracy is not sufficient, of course, for the differential circuit. For the latter, the differential traces are adjusted to agree approximately with the temperature differences over each interval of height as indicated by simul-

TABLE I—MEAN HOURLY VALUES OF THE TEMPERATURE DIFFERENCE IN
THREE YEARS

A.—OVER THE HEIGHT

Hour.	1	2	3	4	5	6	7	8	9	10	11	12
Month.												
J	0.85	0.70	0.72	0.59	0.64	0.61	0.58	0.56	0.38	-0.15	-0.44	-0.48
F	0.83	0.84	0.76	0.67	0.62	0.66	0.66	0.35	-0.08	-0.40	-0.58	-0.63
M	1.10	0.97	0.92	0.88	0.73	0.83	0.50	-0.18	-0.63	-0.89	-1.16	-1.23
A	1.08	1.04	1.03	0.86	0.82	0.47	-0.27	-0.66	-0.86	-0.97	-1.18	-1.30
M	0.91	0.78	0.72	0.68	0.43	-0.18	-0.65	-0.94	-1.06	-1.27	-1.26	-1.34
J	1.04	1.05	0.97	0.88	0.23	-0.57	-1.00	-1.16	-1.36	-1.66	-1.83	-1.90
J	1.17	1.05	1.03	0.90	0.38	-0.36	-0.75	-1.12	-1.33	-1.61	-1.83	-1.84
A	0.93	0.91	0.87	0.80	0.75	0.22	-0.52	-0.91	-1.22	-1.27	-1.47	-1.52
S	1.26	1.02	1.16	0.89	0.78	0.74	-0.03	-0.46	-0.65	-0.97	-1.27	-1.23
O	0.78	0.66	0.64	0.76	0.66	0.68	0.43	-0.17	-0.51	-0.70	-0.76	-0.87
N	0.68	0.63	0.68	0.79	0.76	0.74	0.73	0.57	-0.05	-0.41	-0.64	-0.64
D	0.76	0.72	0.64	0.67	0.61	0.56	0.58	0.56	0.29	-0.19	-0.37	-0.43
B.—OVER THE HEIGHT												
J	1.21	1.14	1.13	0.98	1.12	1.04	0.99	0.92	0.65	-0.10	-0.57	-0.65
F	1.29	1.35	1.28	1.12	1.04	1.14	1.05	0.72	-0.10	-0.59	-0.84	-1.00
M	1.67	1.52	1.46	1.34	1.20	1.16	0.76	-0.17	-0.85	-1.19	-1.54	-1.63
A	1.55	1.68	1.49	1.28	1.35	0.80	-0.37	-0.93	-1.18	-1.38	-1.62	-1.75
M	1.34	1.19	1.11	1.11	0.75	-0.03	-0.80	-1.25	-1.46	-1.79	-1.73	-1.82
J	1.55	1.58	1.49	1.36	0.35	-0.34	-1.25	-1.56	-1.92	-2.24	-2.45	-2.50
J	1.82	1.61	1.44	1.34	0.64	-0.46	-1.10	-1.52	-1.88	-2.17	-2.35	-2.33
A	1.27	1.27	1.22	1.21	1.12	0.41	-0.76	-1.25	-1.67	-1.72	-2.05	-2.07
S	1.60	1.45	1.51	1.32	1.18	1.04	-0.06	-0.77	-1.10	-1.35	-1.73	-1.67
O	1.30	1.08	1.02	1.12	1.02	1.04	0.71	-0.17	-0.70	-0.96	-1.08	-1.12
N	1.12	1.03	1.17	1.27	1.11	1.13	1.16	0.89	0.04	-0.51	-0.87	-0.89
D	1.15	1.07	0.98	1.01	0.95	1.02	1.01	0.96	0.60	-0.18	-0.49	-0.56

taneous readings of the Assmann psychrometers. A series of twenty observations at one-minute intervals is then made, both on the recorder and also with the Assmann thermometers, and the correction to the recorder trace is deduced from the mean of these.

§ 4—MEAN HOURLY VALUES OF THE TEMPERATURE GRADIENT

(a) *Method of analysing Charts.*—It has already been explained that the recorder gives four traces on the chart, viz., the dry and wet bulb readings at a height of 1.2m.

DEGREES FAHRENHEIT OVER TWO HEIGHT INTERVALS FOR EACH MONTH (BASED UPON RECORDS 1923/4/5).

INTERVAL 1.2 M. TO 7.1 M.

13	14	15	16	17	18	19	20	21	22	23	24	Month.
—0.38	—0.21	—0.02	0.34	0.87	0.89	0.87	0.90	0.88	0.76	0.77	0.78	J
—0.60	—0.46	—0.21	0.00	0.50	0.85	0.86	0.88	0.82	0.83	0.81	0.76	F
—1.14	—1.06	—0.80	—0.45	—0.02	0.57	1.26	1.33	1.16	1.10	1.14	1.12	M
—1.29	—1.15	—0.96	—0.67	—0.36	0.13	0.89	1.15	1.10	1.20	1.22	1.14	A
—1.31	—1.17	—0.96	—0.76	—0.45	—0.11	0.36	0.94	0.89	0.90	0.91	1.04	M
—1.81	—1.85	—1.64	—1.39	—0.92	—0.53	0.15	0.86	1.36	1.32	1.25	1.12	J
—1.83	—1.76	—1.63	—1.33	—0.97	—0.60	—0.13	0.46	1.23	1.11	0.98	1.00	J
—1.55	—1.46	—1.37	—1.00	—0.72	—0.33	0.29	0.76	0.82	0.94	0.92	1.02	A
—1.08	—0.89	—0.64	—0.43	—0.04	0.47	0.94	0.99	1.09	1.13	1.08	1.18	S
—0.80	—0.65	—0.34	—0.03	0.64	1.07	1.03	0.86	0.77	0.88	0.92	0.78	O
—0.55	—0.27	0.08	0.64	0.97	0.93	0.95	0.90	0.80	0.80	0.83	0.68	N
—0.36	—0.22	0.13	0.56	0.56	0.60	0.57	0.60	0.63	0.71	0.74	0.61	D

INTERVAL 1.2 M. TO 17.1 M.

—0.57	—0.45	—0.01	0.44	1.33	1.39	1.26	1.30	1.31	1.19	1.18	1.07	J
—0.87	—0.71	—0.43	—0.04	0.75	1.21	1.33	1.36	1.26	1.34	1.24	1.30	F
—1.53	—1.39	—1.06	—0.64	0.08	1.18	1.75	1.90	1.67	1.62	1.73	1.70	M
—1.66	—1.48	—1.30	—0.94	—0.53	0.17	1.27	1.57	1.67	1.68	1.83	1.74	A
—1.79	—1.74	—1.48	—1.10	—0.67	—0.14	0.47	1.37	1.36	1.38	1.35	1.44	M
—2.37	—2.43	—2.17	—1.82	—1.13	—0.73	0.04	1.33	1.95	1.90	1.85	1.71	J
—2.37	—2.30	—2.05	—1.84	—1.27	—0.84	—0.17	1.14	1.61	1.58	1.54	1.50	J
—2.02	—1.97	—1.87	—1.38	—0.98	—0.40	0.43	1.18	1.22	1.30	1.32	1.39	A
—1.48	—1.29	—0.92	—0.57	—0.14	0.57	1.30	1.29	1.41	1.39	1.40	1.45	S
—1.02	—0.87	—0.47	—0.03	0.89	1.56	1.56	1.37	1.26	1.37	1.43	1.24	O
—0.76	—0.49	0.08	0.82	1.42	1.34	1.33	1.42	1.25	1.16	1.22	1.11	N
—0.49	—0.32	0.21	0.83	0.99	1.00	0.90	0.97	1.01	1.02	1.20	1.05	D

(4 feet) on one half of the chart, and on the other half the differences of temperature between heights of 1.2m. and 7.1m., and between 1.2m. and 17.1m. The two latter traces will be referred to as the A and B differential traces.

Although it is usual to consider temperature gradient as a rate of change of temperature with height, it has been deemed preferable to present the results obtained with this apparatus in the form in which they are recorded; that is, as actual differences of temperature of the air between the heights in question.

All temperatures are expressed in degrees Fahrenheit and G.M.T. is used throughout. Hourly values have been extracted from both the differential traces for the three years 1923/4/5. The value allotted to each hour is the mean value of the temperature difference over the interval from 10 minutes before until 10 minutes after the hour in question. With a normally steady trace the mean value can be estimated directly by the aid of a line ruled on a sheet of glass. But when the gradient has been very unsteady the practice has been adopted of reading off the numerical value for each dot over the twenty-minute interval and taking the mean of these values.

The monthly means of the hourly values for each month are given in Table I and are shown graphically in Fig. 10.

In considering these results there are certain points which should be borne in mind. In the first place, individual daily traces show large departures from the mean monthly curves. For example, inversions exceeding 10° F. are by no means uncommon. The occurrence of two such inversions in a month would account for the peak at 20h. in the mean March curve. Similarly the various irregularities in the curves for other months are due to exceptional gradients on particular days. From this point of view it might have been better to draw smooth curves through the mean hourly values for each month. But in as much as the present results are, as far as is known, the first of their kind, it was considered preferable to adhere rigidly to the actual observations and to avoid any such smoothing.

Another point to remember is that, since the times of sunrise and sunset may alter considerably in the course of a month, the changes of temperature gradient which occur at about these times will appear less rapid in the mean monthly curves than they are actually. The effect due to this cause will be most marked at the equinoxes.

(b) *Mean Diurnal Curves for each Month.*—The mean diurnal curves for each month shown in Fig. 10 will now be discussed.

The outstanding feature of the January curve is the predominance of the temperature inversion. Over a period of fourteen hours (1700 to 0700) trace A gives a nearly steady inversion of about $+0.8^{\circ}$ F., and trace B one of $+1.2^{\circ}$ F. From 0700 until 1100 both gradients change over to small lapses of -0.48° F. in the case of trace A and -0.65° F. in the case of trace B. These lapses remain sensibly constant for about two hours (until 1300) when they again give way to inversions, the transition lasting until 1700. The two traces A and B cross twice in the course of the twenty-four hours approximately at the points at which the gradients change sign.

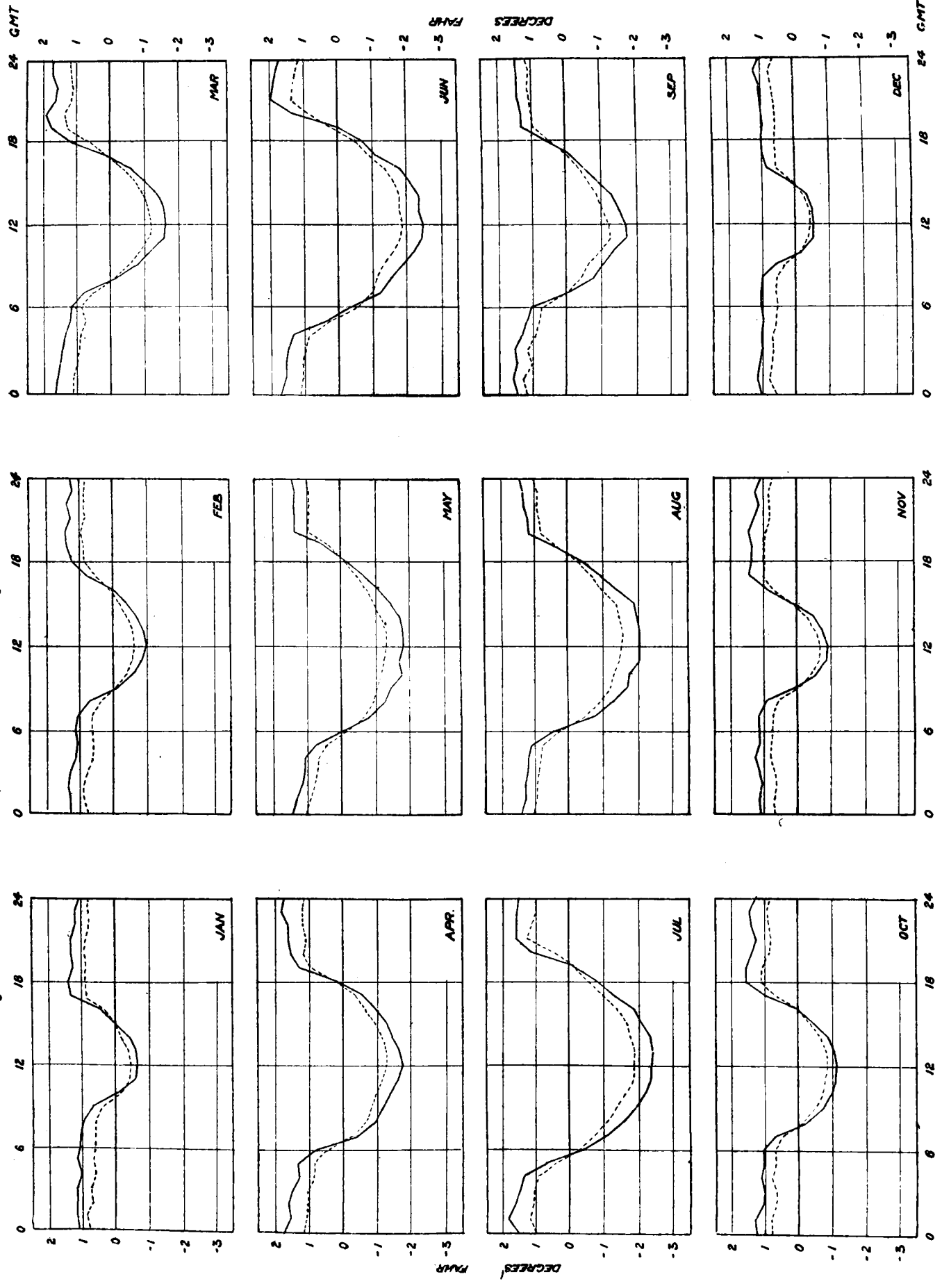
The values of the two traces corresponding to the dry adiabatic lapse rate are as follows :—

Trace A	...	...	...	...	-0.11° F.
Trace B	...	...	...	...	-0.29° F.

It will be seen therefore that even in winter the mean temperature gradient at noon between heights of 1 and 7 metres is at least four times the dry adiabatic value. The gradient, however, decreases rapidly with height and in the next 10 metres is almost exactly equal to the adiabatic value.

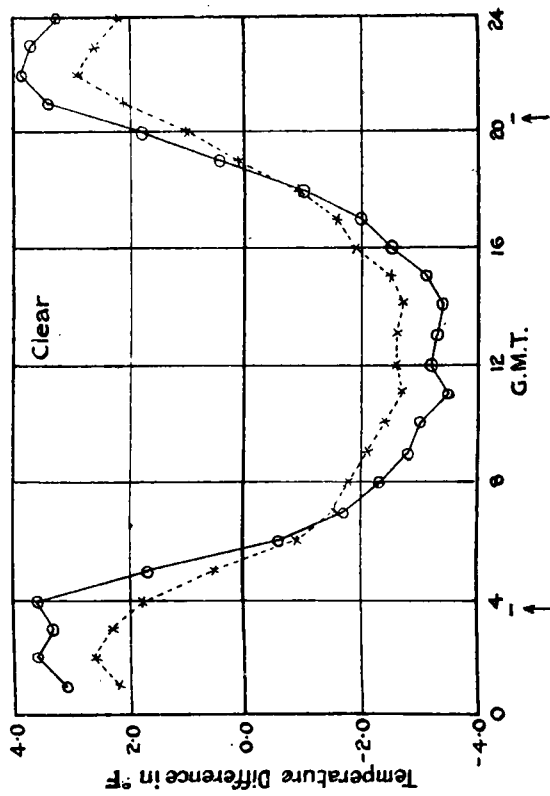
The sequence of changes which has been described in the January curves is repeated in all the other months. The relative duration of the various features and their magnitude vary from month to month. During February the nocturnal inversion persists in the mean from 1800 to 0700 with about the same numerical value as in January. The middle day lapses reach values of -0.63° F. and -1.00° F. for the two traces.

Fig. 10. Mean diurnal Curves showing differences in air temperature between heights of 1.2m and 1.1m (Broken Curves) and between 1.2m and 171m (full curves)



Moby & Co. Inc. 1960

JUNE



DECEMBER

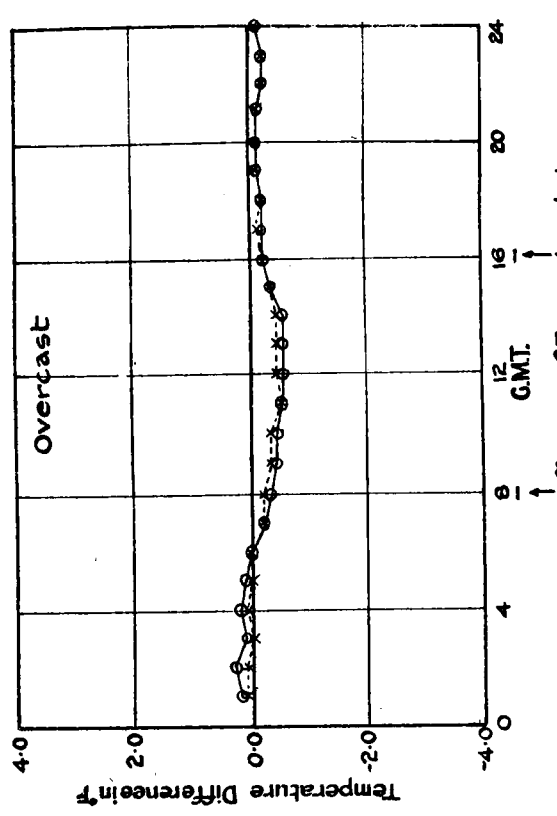
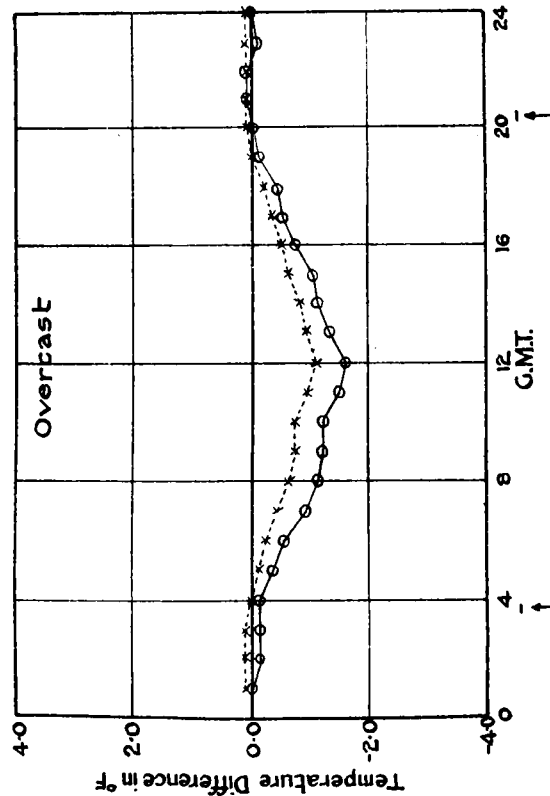
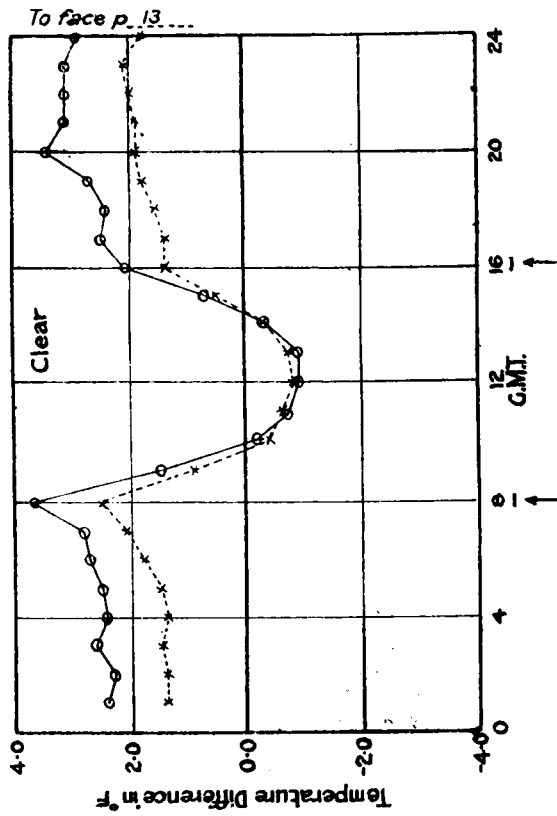


FIG. 11. Showing mean differences of Temperature between heights of 1.2m and 7.1m, and between 1.2m and 17.1m for clear and overcast days in June.

FIG. 12. Showing mean differences of Temperature between heights of 1.2m and 7.1m, and between 1.2m and 17.1m for clear and overcast days in December.

In March the magnitude of the inversion is somewhat greater than before, and the midday lapses have increased to -1.23°F. and -1.63°F. for the A and B traces. The former is now eleven times the dry adiabatic value.

The April and May curves resemble each other and continue the progression which has been observed in the previous months.

The June and July curves represent the culmination of the various features. The nocturnal inversion is approximately steady for only five hours (2200 to 0300), but the mean values for the two traces during this period are as high as $+1.1^{\circ}\text{F.}$ and $+1.6^{\circ}\text{F.}$ The large and prolonged lapses during the day in June reach values of -1.90°F. for trace A and -2.50°F. for trace B. The first of these is seventeen times the adiabatic value and the second eight times. In addition, the temperature decrease between 7m. and 17m. is 0.60°F. , which is 3.3 times the adiabatic difference. Hence there is again a rapid decrease of the lapse rate with height.

The curves from August on to the end of the year are similar to those for the corresponding months in the first half of the year. Both the duration and the magnitude of the day-time lapses decrease steadily whilst the nocturnal inversion increases in duration and shows, on the whole, a diminution in magnitude as winter is approached.

In the December curves we are brought back to a close resemblance to the January curve. The steady inversion of traces A and B is reduced in magnitude to $+0.6^{\circ}\text{F.}$ and $+1.0^{\circ}\text{F.}$ and the noon lapses are reduced to -0.43°F. and -0.65°F.

Regarding the curves for a year as a series, the most outstanding feature is the growth of the midday lapse between one and seven metres from four times the dry adiabatic value in winter to seventeen times that value in midsummer.

It has also been pointed out that in summer the nocturnal inversion is some fifty per cent greater than in winter.

There are certain other features in these curves which deserve attention. In the first place the curves are very nearly symmetrical on either side of the time of steepest lapse. Secondly, this time of maximum lapse occurs very shortly after noon G.M.T. in most cases, and not at about 1400 which is the time at which the air temperature reaches its maximum. It has been pointed out to the writer by Mr. O. F. T. Roberts that the time of maximum lapse follows local apparent noon much more closely than noon G.M.T. The time of occurrence of maximum lapse is somewhat difficult to estimate with accuracy, but if it is taken as occurring midway between the times of zero gradient in the morning and evening, then the time of maximum gradient is found to have an average lag of only three minutes behind local apparent noon.

Direct estimation of the time of maximum gradient from the curves gives the mean value of this lag as eight minutes. Whichever value is adopted it is clear, as Mr. Roberts says, that the temperature gradient follows the changing elevation of the sun with a lag of only a few minutes.

A few words are necessary with regard to the behaviour of the curves at the times of cross over from inversion to lapse and *vice versa*. Although the A and B traces intersect each other nearly at the same time as they cross the line of zero gradient, closer inspection shows that the A trace crosses the zero, or isothermal line on the average slightly before the B trace. This is true of both morning and evening. It is found from the graphs that on the average the A trace crosses the zero line in the morning five minutes before the B trace crosses it, and in the evening the A trace crosses about six minutes before the B trace. Thus in the morning it takes, on the average, about five minutes for the temperature at one metre to rise from that at seven metres to that at seventeen metres.

If instead of considering actual temperature we take potential temperature, then we find that in the morning an average adiabatic lapse rate between one and seventeen metres is not established until about twenty-two minutes after it is established between one and seven metres. Similarly in the evening the average gradient

between one and seventeen metres does not fall to the adiabatic value until about ten minutes after the mean gradient between one and seven metres has fallen to that value.

(c) *Mean monthly and yearly Values.*—The hourly values of temperature difference shown in Table I have been meaned by months and the means are given in Table II. These values may be regarded as the mean monthly values of the temperature difference over the two intervals of height to which the A and B traces correspond.

TABLE II—MEAN VALUES OF THE TEMPERATURE DIFFERENCE IN DEGREES FAHRENHEIT OVER TWO HEIGHT INTERVALS FOR EACH MONTH (BASED UPON THREE YEARS RECORDS, 1923/4/5).

Month				Height Interval	
				1·2–7·1 m.	1·2–17·1 m.
J.	..	..	..	0·46	0·72
F.	..	..	..	0·36	0·59
M.	..	..	..	0·25	0·45
A.	..	..	..	0·10	0·21
M.	..	..	..	–0·12	–0·12
J.	..	..	..	–0·31	–0·33
J.	..	..	..	–0·32	–0·35
A.	..	..	..	–0·17	–0·20
S.	..	..	..	0·21	0·24
O.	..	..	..	0·28	0·48
N.	..	..	..	0·44	0·69
D.	..	..	..	0·40	0·66
Annual Mean ..				0·13	0·25

It will be seen that from September to April inclusive the average gradient is an inversion, and that it is only during the four summer months, May to August, that the average of the gradient has a negative sign.

The maximum monthly means occur in January and July, the values of the mean inversion being 0·46° F. and 0·72° F. for the two intervals of height in January, and the mean lapses in July being –0·32° F. and –0·35° F. respectively.

The averages of the monthly means are given at the foot of Table II, and may be regarded as the mean annual values. Thus, for the three years under consideration the average temperature difference between heights of 1·2 and 7·1 metres was an inversion of 0·13° F., whilst between 1·2 and 17·1 metres it was also an inversion but of magnitude 0·25° F.

§ 5—TEMPERATURE GRADIENTS FOR CLEAR AND OVERCAST DAYS

In the previous section we have considered the mean values of temperature difference over certain intervals of height without regard to other meteorological conditions. We will now examine the variation which occurs in these temperature differences according to whether the sky is clear or overcast.

June will be taken as representative of the summer and December of winter. These two months are selected because in both of them the times of sunrise and sunset remain approximately constant. As a result, the portions of the mean diurnal curves representing the change over from inversion to lapse, and *vice versa*, bear a closer resemblance to the actual changes which occur on any particular day than is the case for the other months of the year.

In Table III are shown the mean hourly values of the two traces A and B for clear and overcast days and nights during the two months, June and December. The criterion for a clear day has been a continuous, or almost continuous, trace on the sunshine recorder. In the same way, the records of the night-sky camera have been utilised in classifying the nights. A complete absence of any trace on both the sunshine recorder chart and on the night-sky camera film have been required to admit a day into the overcast group. Only those days have been included in which the sky remained continuously clear or overcast throughout the twenty-four hours. The additional restriction was imposed that a day should be included only if the sky had been similar during the preceding twelve hours. This last condition was found necessary since a preliminary analysis showed that the temperature was largely affected by the state of sky during the previous day. The temperature gradient itself was very little affected in this way, but when we come to § 8 (b) it will be seen that it is desirable to consider only observations which correspond with steady conditions.

As a result of this strict system of classification, the number of days in some of the groups is rather small, the actual numbers being given in the last column of Table IV. This latter table also shows the mean hourly wind velocity for each group as recorded by the Dines pressure tube anemometer, the head of which is at a height of 13 metres. The data contained in Table III are also shown plotted in Figs. 11 and 12.

The curves for the clear days in June show maximum lapses of 2.7° F. and 3.5° F. for the A and B traces, compared with 1.9° F. and 2.5° F. already given as the means for all states of sky. The nocturnal inversions also reach values of 2.9° F. and 3.9° F. for the two traces, as opposed to values of 1.36° F. and 1.95° F. given in Table I.

On overcast days in June the greatest lapses are only 1.1° F. for trace A and 1.6° F. for trace B. The overcast nights in June are characterized by only very slight inversions.

Reference to Table IV shows that the wind velocity is at all hours lower on clear days in June than on overcast days. Moreover, in the first case the diurnal variation of velocity is very strongly shown, whilst in overcast weather it is much less marked.

On clear days in December the maximum lapses reach values of 0.8° F. for trace A and 0.9° F. for trace B, both of which are nearly double the mean value shown in Table I. On clear nights in December the two traces attain mean inversions of roughly 2° F. and 3° F., which are approximately three times as large as the mean inversions for the same month in Table I.

Overcast days and nights in December yield very flat traces. But even then it may be noted that towards noon the mean lapse between one and seven metres is about four times the dry adiabatic value. Between seven and seventeen metres, however, it decreases to less than the adiabatic value.

§ 6—EXTREME VALUES OF THE TEMPERATURE GRADIENT

The hourly analysis of the values of the temperature differences over the intervals of height 1.2m. to 7.1m. and 1.2m. to 17.1m. has been examined, and the extreme hourly values of both lapse and inversion which occur during each month have been extracted. The results are shown in Tables V and VI, together with the hour at which the extreme value occurred.

In Table VA are given the maximum hourly values of temperature lapses between heights of 1.2m. and 7.1m. The extreme hourly lapse in midwinter is one of 1.4° F. In midsummer the largest recorded hourly value is 3.8° F. The first of these is about twelve times the dry adiabatic value, and the second about thirty-four times.

TABLE III—MEAN HOURLY VALUES OF THE TEMPERATURE DIFFERENCE IN DEGREES
JUNE AND

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
Height Interval	JUNE											
	Clear days											
1·2 m. to 7·1 m. ..	2·2	2·6	2·3	1·8	0·5	-0·9	-1·6	-1·8	-2·1	-2·4	-2·7	-2·6
1·2 m. to 17·1 m. ..	3·1	3·6	3·3	3·6	1·7	-0·6	-1·7	-2·3	-2·8	-3·0	-3·5	-3·2
	Overcast days											
1·2 m. to 7·1 m. ..	0·1	0·1	0·1	0·0	-0·1	-0·2	-0·4	-0·6	-0·7	-0·7	-0·9	-1·1
1·2 m. to 17·1 m. ..	0·0	-0·1	-0·1	-0·1	-0·3	-0·5	-0·9	-1·1	-1·2	-1·2	-1·5	-1·6
	DECEMBER											
	Clear days											
1·2 m. to 7·1 m. ..	1·4	1·4	1·5	1·4	1·5	1·8	2·1	2·5	0·9	-0·4	-0·6	-0·8
1·2 m. to 17·1 m. ..	2·4	2·3	2·6	2·4	2·5	2·7	2·8	3·7	1·5	-0·2	-0·7	-0·9
	Overcast days											
1·2 m. to 7·1 m. ..	0·1	0·1	0·0	0·1	0·0	0·0	-0·2	-0·2	-0·3	-0·3	-0·5	-0·4
1·2 m. to 17·1 m. ..	0·2	0·3	0·1	0·2	0·1	0·0	-0·2	-0·3	-0·4	-0·4	-0·5	-0·5

TABLE IV—MEAN HOURLY VALUES OF WIND VELOCITY IN METRES

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
June—												
Clear	1·6	c	c	1·4	c	1·7	2·4	3·2	4·0	4·2	4·1	3·7
Overcast	3·9	3·6	3·4	3·2	3·3	3·2	3·4	4·4	5·0	5·0	5·2	5·5
December—												
Clear	4·3	3·9	4·2	4·0	3·7	3·9	3·9	3·7	3·7	3·0	3·9	5·5
Overcast	5·6	5·7	6·1	5·5	6·6	6·7	7·7	7·4	7·3	7·5	7·5	7·9

NOTE.—Mean velocities less than 1 m./sec.

FAHRENHEIT OVER TWO HEIGHT INTERVALS FOR CLEAR AND OVERCAST DAYS IN DECEMBER

13	14	15	16	17	18	19	20	21	22	23	24	
JUNE												Height Interval.
and nights												
-2.6	-2.7	-2.5	-1.9	-1.6	-0.9	0.1	1.0	2.1	2.9	2.6	2.2	1.2 m. to 7.1 m.
-3.3	-3.4	-3.1	-2.5	-2.0	-1.0	0.4	1.8	3.4	3.9	3.7	3.2	1.2 m. to 17.1 m.
and nights												
-0.9	-0.8	-0.6	-0.5	-0.3	-0.2	0.0	0.1	0.1	0.1	0.1	0.1	1.2 m. to 7.1 m.
-1.3	-1.1	-1.0	-0.7	-0.5	-0.4	-0.1	0.0	0.1	0.1	-0.1	0.0	1.2 m. to 17.1 m.
DECEMBER												
and nights												
-0.7	-0.3	0.5	1.4	1.4	1.6	1.8	1.9	1.9	2.0	2.1	1.8	1.2 m. to 7.1 m.
-0.9	-0.3	0.7	2.1	2.5	2.4	2.7	3.4	3.1	3.1	3.1	2.9	1.2 m. to 17.1 m.
and nights												
-0.4	-0.4	-0.3	-0.2	-0.1	-0.2	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	1.2 m. to 7.1 m.
-0.5	-0.5	-0.3	-0.2	-0.2	-0.2	-0.1	-0.1	-0.1	-0.2	-0.2	-0.1	1.2 m. to 17.1 m.

PER SECOND CORRESPONDING TO THE OCCASIONS SHOWN IN TABLE III

13	14	15	16	17	18	19	20	21	22	23	24	No. of days
3.8	3.7	3.7	3.6	3.5	3.8	3.6	3.5	3.2	2.4	1.9	1.9	5
5.7	5.3	5.6	5.2	5.2	5.0	4.6	4.1	3.8	4.2	4.9	4.7	6
4.9	4.8	4.5	4.7	4.4	3.1	3.4	2.9	3.2	3.2	3.4	3.4	8
7.6	7.5	7.0	6.6	6.7	7.2	6.9	6.5	7.5	7.3	7.1	6.6	10

have been indicated as "calm" (c).

TABLE V—EXTREME HOURLY VALUES OF TEMPERATURE LAPSE IN EACH MONTH

A.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1.2 m. to 7.1 m.

Month.	1923		1924		1925	
	Max. Lapse.	G.M.T. of occurrence.	Max. Lapse.	G.M.T. of occurrence.	Max. Lapse.	G.M.T. of occurrence.
J.	-1.3	1100	-1.0	1300	-1.1	1100
F.	-1.5	1200	-2.4	1300	-2.8	1100
M.	-3.2	1300	-2.6	1200	-2.7	1200
A.	-3.2	1200	-3.4	1100	-2.9	1300
M.	-3.5	1000	-2.4	1300	-3.3	1100
J.	-3.5	1500	-3.8	1000	-3.6	1100
J.	-3.5	1300	-2.9	1300	-3.1	1400
A.	-3.5	1500	-3.3	1100	-2.9	1200
S.	-2.7	1200	-2.0	1200	-2.3	1300
O.	-1.7	1200	-1.8	1300	-2.4	1200
N.	-1.7	1100	-1.2	1300	-2.4	1200
D.	-1.0	1300	-1.1	1300	-1.4	1200

NOTE.—Adiabatic Temp. Difference = -0.11°F .

B.—Temperature Difference in Degrees Fahrenheit over the Height Interval 1.2 m. to 17.1 m.

Month.	1923					1924					1925				
	Max. Lapse.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 21 h.	Max. Lapse.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 21 h.	Max. Lapse.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 21 h.
J.	-1.4	1200	b	m/s.	bc	-0.9	1300	b	m/s.	b	-1.8	1200	b	m/s.	co
F.	-1.6	1300	b	3.4	bc	-2.8	1200	b	2.0	b	-3.0	1100	c	2.0	om
M.	-3.6	1300	c	4.3	co	-3.8	1300	b	2.5	bc	-3.2	1200	bc	3.0	bc
A.	-3.4	1200	b	2.4	bc	-4.2	1100	b	3.5	b	-3.7	1300	bc	6.2	bc
M.	-4.2	1000	bc	4.2	c	-3.2	1200	bc	5.8	bc	-3.5	1200	bc	0	bc
J.	-4.0	1000	bc	4.8	bc	-4.5	1000	b	3.2	bc	-4.4	1100	b	4.5	b
J.	-4.5	1300	bc	4.9	bc	-4.0	1400	b	4.7	b	-4.5	1200	b	2.5	b
A.	-4.6	1300	bc	7.8	c	-4.1	1100	b	6.0	bc	-3.5	1100	cm	2.8	b
S.	-3.3	1100	b	4.5	bc	-3.0	1200	bc	3.4	bc	-3.0	1300	bc	3.0	cm
O.	-2.2	1200	b	0	ffb	-2.5	1300	b	4.4	bc	-3.2	1200	b	5.1	bf
N.	-2.1	1100	bc	3.2	b	-2.0	1100	bc	3.9	c	-2.8	1200	bm	4.0	b
D.	-1.4	1300	bc	0	b	-1.5	1100	c	0	c	-1.7	1300	b	3.5	b

NOTE.—Adiabatic Temp. Difference = -0.29°F .

Of the 36 values given it will be seen that 31 occur within one hour of noon, 3 occur within two hours of noon, and 2 occur at 1500. This distribution of the times of occurrence of maximum lapse supports the conclusion which was reached earlier in this paper that the maximum gradients occur within a comparatively short time of noon.

The maximum temperature differences during the day between heights of 1.2m. and 17.1m. are shown in Table VB. The maximum hourly lapses are 1.7°F . in December and 4.9°F . in July. The mean lapse rate between 1m and 17m. is thus liable to be six times the adiabatic value in winter and seventeen times in summer. The times of occurrence of these maxima are grouped about noon in the same manner as the maxima between one and seven metres just considered.

Turning to the extreme hourly values of temperature inversion, the results are given in Table VI A and B for the two height intervals. Taking the lower interval, it

TABLE VI—EXTREME HOURLY VALUES OF TEMPERATURE INVERSIONS IN EACH MONTH

A.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1·2 m. to 7·1 m.

Month.	1923		1924		1925	
	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.
J.	+4·2	1800	4·1	0100	4·6	2000
F.	5·4	1800	3·4	0100	4·9	0200
M.	5·0	2300	6·9	2000	4·6	1800
A.	5·6	2000	6·1	0200	6·0	0300
M.	3·4	2400	4·6	2000	3·7	0200
J.	4·9	2200	3·9	0400	6·3	2300
J.	5·6	0400	3·0	2200	5·2	2100
A.	4·3	0100	4·7	2200	4·5	0400
S.	5·9	0100	5·4	0600	4·5	2400
O.	3·9	2200	5·6	2300	6·0	0100
N.	7·0	0100	2·9	0100	4·9	2200
D.	4·4	0100	5·0	0200	5·0	1900

B.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1·2 m. to 17·1 m.

Month.	1923					1924					1925				
	Max. Inversion.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 15 h.	Max. Inversion.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 15 h.	Max. Inversion.	G.M.T. of occurrence.	Sky.	Wind.	Sky at preceding 15 h.
J.	5·0	2100	b	m/s.	b	5·0	0100	b	0	b	8·5	2300	c	m/s.	cm
F.	7·6	1900	b	2·8	bc	5·0	0100	b	2·0	b	7·3	0300	bc	0	bc
M.	6·0	2400	b	4·8	c	9·8	2400	b	0	b	6·6	2000	b	2·0	cm
A.	7·0	2400	bc	1·0	bc	5·9	2400	bc	0	bc	7·6	0500	b	0	bc
M.	4·8	2200	bc	4·5	c	5·5	2300	bc	2·5	c	5·8	0400	bc	0	bc
J.	7·4	2300	bc	2·5	bc	6·0	0300	c	0	c	9·5	0100	b	0	b
J.	7·7	2200	b	0	b	5·8	0400	b	0	b	6·6	2400	b	0	bc
A.	7·1	0100	b	2·0	b	7·0	2300	bc	0	b	8·0	0400	bf	0	b
S.	7·2	0300	b	0	b	9·5	0600	bc	0	bc	5·6	0300	b	0	or
O.	5·7	0200	b	0	b	6·9	1800	b	0	b	10·2	0100	bc	0	b
N.	9·3	0100	bc	0	b	5·5	2400	bc	0	bc	6·6	2200	bc	0	bc
D.	5·7	0100	ofe	0	o	8·1	2200	oFx	0	om	7·4	2100	b	0	b

will be seen that inversions ranging between 5° F. and 7° F. are liable to occur at any time of the year. Similarly for the interval between 1·2m. and 17·1m, inversions of from 8° F. to 10° F. may occur in any month.

The highest hourly value for an inversion recorded during the three years was 10·2° F. in October, 1925.

The times of occurrence of maximum inversions are not closely grouped about any particular hour. About three quarters of the times of occurrence are distributed nearly uniformly between 2100 and 0300.

The weather conditions under which these extreme gradients occurred are included in Tables V and VI. The state of sky and the wind velocity in metres per second at a height of 13m. are given for the hour at which the maximum gradient

occurred. And since the magnitude of the gradient during a day or night is likely to depend to some extent upon the weather during the preceding night or day, this latter information is added.

Taking the case of the inversions first (Table VI) it will be seen that in all cases except two the maximum hourly inversions occurred under clear or nearly clear skies, and with little or no wind. In addition, the sky at 1500 on the days preceding these nights was nearly always either clear or only partially clouded.

The two exceptions which have just been mentioned were in December, 1923 and 1924. These extreme inversions occurred in fog.

Turning to the lapses (Table V) the extreme hourly values occur also with clear or nearly clear skies. In many cases there was little or no wind, but on quite a number of occasions the wind velocity exceeded 4 m/s. It appears, therefore, that a moderate wind is not so destructive of steep lapse rates as it is of large inversions. The sky at 2100 on the night preceding these extreme lapses is also seen to be in most cases either clear or only partially clouded.

The extreme values which have been considered above were extracted from the hourly means taken from the differential temperature traces. It has already been explained that these hourly means are estimated as the mean positions of the traces during a twenty-minute period centred on the hour in question.

Each trace is composed of a sequence of dots made at intervals of two minutes. It has been thought desirable to ascertain the extreme maximum lapses and inversions recorded by individual dots in the two traces in the same way as has been done with the hourly means. For want of a better term it has been decided to call these the "absolute extreme lapses" and inversions. The use of the word "absolute" in this connexion is not intended to imply that the values quoted are the greatest instantaneous values of temperature difference which actually occur. It is used solely to indicate the maximum excursion of the individual dots which constitute the trace.

The "absolute extreme" values of temperature lapse are given in Table VII A and B. Table VII A refers to the interval of height 1.2 m. to 7.1 m. (trace A) and Table VII B to the interval 1.2 m. to 17.1 m. (trace B).

TABLE VII—"ABSOLUTE EXTREME" VALUES OF TEMPERATURE LAPSE IN EACH MONTH

A.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1.2 m. to 7.1 m.

Month.	1923		1924		1925	
	Maximum Lapse.	G.M.T. of occurrence	Maximum Lapse.	G.M.T. of occurrence.	Maximum Lapse.	G.M.T. of occurrence.
J.	-1.6	1145	-1.6	1100	-2.0	0955
F.	-2.1	1150	-2.8	1200	-3.0	1100
M.	-3.5	1230	-3.2	1225	-3.4	1125
A.	-4.1	1130	-4.0	1110	-3.5	1235
M.	-4.3	1450	-3.0	1230	-4.1	1030
J.	-4.3	1430	-4.7	1000	-4.2	1120
J.	-4.8	1155	-3.5	1215	-4.0	1410
A.	-4.5	1300	-4.2	1110	-3.5	1335
S.	-3.5	1100	-2.9	1025	-3.0	1120
O.	-2.3	1250	-2.3	1005	-3.6	1030
N.	-2.0	1100	-1.8	1140	-2.6	1210
D.	-1.6	1230	-1.5	1050	-1.6	1200

NOTE.—Adiabatic Temp. Difference = -0.11°F .

B.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1.2 m. to 17.1 m.

Month.	1923		1924		1925	
	Maximum Lapse.	G.M.T. of occurrence.	Maximum Lapse.	G.M.T. of occurrence.	Maximum Lapse.	G.M.T. of occurrence.
J.	-2.4	1145	-2.1	1350	-2.3	0955
F.	-2.9	1150	-3.3	1130	-3.8	1102
M.	-4.0	1245	-4.1	1235	-4.3	1255
A.	-4.5	1130	-4.5	1100	-4.1	1120
M.	-5.1	1125	-4.1	1120	-4.9	1035
J.	-5.4	1020	-5.5	1000	-5.0	1150
J.	-5.8	1210	-4.8	1435	-4.6	1125
A.	-5.8	1250	-5.0	1535	-4.2	1335
S.	-4.7	1200	-3.9	1125	-4.0	1120
O.	-3.1	1250	-3.2	1310	-3.8	1245
N.	-2.6	1240	-2.5	1155	-3.1	1145
D.	-2.0	1250	-2.4	1050	-1.9	1100

NOTE.—Adiabatic Temp. Difference = -0.29°F .

In the case of both traces it will be seen that the values average from 20 to 50 per cent higher than the extreme hourly values. It will also be noted that the times of occurrence of these "absolute extremes" are again closely grouped around noon. The greatest lapses recorded as "absolute extremes" are 4.8°F . for trace A and 5.8°F . for trace B. These values are 43 times and 20 times the dry adiabatic values respectively.

Turning to the inversions (Table VIII A and B) we find that the "absolute extremes" are also on the average some 30 per cent. greater than the extreme hourly values. The largest inversion recorded during the three years was 9.6°F . in the case of trace A. On the other hand, trace B has exceeded the limits of the rulings of the chart (10°F .) on at least ten occasions. In such cases the extreme deflection has been estimated from the trend of the adjacent portions of the trace.

TABLE VIII—"ABSOLUTE EXTREME" VALUES OF TEMPERATURE INVERSION IN EACH MONTH

A.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1.2 m. to 7.1 m.

Month.	1923		1924		1925	
	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.
J.	5.0	1730	4.6	0130	7.8	2005
F.	8.0	1945	4.5	1715	7.9	0335
M.	6.5	2250	8.2	1940	7.9	0140
A.	5.8	2210	7.1	0150	8.4	2040
M.	4.4	2325	6.5	2010	5.0	0130
J.	6.1	2110	5.0	0255	7.7	0140
J.	6.8	2220	5.1	0225	6.1	2115
A.	5.4	0055	6.0	2320	6.2	0335
S.	7.3	0115	6.5	0230	6.6	0050
O.	6.0	0105	7.9	2135	8.1	0600
N.	9.2	2010	6.9	1945	5.9	1850
D.	5.0	1910	7.8	1730	9.6	0635

B.—Temperature Differences in Degrees Fahrenheit over the Height Interval 1·2 m. to 17·1 m.

Month.	1923		1924		1925	
	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.	Maximum Inversion.	G.M.T. of occurrence.
J.	8·4	1730	7·3	0105	10·0	2005
F.	9·9	2320	6·7	2335	8·4	0335
M.	8·2	2255	11±	1940	8·4	0135
A.	8·2	2355	8·0	0210	10·1	1945
M.	6·2	0115	7·0	2010	6·1	0400
J.	9·2	0340	6·7	0255	10·5	0105
J.	12±	0010	7·5	0310	8·6	2125
A.	11±	2215	7·6	0205	9·1	0400
S.	8·9	0250	12±	0555	7·7	0020
O.	8·7	0255	8·4	2135	10·2	0130
N.	10·2	0100	7·4	1945	7·9	2220
D.	6·0	2000	11±	2215	10·2	0635

An "absolute extreme inversion" for trace B of approximately 12° F. may be accepted as the greatest which would have been recorded. It is unfortunate that the instrument was not capable of recording inversions greater than 10° F. At the time when the apparatus was designed it was not expected that inversions greater than this would be found.

§ 7—FREQUENCY OF OCCURRENCE OF TEMPERATURE GRADIENTS OF VARIOUS MAGNITUDES

The hourly values of temperature difference over the interval of height from 1·2m. to 17·1m. which were used in constructing the mean hourly values shown in Table I have been analysed to show the frequency of occurrence of various values of temperature difference during each month. The result is contained in Table IX, the frequencies being expressed as percentages of the total number of hourly readings. The values of temperature difference have been arranged in groups each of which embraces a range of 1·0° F.

Every month shows a maximum frequency for lapses lying between zero and 0·9° F. In midwinter nearly 40 per cent of the hourly values fall within this group. In midsummer the number falls to about 2 per cent. Small inversions of less than 1° F. constitute nearly 30 per cent of the total number of readings in winter and only about 12 per cent in summer.

The summer months are, of course, characterized by an increase in the frequency of large lapses. In June, for example, hourly values exceeding 3° F. represent 9 per cent of all the hourly readings. Thus during 64 hours in June the lapse rate between 1·2 m. and 17·1 m. exceeds 10 times the dry adiabatic value.

The greater frequency of inversions in winter is very marked up to inversions of 2° F. in magnitude. For larger inversions than this the difference becomes less. For example, inversions of 5° F. are of nearly the same frequency in summer and winter.

The average frequency for the year is shown at the bottom of Table IX and is plotted in Fig. 13. The maximum frequency is seen to occur very nearly at the

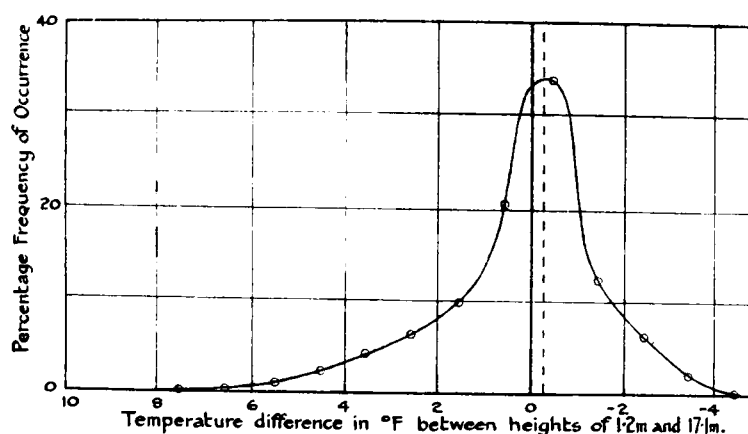


FIG. 13.—FREQUENCY OF OCCURRENCE OF VARIOUS TEMPERATURE GRADIENTS.

TABLE IX.—FREQUENCY OF OCCURRENCE OF VARIOUS TEMPERATURE GRADIENTS

Showing Percentage Frequency of stated Temperature Differences over the Height Interval 1.2 m. to 17.1 m. for each Month based on Three Years Records 1923/4/5.

Limits of Temperature Difference in Degrees Fahrenheit.

Month.	Inversions.										Lapses.				
	10 to 9.1	9 to 8.1	8 to 7.1	7 to 6.1	6 to 5.1	5 to 4.1	4 to 3.1	3 to 2.1	2 to 1.1	1 to 0.1	0 to -0.9	-1 to -1.9	-2 to -2.9	-3 to -3.9	-4 to -4.9
J.	—	0.1	0.2	0.3	0.8	2.5	5.0	7.7	16.9	27.4	34.9	4.2	—	—	—
F.	—	—	0.2	0.3	0.8	2.1	4.6	6.7	10.3	32.5	34.6	6.8	—	—	—
M.	0.1	0.2	0.3	0.4	1.4	3.2	5.6	6.1	10.6	18.8	31.0	15.9	5.7	0.7	—
A.	—	—	0.3	0.5	1.6	2.3	4.9	6.5	7.2	17.5	34.3	14.9	8.4	1.6	—
M.	—	—	—	—	0.2	2.1	3.3	5.9	7.9	15.3	34.3	18.9	10.5	1.6	—
J.	0.1	0.2	0.3	0.5	1.0	2.5	4.2	4.8	5.9	12.7	26.1	18.2	14.5	8.0	1.0
J.	—	—	0.1	0.3	0.9	1.6	3.0	6.5	7.8	12.1	26.1	19.0	14.6	7.1	0.9
A.	—	—	0.1	0.3	0.7	2.0	3.3	5.0	7.3	13.7	33.3	19.0	10.1	4.6	0.6
S.	0.1	0.1	0.1	—	0.6	2.1	6.4	6.4	7.7	20.0	34.7	15.0	6.2	0.6	—
O.	0.1	0.1	0.1	0.9	1.6	2.9	4.3	4.9	9.3	23.7	39.6	9.7	2.7	0.1	—
N.	0.1	0.1	0.1	0.4	1.0	2.4	4.4	8.0	13.6	27.0	36.7	5.5	0.7	—	—
D.	—	0.1	0.2	0.4	1.2	1.5	4.0	7.0	14.6	28.1	39.6	3.3	—	—	—
Year	0.0	0.1	0.2	0.4	1.0	2.3	4.4	6.3	9.9	20.7	33.8	12.5	6.2	2.0	0.2

NOTE.—Adiabatic Temp. Difference = -0.29° F.

dry adiabatic value. In addition, about 67 per cent of all the readings fall within 1.5° F. on either side of this maximum position. Of the remainder 8.4 per cent represent steeper lapse rates and 24.6 per cent larger inversions.

§ 8—MEAN DIURNAL TEMPERATURE VARIATION AT THREE HEIGHTS

(a) *Three-year means.*—Up to this point the results obtained from the temperature gradient recorder have been presented in the manner in which the charts of the recording instrument present them—that is, as differences of temperature between stated heights. It is instructive to use these data to construct curves showing the actual diurnal variation of temperature at these heights. For this purpose the records given by the aspirated dry bulb at a height of 1.2m. have been taken as giving the actual temperature at this height. By adding to these values the temperature

differences given by the A and B differential traces we obtain the actual temperatures at heights of 7·1m. and 17·1m. respectively.

In analysing the dry-bulb charts, the hourly values of temperature have been taken as the mean position of the trace during a twenty-minute period centred on the hour. This procedure is the same as that adopted for the analysis of the differential traces.

TABLE X—MEAN HOURLY VALUES OF AIR TEMPERATURE AT A HEIGHT.

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
Month	°F.											
J.	39·1	39·1	39·1	39·1	39·1	39·1	39·1	39·2	39·7	40·8	42·7	43·9
F.	37·9	37·9	37·6	37·6	37·6	37·5	37·6	38·2	39·7	41·6	42·6	43·2
M.	39·1	38·9	38·6	38·5	38·3	38·2	38·6	40·5	42·8	45·4	47·4	48·8
A.	40·5	40·0	39·5	39·4	38·9	39·9	40·9	44·6	46·7	49·1	50·4	51·3
M	44·4	44·4	44·1	43·8	44·0	46·1	48·0	50·2	51·4	53·4	54·3	55·4
J.	49·1	48·4	48·1	47·9	48·7	51·1	53·6	55·6	47·5	59·2	60·6	61·8
J.	53·4	53·1	52·7	52·5	53·2	55·2	57·7	60·1	62·3	64·3	65·7	66·2
A.	52·5	52·4	52·2	51·9	51·9	53·0	55·4	57·6	59·4	61·4	62·7	63·5
S.	49·1	49·2	48·9	48·9	49·0	49·0	51·0	52·8	55·4	57·3	59·0	59·7
O.	47·6	47·5	47·4	47·2	47·1	46·8	47·2	48·7	50·6	52·7	53·9	54·8
N.	37·9	37·7	37·5	37·3	37·1	36·8	36·8	37·3	38·8	40·9	42·4	43·1
D.	37·4	38·5	38·4	38·3	38·2	38·0	37·8	37·9	38·9	40·6	41·7	42·5

TABLE XI—MEAN HOURLY VALUES OF AIR TEMPERATURE AT A HEIGHT

G.M.T.	1	2	3	4	5	6	7	8	9	10	11	12
June—	°F.											
Clear ..	47·2	45·0	43·6	42·0	43·6	48·9	53·5	56·9	60·4	62·8	64·5	65·3
Overcast ..	40·2	49·0	48·8	48·6	49·0	49·8	51·4	52·9	53·8	55·0	55·9	57·0
December—												
Clear ..	30·3	30·0	29·3	29·3	28·9	28·8	28·8	27·5	30·5	33·0	35·7	37·1
Overcast ..	42·8	42·4	42·3	42·1	42·2	42·2	42·2	42·4	42·8	42·9	43·3	43·2

The mean hourly values for the three years of the temperature at a height of 1·2m. obtained in this way are given in Table X. These results are also shown plotted in Fig. 14. The other two curves in each of these twelve monthly graphs are obtained by combining the data of Tables I and X in the manner just described.

Smooth curves have been drawn through the plotted points. It is seen that curves based upon observations extending over only three years are not good means. An illustration of this is afforded by a comparison of the April curves with those for March and May.

Certain broad features, nevertheless, stand out. Thus the crossing of the three curves occurs very nearly at a point. The actual temperature at which this crossing occurs is much higher in the evening than in the morning. After the rapid fall of temperature in the evening, the three curves become nearly parallel for the remainder of the night. It is noteworthy that the January curves are nearly horizontal from midnight till 0800. During November and December the curves show a definite

OF 1·2M. FOR EACH MONTH (BASED UPON THREE YEARS RECORDS, 1923/4/5)

13	14	15	16	17	18	19	20	21	22	23	24	
°F.												Month
45·0	44·9	44·1	42·7	41·4	40·7	40·4	40·0	39·7	39·7	39·5	39·3	J.
44·1	44·5	44·2	43·2	41·5	40·1	39·5	39·3	38·8	38·5	38·3	38·2	F.
49·8	49·9	49·6	49·1	47·5	44·8	42·9	41·9	41·1	40·4	39·8	39·4	M.
51·6	51·8	51·7	50·8	49·4	48·1	45·5	43·8	42·9	42·3	41·3	40·9	A.
56·1	55·9	55·6	55·3	54·1	52·7	50·6	48·2	46·8	46·2	45·3	44·6	M.
62·5	63·0	62·8	62·2	61·1	59·9	57·7	54·6	52·4	51·4	50·4	49·7	J.
66·8	66·9	66·5	66·2	65·3	64·3	62·1	58·8	56·7	55·7	55·1	54·3	J.
64·1	64·0	63·8	63·1	62·0	60·4	58·0	55·8	54·7	53·8	53·3	52·7	A.
59·9	59·9	59·2	58·4	57·2	55·4	52·8	51·7	50·8	50·2	49·8	49·3	S.
55·2	55·4	54·8	53·6	51·6	49·9	48·8	48·6	48·4	48·0	47·6	47·6	O.
44·1	43·9	42·9	40·9	39·4	38·8	38·4	38·0	37·9	37·8	37·7	37·7	N.
42·9	42·0	42·1	40·6	40·0	37·6	39·0	38·9	38·7	38·6	38·6	38·8	D.

OF 1·2M. FOR CLEAR AND OVERCAST DAYS IN JUNE AND DECEMBER

13	14	15	16	17	18	19	20	21	22	23	24	G.M.T.
°F.												June—
67·1	68·8	68·4	68·0	68·0	65·8	62·9	57·8	54·0	52·5	50·8	50·3	Clear
57·1	57·3	57·1	57·1	56·9	56·5	55·8	54·7	53·5	52·6	52·0	51·5	Overcast
												December—
37·5	37·3	35·8	32·8	31·2	30·6	30·0	28·7	29·0	28·9	28·8	29·0	Clear
43·4	43·7	43·4	43·0	42·7	42·6	42·5	42·0	41·8	41·4	41·0	41·1	Overcast

flattening out for some four hours towards the middle of the night and then show a subsequent fall of temperature.

Some of these features are, of course, simply a statement in different words of points which have been discussed previously when dealing with the mean hourly values of temperature difference between these heights.

The curves of Fig. 14 present one unexpected feature which calls for comment. It is the large time lag which occurs in many months between the times of occurrence of maximum air temperatures at 17m. and 1m. In several of the months this lag

appears to be about 25 minutes. This value is considerably greater than that to be expected by assuming probable values for the coefficient of eddy conduction.

The limits between which sunrise and sunset vary during each month are indicated by the short lines and arrows beneath each of the graphs constituting Fig. 14.

(b) *Means for clear and overcast days.*—The diurnal temperature curves which have just been considered are based upon the mean monthly values of temperature. That is to say, they are mean curves for all types of weather. The corresponding curves representing the observational data grouped according to the state of sky are given in Figs. 15 a—d. These curves are the counterpart of the data given in Table III. The aspirated dry-bulb records for a height of 1.2m. have been meaned for the same days as were employed in constructing Table III. The results are shown in Table XI, which contains the mean hourly values of air temperature at 1.2m. for clear and overcast days and nights in both June and December. The addition of Table III to Table XI gives the mean hourly values of temperature at the other two heights, viz., 7.1m. and 17.1m. The values so obtained are shown plotted in the four sets of curves of Fig. 15. The number of observations upon which these curves are based, and also the mean wind velocities, are those already given in Table IV. The relatively small number of observations results in some scatter of the plotted points in places, particularly for the clear days and nights. For the most part, however, the curves are reasonably smooth, and it is considered that they may be regarded as fairly accurate representations of the average temperature variations which occur under the specified conditions.

Fig. 15a shows that during clear weather in June the temperature at all three heights is varying rapidly throughout most of the 24 hours. In spite of the variation, however, the large lapse from 0900 to 1500 and the large inversion from 2100 to 0400 maintain their nearly uniform values.

Overcast skies in June are seen (Fig. 15b) to reduce the diurnal range of temperature to about one third of the clear sky value. The midday lapse is also reduced in about the same proportion, but the nocturnal inversion is practically annihilated.

From Fig. 15c we may notice that the midday lapse produced by sunshine in December is of very small vertical extent, the adiabatic value not reaching above about 7 metres.

Comparison of Fig. 15c and d shows us, in passing, that the average overcast December day, and night too, are some 4° F. warmer than the clear December day at noon. The same result was found by classifying the days and nights independently and without regard to the preceding weather.

Times of sunrise and sunset are shown in Fig. 15 in the same way as in Fig. 14.

§ 9—TEMPERATURE CHANGES DURING EARLY MORNING

In § 8 very brief descriptions have been given of the broadest features presented by the curves of Figs. 14 and 15.

It is now proposed to discuss in some detail a feature which is shown by several of the curves just referred to. The feature in question consists of a rise in temperature of the air at the two upper heights while there is still an inversion of temperature both at and below these heights. The phenomenon occurs shortly after sunrise and is well seen in Fig. 14 (February) at about 0800. The importance of this result lies in the fact that, if it can definitely be established as genuine, then the rise in temperature which occurs at this time at the upper heights must be due to some other factor than convection, or eddy conduction. Attention was directed to this point by Prof. Sydney Chapman¹ who discovered the same phenomenon in an analysis of the Eiffel Tower observations. Considerable criticism was levelled at this result at the time.² Much doubt was expressed as to the reliability of the Eiffel Tower data for an analysis of this type, and up to the present no further evidence in support of Prof. Chapman's discovery has been forthcoming.

In view of the greater accuracy in measuring air temperature which is possible by means of the aspirated resistance elements described earlier in this paper, it was

¹ *Q.J.R. Meteor. Soc.* **51**, 1925 p. 101 et seq.

² Loc. cit., pp. 116-119.

FIG. 14. MEAN HOURLY TEMPERATURE AT THREE HEIGHTS FOR EACH MONTH, 1923-4-5.

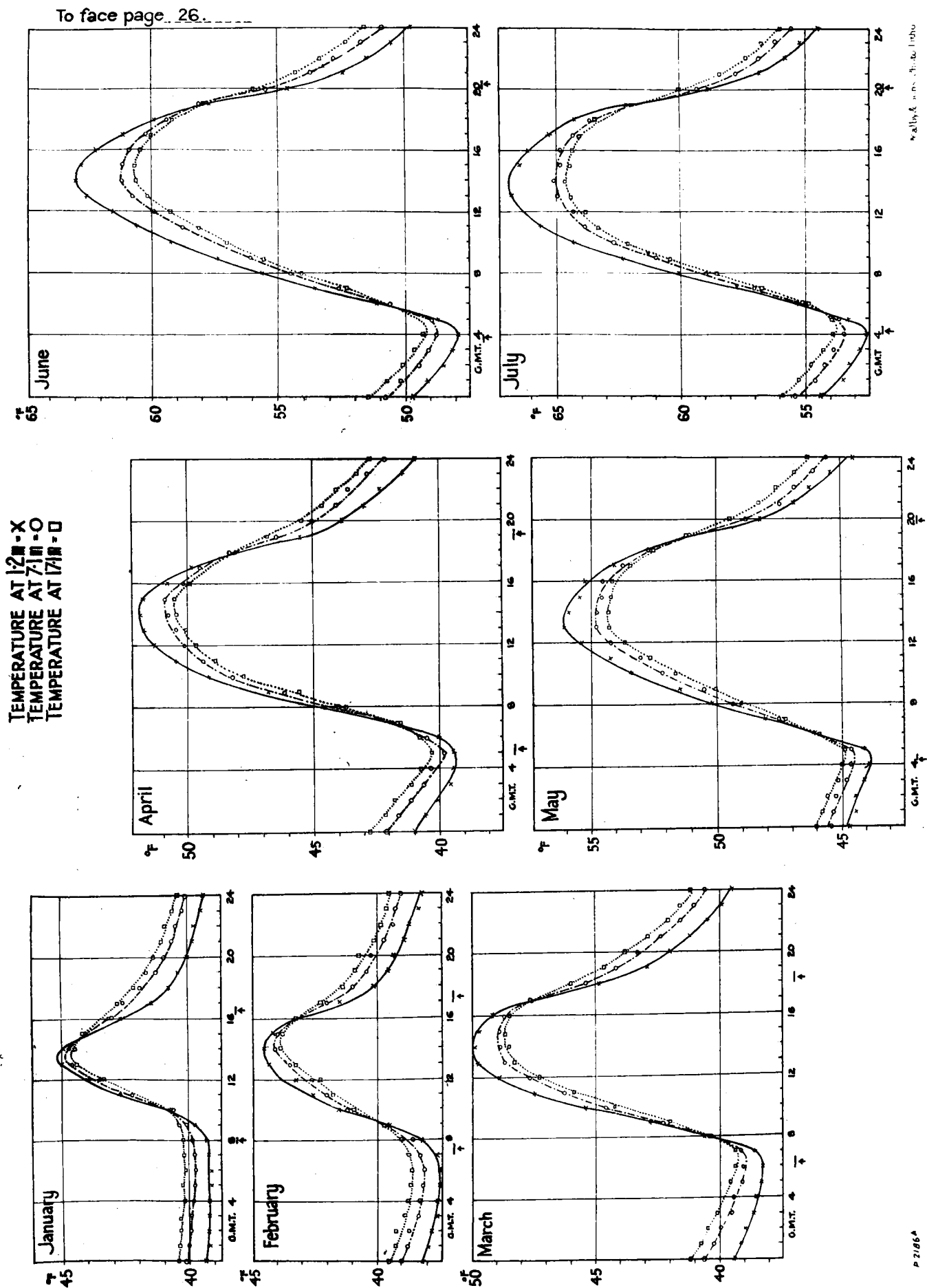
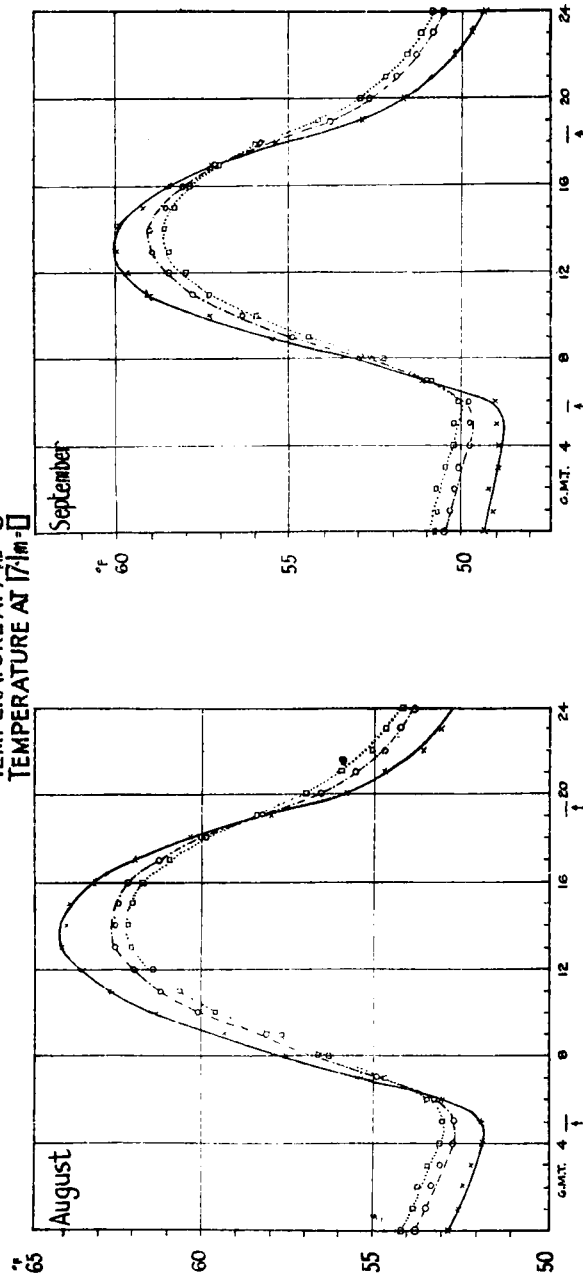
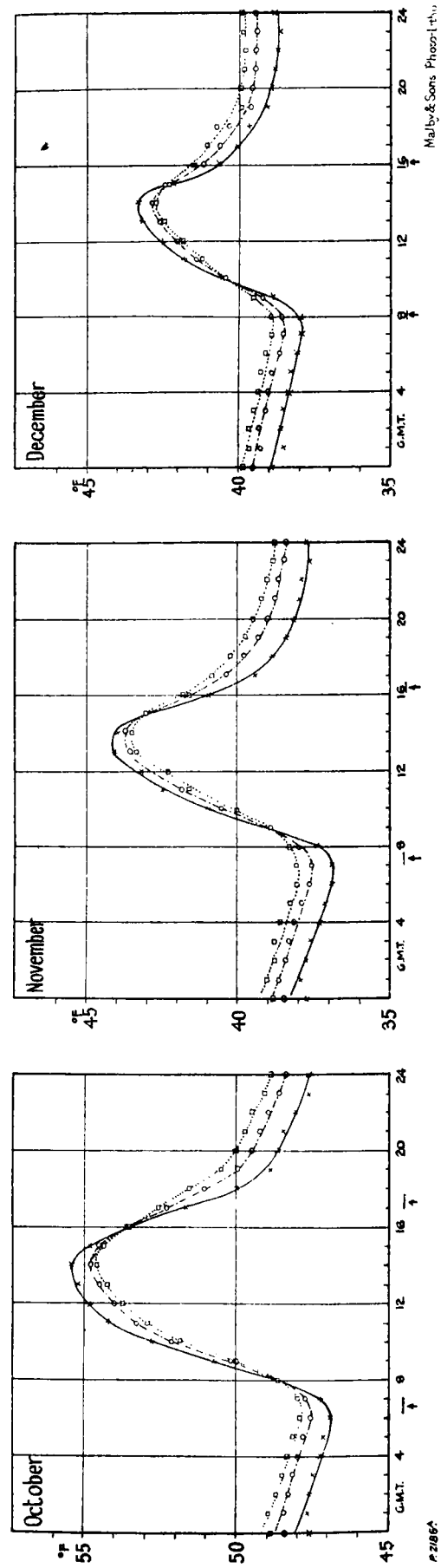


Fig. 14. (Contd.) MEAN HOURLY TEMPERATURE FOR EACH MONTH 1923-4-5.

TEMPERATURE AT 12M - X
TEMPERATURE AT 71M - O
TEMPERATURE AT 171M - □



To face page 27.



decided to examine this point in the light of the data provided by these aspirated elements.

The line of reasoning adopted by Prof. Chapman is as follows :—

The rate of change of potential temperature (θ) at any height (z) due to eddy conduction (κ) is given by

$$\rho\sigma \frac{d}{dt} = \frac{d}{dz}(\kappa\rho\sigma \frac{d\theta}{dz}) \quad (1)$$

ρ being the density of the air and σ its specific heat. Neglecting variations in ρ and σ this gives

$$\frac{d\theta}{dt} = \kappa \frac{d^2\theta}{dz^2} + \frac{d\kappa}{dz} \frac{d\theta}{dz} \quad (2)$$

During a temperature inversion $d\theta/dz$ is positive, and at such times κ may be expected to decrease upwards, $d\kappa/dz$ being thus negative. The product $d\kappa/dz \cdot d\theta/dz$ will thus be negative during an inversion of potential temperature.

κ is essentially positive. If, therefore, $d^2\theta/dz^2$ is zero or negative, then the first term on the right of equation (2) will also be zero or negative. Under such conditions, therefore, the rate of change of temperature due to eddy conduction must be negative. If it is found that, under these conditions, temperature is rising, then this increase of temperature must be due to some other factor than eddy conduction.

Prof. Chapman detected a rise in temperature in the Eiffel Tower observations during a period following sunrise when the conditions just specified appeared to be complied with, and he attributed the rise in temperature to the absorption by the atmosphere of long wave radiation emitted from the ground.

What appears to the writer to be a weakness in the analysis of the Eiffel Tower observations is the absence of any proof that the observed temperature increase is not simply a heating up by direct solar radiation of the thermometer housings.

The procedure of averaging temperatures over a four month period also seems unsatisfactory, since the time of sunrise varies by more than an hour and a half during this period (May–August).

For our present investigation use has been made of records obtained at Porton during June, 1926 and 1927. In 1926 the temperature gradient apparatus was re-arranged so as to give temperature readings at the following heights: 0.6, 1.2, 2.8, 7.1 and 17.1 metres. The improved type of housing shown in Fig. 4 was employed throughout.

Six early mornings with cloudless skies have been selected, and mean temperature readings for every ten minutes have been taken out for each height from 0300 until 0630 G.M.T. The values so found from each chart have been meaned and are shown in Table XII. The actual times of local sunrise range from 0352 to 0357 with a mean at 0354 G.M.T.

TABLE XII—EARLY MORNING TEMPERATURE CHANGES AT VARIOUS HEIGHTS

G.M.T.	Temperature at height of					G.M.T.	Temperature at height of				
	0.6	1.2	2.8	7.1	17.1 m.		0.6	1.2	2.8	7.1	17.1 m.
0305	42.9	43.5	44.3	45.9	47.2	0505	43.3	43.5	43.9	44.9	46.1
15	42.9	43.6	44.3	45.7	47.0	15	44.3	44.4	44.6	45.2	46.0
25	42.8	43.5	44.2	45.7	47.1	25	44.9	45.0	45.1	45.4	46.2
35	43.0	43.7	44.4	46.0	47.4	35	45.6	45.8	45.8	46.0	46.6
45	42.0	43.1	43.9	45.4	46.9	45	46.8	46.8	46.7	46.7	46.8
55	41.9	42.7	44.0	45.3	46.8	55	48.2	48.1	48.0	47.9	47.8
0405	42.0	42.8	43.7	44.9	46.3	0605	49.0	48.9	48.9	48.7	48.6
15	41.7	42.4	43.4	44.7	45.8	15	49.5	49.4	49.4	49.2	49.0
25	41.9	42.6	43.4	44.4	45.9	25	50.3	50.1	50.0	49.7	49.5
35	41.9	42.5	43.0	44.0	45.7	35	50.8	50.6	50.3	49.9	49.7
45	42.3	42.8	43.3	44.3	46.0						
55	42.6	42.9	43.4	44.5	45.8						

Before carrying out this detailed analysis, the ordinary hourly values were taken from the same charts for the period 0100 to 0700. The mean values when plotted were found to give curves which presented precisely the same features as the corresponding portion of Fig. 15a. This result is valuable since it indicates that the earlier form of housing (Fig. 3) yields temperature readings which, under these conditions at any rate, are as reliable as those obtained with the later type of housing.

The data contained in Table XII are shown plotted in Fig. 16. During the period from 0430 to 0545 where the traces cross, it will be seen that the temperature is rising at all the heights considered.

We will take the observations at 0505 as typical. At this time the temperature at 7·1m. is rising steadily. By plotting the structure of the vertical potential temperature at this time it is found that $d\theta/dz$ is positive and $d^2\theta/dz^2$ negative. There can be very little doubt³ that with such a strong inversion turbulence must decrease upwards, implying a negative value for $d\kappa/dz$.

From equation (2) it is clear, therefore, that, as far as the effect of turbulence is concerned, the temperature at a height of 7·1m. should be decreasing. The fact that it is observed to be increasing indicates the effect of some other factor.

Further, since all the housings and aspirations are identical, it follows that the heating of the thermometer elements by direct solar radiation must be equal at all heights. Now the actual rate of rise of temperature at 17·1m. is less than at the other heights, and this rate therefore represents a maximum for the effect of solar radiation, and the more rapid rate at the other heights must be attributed to some other factor.

It is seen, therefore, that these observations contain internal evidence which shows that the rise in temperature which is observed to be in progress at 7·1m. at 0505 G.M.T. must be due, partly at least, to some other factor than turbulence or direct heating of the thermometer housing.

Up to this point we have followed Prof. Chapman in assuming that, with a nocturnal inversion, turbulence decreases upwards. If this assumption should be incorrect, the whole of the preceding argument falls to the ground. It is therefore desirable to examine this assumption further. In this connexion it will be observed that, in so far as the turbulence is generated dynamically at the ground, there can be little doubt that the temperature inversion will rapidly destroy the turbulence and so produce a negative value for $d\kappa/dz$. But at night with a strong inversion there is normally very little air movement close to the ground, whilst higher up there may be a considerable velocity. It is not inconceivable, therefore, that under such conditions turbulence might originate overhead in the region where the relatively stagnant surface air is over-ridden by the fast-moving air above. Turbulence generated in this way would decrease downwards towards the ground and thus give a positive value to $d\kappa/dz$.

Let us, therefore, consider Fig. 17, which is similar to Fig. 16 except that it refers to one particular morning, June 4th, 1927. This morning is one of those included in Fig. 16, but it has been chosen on account of its calmness. From 0250 until 0630 the trace of the Dines pressure-tube wind recorder lay on the zero line, whilst the recorded (uncorrected) air flow given by the Robinson cup anemometer at a height of 25m. was only $1\frac{1}{2}$ miles during this time. With so little wind and the strong inversions which existed, there can have been very little ordinary turbulence in the first seven metres above the ground. Reference to the temperature variations recorded between 0300 and 0400 in Fig. 17 shows that such air disturbance as does occur under these conditions consists of the slow movement of relatively large masses of air.⁴ The portions of the curves referred to indicate the temporary replacement of cold surface air by warmer air. The effects of these movements are clearly larger near the ground than higher up—they are not noticeable at a height of 17m. We

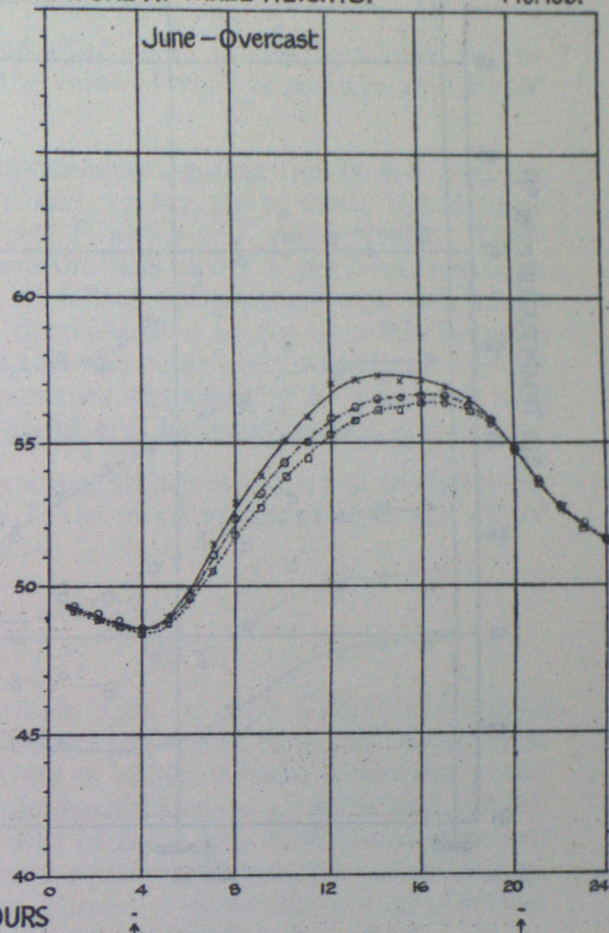
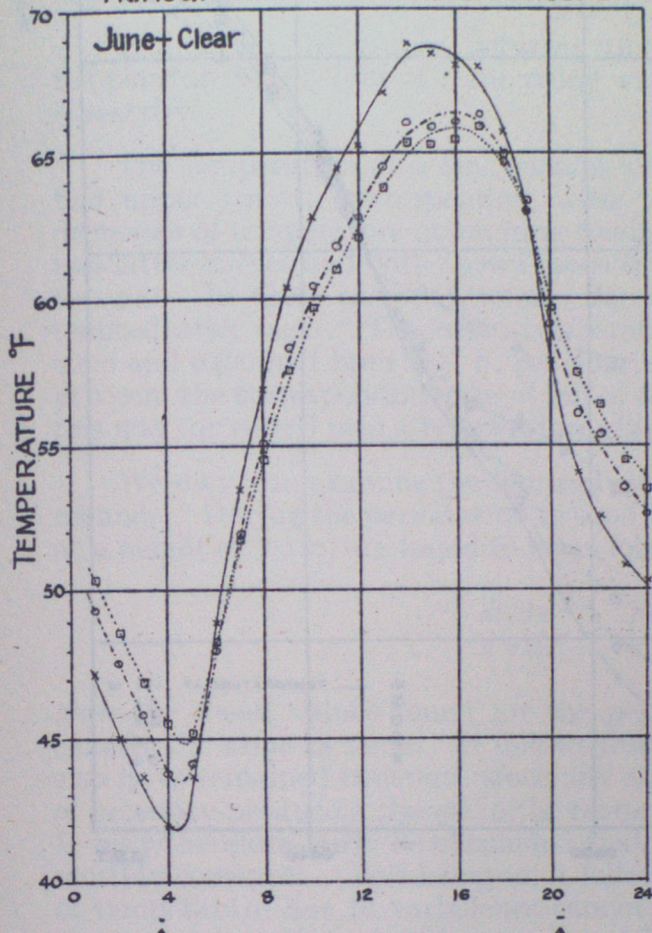
³ See p. 29.

⁴ See also § 10.

FIG. 15a.

MEAN HOURLY TEMPERATURE AT THREE HEIGHTS.

FIG. 15b.

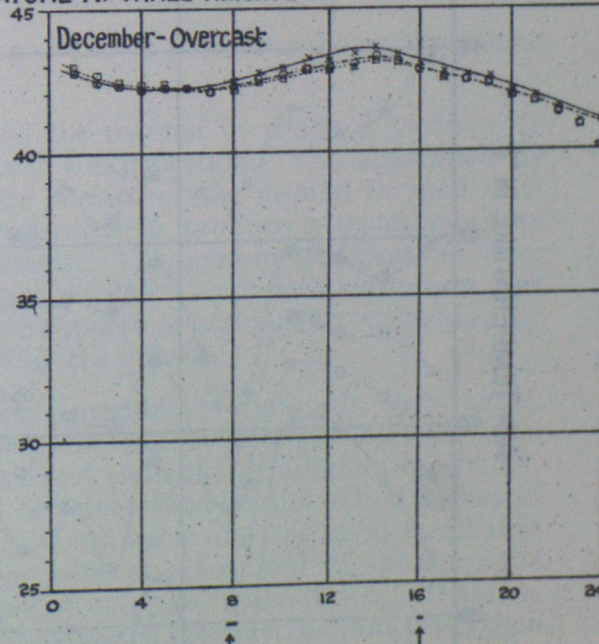
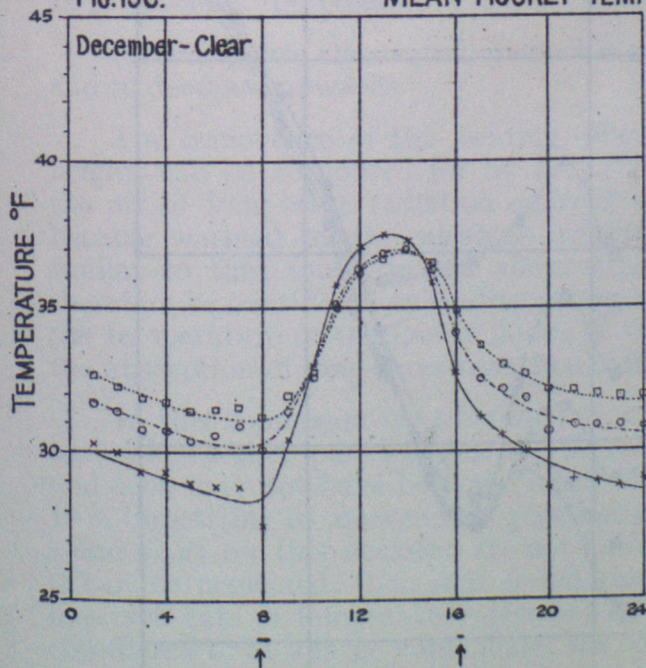


Malby & Sons, Photo-Litho

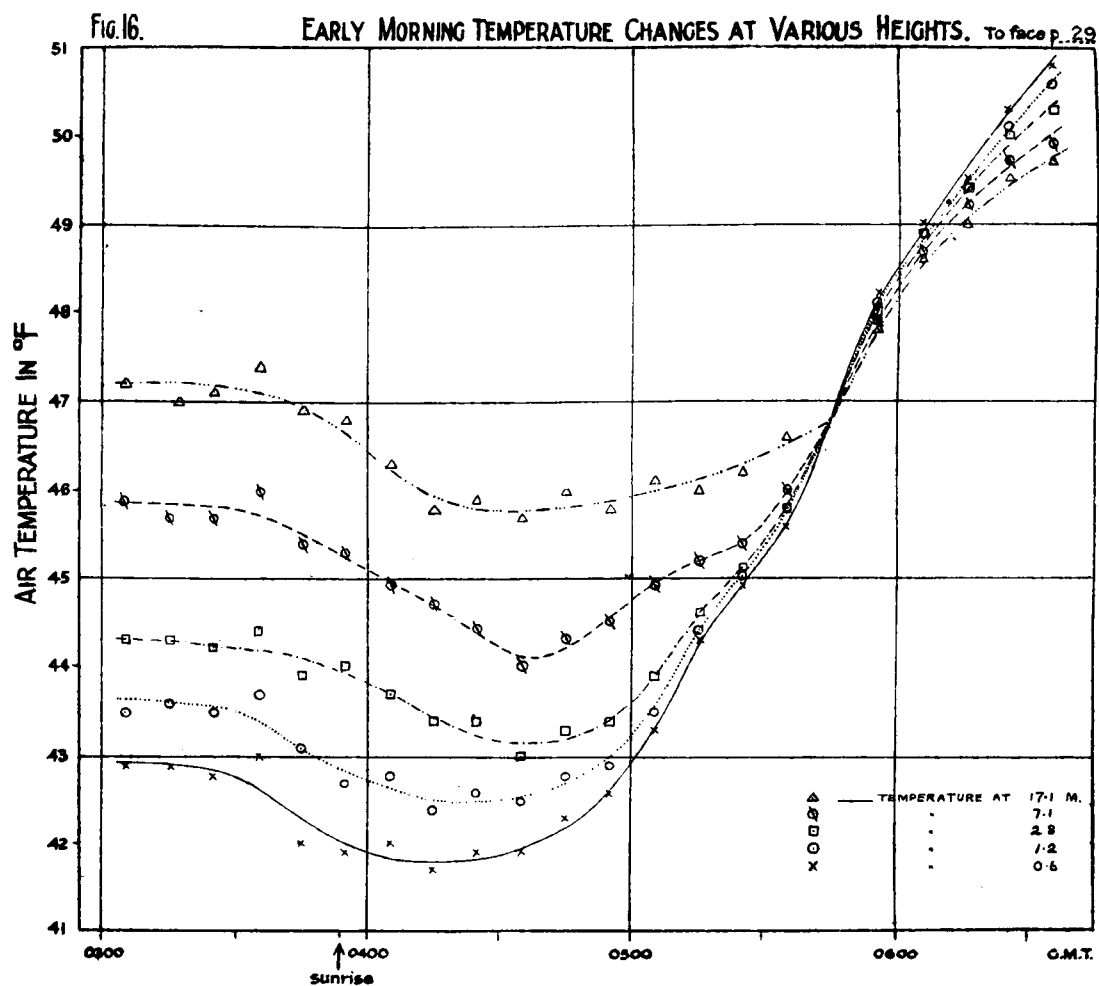
FIG. 15c.

MEAN HOURLY TEMPERATURE AT THREE HEIGHTS

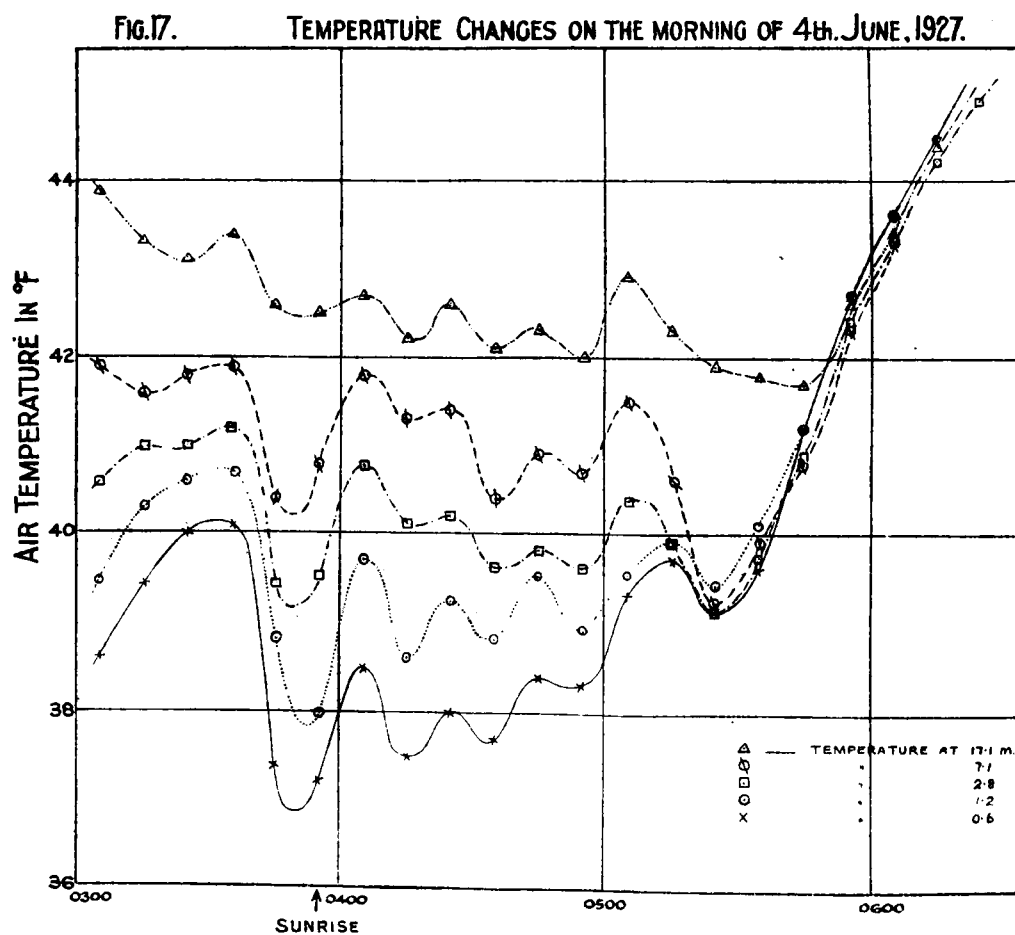
FIG. 15d.



A. B. C. A.



Malby & Sons Litho



P 21064

thus have here conditions of very small turbulence, and such turbulence as does exist is seen to decrease upwards. In this case, Prof. Chapman's assumption of a negative value for $d\kappa/dz$ may be fairly regarded as fulfilled.

Examining the graphs between 0400 and 0500 there is clear evidence of the temperature at a height of 1.2m. rising while the value of $d\theta/dz$ is positive and $d^2\theta/dz^2$ is negative.

The temperature at 2.8m. remains sensibly constant during this period, and the two upper curves, corresponding with 7.1m. and 17.1m. show small but definite decreases of temperature amounting to about 0.2°F . and 0.3°F . respectively. These two latter curves had both shown mean temperature falls of 1.4°F per hour from 0200 to 0400. In these cases, therefore, the rate of fall of temperature was very much reduced after 0400. The mean temperature decrease at a height of 2.8m. between 0200 and 0400 had been 1.3°F . per hour, and this was completely wiped out. Whilst at 1.2m. the corresponding rate of fall of temperature was also 1.3°F . per hour, and this was converted into a temperature rise of about 0.2°F . between 0400 and 0500.

We may also examine the temperature structure shown in Fig. 17 in the following manner. During the period 0200 to 0400 G.M.T. the mean values of $d\theta/dz$ and $d^2\theta/dz^2$ at a height of 7.1m. are found to be as follows :—

$$\begin{aligned} d\theta/dz &= 2 \times 10^6 \text{F/cm.} \\ d^2\theta/dz^2 &= -2 \times 10^3 \text{F/cm}^2 \end{aligned}$$

Now the mean values found for the period from 0400 to 0500 G.M.T. are almost exactly the same as these. It follows from this that the values of κ and $d\kappa/dz$ must also have remained constant, since any alteration in either of these quantities would of necessity produce a change in the temperature distribution—i.e., $d\theta/dz$ and $d^2\theta/dz^2$. It may therefore fairly be concluded that all four of these quantities have remained sensibly constant. This being so, it follows from equation (2) that the rate of change of temperature due to turbulence cannot have altered. Hence the actual observed change in the value of $d\theta/dt$ must be attributed to some other factor.

Fig. 17 thus affords clear evidence of the operation of a factor which heats the air at various levels between 0400 and 0500 G.M.T. when the conditions are such as to preclude the possibility of the effect being due to turbulence.

As in Fig. 16, this warming effect is seen to be most pronounced near the ground and to decrease upwards.

The occurrence of this heating effect, and the manner in which it varies with height, can be accounted for by Prof. Chapman's explanation. The absorption by the air of long-wave radiation emitted by the surface of the ground as soon as it became warmed by the sunshine would be expected to produce a result precisely similar to that found in the above observations. The present observations may therefore be considered as lending strong support to Prof. Chapman's suggestion that the temperature of the lowest layers of the atmosphere is appreciably influenced by the absorption of long-wave radiation emitted by the ground.

In this connexion we may refer to the early morning of June 4th, 1927, again, and ask whether part at least of the recorded temperature decrease between 0200 and 0400 may not have been the result of the direct emission of radiation by the air. It is impossible to answer this question with certainty because the actual values of κ and $d\kappa/dz$ on this occasion are not known. If the value of $d\kappa/dz$ is so small that it can be neglected, then it is found that the value of κ required to produce the observed rate of temperature decrease at a height of 7.1m. is about 200. If this is considered to be a large value under the conditions which prevailed at that time, then there would be justification in invoking the aid of direct outgoing radiation to account for the observed rate of fall of temperature.

§ 10—A STUDY OF SOME CHARACTERISTIC CHARTS

In this section it is proposed to give illustrations and brief descriptions of a few charts obtained by means of the apparatus described earlier in this paper. The charts have been selected to show certain features which are characteristic of the records under various meteorological conditions.

Where reference is made to the wind velocity in the following descriptions, the value referred to is that given by the Dines pressure tube anemometer situated room to the west of the temperature gradient recorder, the pressure head being at a height of 13m.

Chart of June 29-30, 1923. (Fig. 18).—This chart has been selected mainly because it affords a good illustration of the types of trace obtained during a summer day and night with a light wind and a uniformly clear sky.

The dry and wet bulb traces are noteworthy for their unsteadiness during both day and night, indicating rapid fluctuations in the temperature of the air. During the day time (1000 to 1700) the dry-bulb trace consists of a band some $2\frac{1}{2}^{\circ}$ wide. The width of the wet-bulb trace is slightly less. During the night the minute-to-minute fluctuations are smaller, but there now occur irregular variations which involve a time interval of the order of half an hour. Connecting the unsteady day and night traces are two portions of much steadier trace (1800—2000 and 0500—0700).

Each of the features just described is shown even more clearly in the differential traces. Up to about 1600 both the differential traces degenerate into wide bands of irregularly scattered points. The width of each band is about $1\frac{1}{2}^{\circ}$, whilst the middle of the bands corresponds to lapses of about $2\frac{1}{2}^{\circ}$ F. and $3\frac{1}{2}^{\circ}$ F. for the two traces.

Variations in the temperature gradient of this sort are to be expected when the mean value of the gradient exceeds ten times the adiabatic value. It would seem clear, too, that the fluctuations which actually occur are of much shorter duration than the two-minute intervals at which the points of the trace are recorded.

The sunshine and starshine records give continuous traces throughout this day and night. The two decreases in the lapse which occur at 1600 and 1640 are, nevertheless, probably due to the passage of cloud which was of insufficient density to cause breaks in the sunshine trace.

From about 1600 onwards the lapse begins to fall off and by 1900 it has become reduced to zero. The wind velocity during the morning had been about 2 to 3 m/s., and this had fallen steadily throughout the day to a calm at 1900. At this time an inversion is seen to be building up rapidly. At 1908, however, the wind suddenly rose to 4 m/s., and the temperature inversion of 1° F. was immediately reduced to zero. The wind velocity remained about 3 m/s. until 2040, during which period the inversion grew slowly. The subsequent decrease in the wind is associated with a more rapid growth of the inversion.

It is interesting to note the fall in the dry bulb trace and the rise in the wet bulb trace which coincide with the increase in the wind at 1908. From 2100 onwards the wind remained light (1 to 2 m/s.).

The fluctuations shown in the gradient traces during the night are even greater than during the day. Furthermore, the nature of the fluctuations is completely altered. As in the case of the dry bulb trace, so here the minute-to-minute variations have given place to others which occupy a period comparable with half an hour. It is noteworthy that, in spite of the apparently random fluctuations in the traces, at no time during the night do the traces cross. There is always an inversion between 7 and 17m.

Finally we may note the rapidity with which the inversion is destroyed. Sunrise occurred at 0346 but the minimum night temperature did not occur until about 40 minutes later. The inversion up to 17m. was annihilated in just an hour (0425 to 0525).

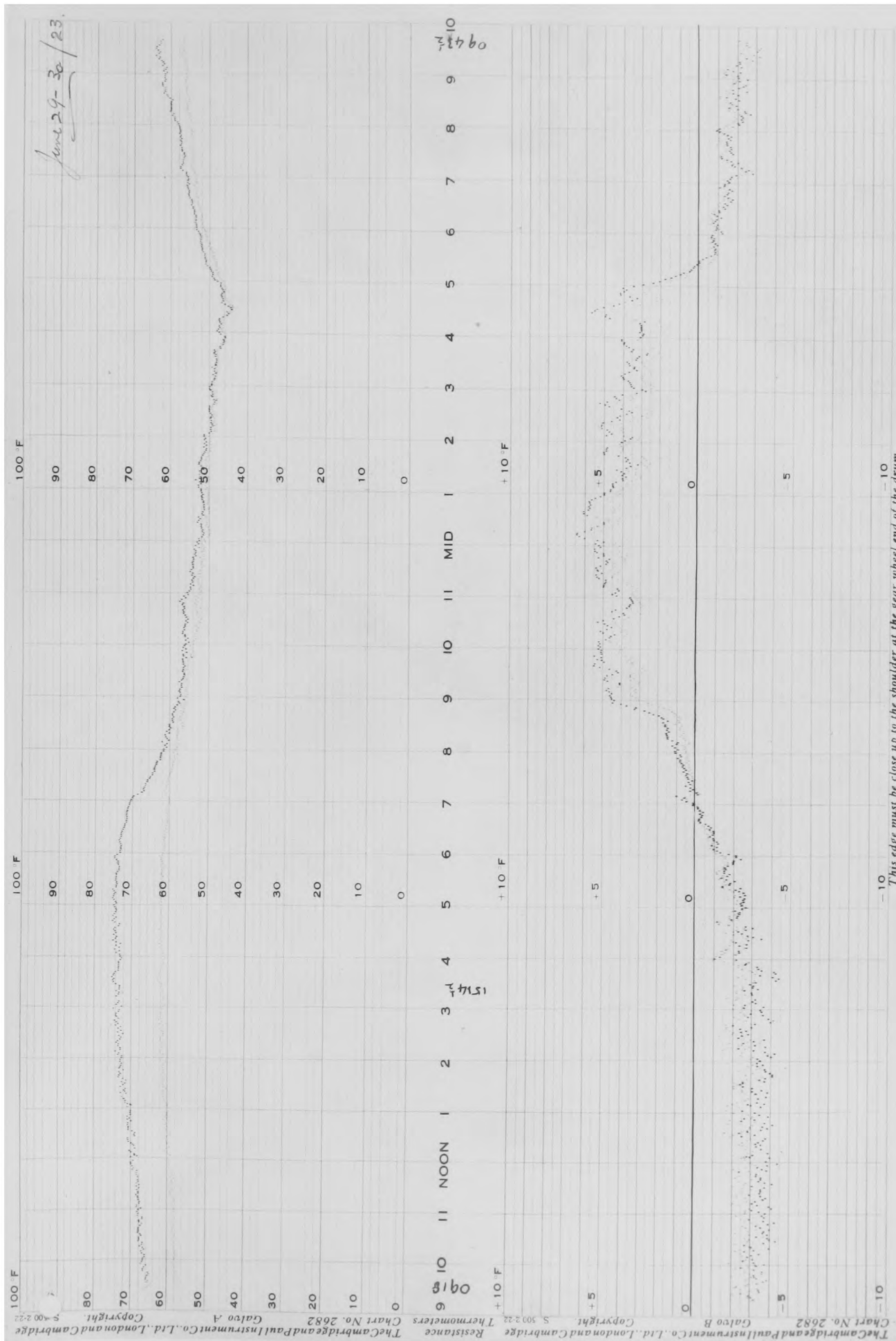


FIG. 18 -- DRY AND WET BULB TEMPERATURES AND TEMPERATURE GRADIENTS, JUNE 29-30, 1923.

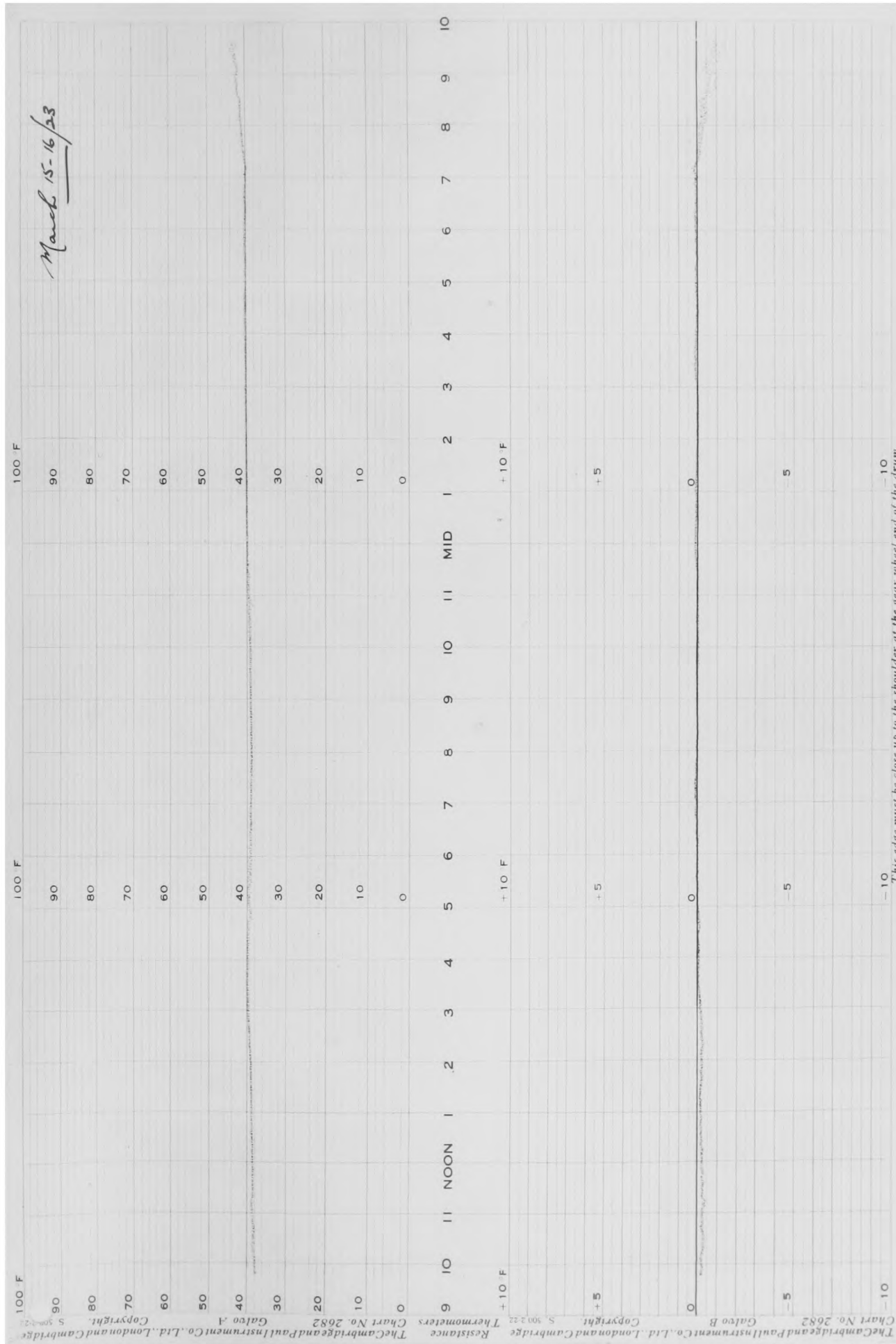


FIG. 19.—DRY AND WET BULB TEMPERATURES AND TEMPERATURE GRADIENTS, MARCH 15-16, 1923.

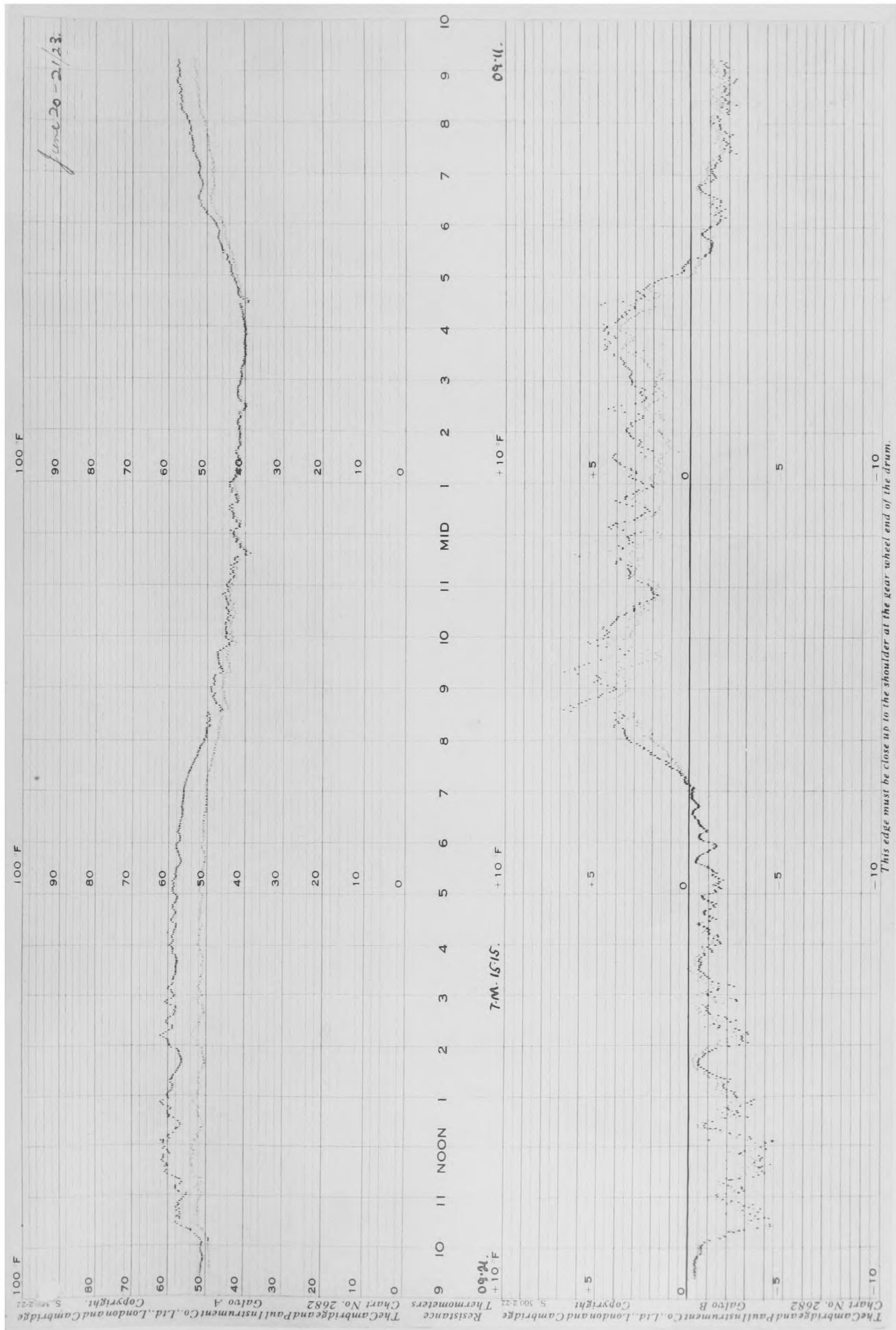


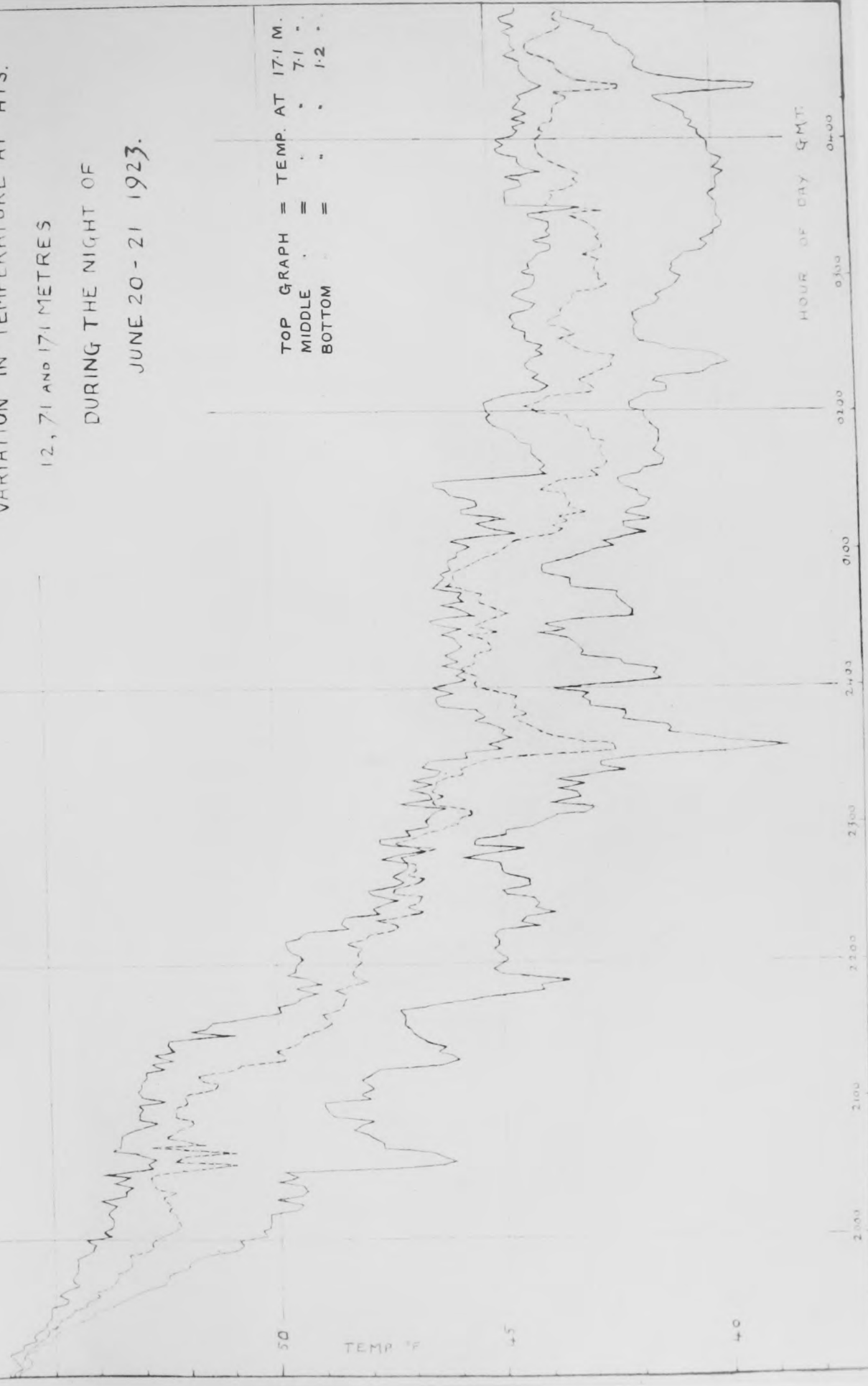
FIG. 21.

VARIATION IN TEMPERATURE AT HTS.

12, 71 AND 171 METRES

DURING THE NIGHT OF

JUNE 20 - 21 1923.



The analysis which has been given of this chart provides an excellent illustration of the wealth of detail which can be obtained by the use of instruments of this type. Another example showing how this type of record may be employed for the analysis of the structure of a cold front was given by the writer in the *Meteorological Magazine* for April, 1925.

Chart of March 15-16, 1923. (Fig. 19).—In striking contrast with the traces just considered are those shown in this chart. The latter are conspicuous for their nearly featureless uniformity. They correspond with a heavily overcast day in early spring with a strong wind. The sky was continuously overcast until between 0700 and 0800 on the 16th. The sky then began to clear and the first sunshine occurred at 0830. The wind velocity was fairly steady at 8 m/s. from 0900 to 1900 at 6 m/s. from 1900 until midnight, and at 4 to 5 m/s. from then onwards. The rainfall during the 24 hours was inappreciable (0.2mm.) and occurred between 0900 and 1500.

Under these conditions the temperature gradient during the day conforms approximately to the adiabatic lapse rate, whilst during the night the lowest 17m. of the atmosphere becomes virtually isothermal. Even under these conditions, therefore, the effects of incoming and outgoing radiation are appreciable.

It should be stated that traces as uniform and flat as those just considered are somewhat rare, and occur only about once or twice a year. The differences between the temperature gradients obtained with clear and overcast skies have been considered in an earlier section of this paper. In addition to these results it may be noted that the effect of wind is to decrease the numerical magnitude of the temperature gradient. Thus, normally, steep lapse rates and large inversions are associated with clear skies and light winds. Of the two factors, radiation and turbulence, the former is perhaps the more important in determining the gradient of temperature. Radiation, either incoming or outgoing, is positive in its action, in the sense that its presence is necessary to the formation of large gradients. The effect of turbulence is negative, in the sense that it tends to destroy the gradient which radiation would otherwise establish. That the turbulence associated with a wind as strong as 18 m/s. (40 mi/hr.) is not always capable of reducing the temperature gradient to a small value has been shown by the writer in a recent paper.⁵

Chart of June 20-21, 1923. (Fig. 20).—This chart has been selected primarily to show the manner in which the temperature gradient varies on a day during which bright sunshine is broken intermittently by the passage of cumulus clouds. On this occasion the sky was overcast until 1005. From this time until 1830 the occurrence of each interval of sunshine is clearly marked in both the dry bulb record and the two temperature gradient traces.

Sunset occurred on this date at 2010, by which time the inversion between 1.2m. and 17.1m. had reached a value of 3.5° F. The inversion reached its maximum value about half an hour after sunset.

The sky was clear throughout the night except during an interval of 1½ hours between 0040 and 0155, when some intermittent breaks occur in the starshine trace. A number of sudden falls in the dry bulb trace occur at 2030, 2115, 2332 and 0430. On each occasion the nocturnal inversion shows a corresponding temporary increase. Reference to the anemometer records shows that the wind was very light during this night (perhaps 1 m/s.) and that at three of the four times mentioned definite lulls occurred in this light wind.

The problem of the nature of the air movements which occur on a calm night was thought to be of sufficient importance to justify the construction of Fig. 21. In this diagram a dot-to-dot analysis has been made of Fig. 20, between the hours of 1900 and 0500. From the extracted readings the temperature curves for the three heights 1.2, 7.1, and 17.1m. have been drawn. The resulting curves are most interesting. In certain cases, notably at 2030, 2330 and 0430, sudden decreases in temperature occur at all three heights, the magnitude of the fall being greatest near the ground.

⁵ London, Q. J. R. Meteor. Soc. 54, 1928. p. 179.

These are three of the four cases just considered which were found to coincide with lulls in the wind.

In contrast with these cases, there are others (*e.g.*, 0135 and 0330) in which large and sudden falls of temperature occur at 17m., and are less marked near the ground. In the second example quoted there is no change recorded at 1·2m.

There is a third class of occasion on which a marked temperature change occurs at one height without any corresponding changes at the other heights. Thus, just after the general decrease in temperature at 2030, a sudden temporary rise is shown at 7·1m. Again, the sudden fall in temperature at 1·2m. at 2140 occurs only at that height. A similar fall at midnight is also restricted to the lowest curve. Other examples could be quoted if necessary.

These observations show quite clearly that either the air movements which occur on such a night as this are of very limited vertical extent, or else that under the conditions of a temperature inversion the horizontal gradient of temperature must be very steep in places. In either case it would follow that the degree of atmospheric turbulence which exists under such conditions must be extremely small.