THE EFFECT OF SOLAR RADIATION ON RADIO SONDE TEMPERATURE MEASUREMENTS.

By D E Handcock
(Cadet Meteorologist, Central Weather Bureau, Melbourne)

Introduction

Using the results of a preliminary investigation of the problem made by the United States Weather Bureau (U.S.W.B. 1947). theoretical values of the error in temperature measurement caused by the incidence of solar radiation on the radiosonde, have been determined for Australian stations. These values have been compared with corrections (Vaisala 1948) which are applied to radiosonde temperatures measured by the U.S.W.B. Using these corrections the probable error in temperatures and heights of pressure surfaces, measured by the radiosonde, have been determined for flights performed at 0400 and 0700 hours G.M.T.

1. INVESTIGATIONS BY THE U.S. WEATHER BUREAU.

The U.S.W.B. reproduced flight conditions in the laboratory by the use of a small vertical wind tunnel in which the radiosonde was suspended. A bank of incandescent lamps produced 2 cals.cm^{-2} min^{-1} radiation at an angle of incidence of 35° to the vertical of the radiosonde. The increment in temperature between "lights on" and "lights off" was measured, also the air temperature and wind speed. Measurements of the temperature increment were made for both the radiosonde and a separate radiosonde resistor exposed to the radiation, and were made for direct and reversed air flow, corresponding to ascent and descent respectively of the radiosonde.

It was found that the temperature increment due to radiation was much greater for direct than for reversed flow and it was suggested that this was due to the radiosonde design.

1.1 Causes of the Radiation Error

It is suggested that the above effect is due to the fact that, under ascent conditions, the temperature element is not directly heated by the radiation but that the temperature increment is produced by the heating of the top of the radiosonde box, particularly the louvres which in turn heat the air in contact with them. This air then passes through the duct to the temperature element. Thus the temperature increment will be greater the lower the pressure (and therefore density) of the air. During descent the air contacts only the unheated bottom of the box and the temperature increment is zero.

1.2 Theory of the Radiation Effect

The results of the U.S.W.B. investigation were expressed as a graph of the temperature error (ΔT) plotted against a scale of $\frac{\rho \times v}{u}$. The use of this scale is based on the theory of the heat balance of a thermometer, for which, considering only the problem under discussion, the following equation can be obtained

$$\frac{dq}{dt} = \text{Const.} \left(\frac{\rho \times v}{u}\right)^n (\Delta T)$$

where $\frac{dq}{dt}$ = the rate of absorption of radiant energy by the thermometer.
ρ = the air density
v = the air speed
u = the viscosity of the air
n = a constant
T = the difference between thermometer temperature and air temperature.

Putting $\frac{dq}{dt}$ = constant. i.e. 2 cal. $cm^{-2}min^{-1}$ and taking logarithms of both sides we obtain

$$n \log \left(\frac{\rho \times v}{u}\right) + \log (\Delta T) = \text{const.}$$

This equation gives a straight line when plotted on log-log paper and the results of the U.S.W.B. investigation were given in this form.

2. MODIFICATION OF THE U.S. DATA FOR AUSTRALIAN CONDITIONS.

Values of $\frac{\rho \times v}{u}$ were first converted to pressures in mb. by the writer, ρ and u being determined from the U.S. standard atmosphere and v chosen as 275 metres min^{-1} which is roughly the rate of ascent of the Australian radiosonde. Thus from the U.S.W.B. data a graph of T against pressure was obtained, the values shown applying to a flight conducted when the zenith angle of the sun was 35°.

To determine the radiation error at various stations and times these values were then modified for other zenith angles. The assumption was made that the radiation effect is a maximum with the sun overhead (zenith angle 0°) and is zero for the sun at the horizon (zenith angle 90°). This was an attempt to allow for both the depleting effect of the atmosphere on the incoming radiation, and the heating of the radiosonde box with varying zenith angles of the sun, and to make a simple correction for the two effects. The depleting effect has been computed for various altitudes and zenith angles by Vaiszala (1948) but as the variations in the heating of the sonde box were not accurately known the approximation was at best a very rough one but was necessary to simplify calculation.

Values of the radiation error $(\Delta T)_{35}$ given by the U.S.W.B. were therefore modified using the following equation :

$$(\Delta T)_{\phi} = (\Delta T)_{35} \times \frac{\cos \phi}{\cos 35^\circ}$$

where ϕ is the sun's zenith angle for a particular station and time,

and graphs of the radiation error plotted against pressure were prepared for selected stations.

3. COMPARISON OF THEORETICAL VALUES WITH CORRECTIONS APPLIED BY THE U.S.W.B.

Subsequent to this work a copy of the U.S.W.B. Manual of Radiosonde Observations (1950) giving corrections to be applied to radiosonde temperatures was received by the writer. This included a nomogram for determining the corrections and enabled them to be calculated quickly for any rate of ascent. Use of this diagram showed that, as already found, the error was a function of

(1) the sun's elevation, and increased as the elevation angle increased, and
(2) the rate of ascent of the radiosonde balloon, and increased as the rate of ascent decreased.

The graph of the error against pressure was a straight line on log-log paper but with a different slope to the theoretical curve.

The difference in the error determined by the two methods was of the order of 0.5°C at 100 mb. for 275 metres min^{-1} rate of ascent.

4. VALUES OF THE RADIATION ERROR.

Based on the U.S.W.B. Radiosonde Manual (1950) the following table of errors was prepared. The rates of ascent were chosen to approximate to the maximum, minimum, and mean values for Australian radiosondes.

0400 Z release.

Station	Pressure mb.	Summer: Rate of ascent :- 200 Temperature (°C.)	275	400	200 Height (Feet.)	275	400	Winter: Rate of ascent :- 200 Temperature (°C.)	275	400	200 Height (Feet.)	275	400
Darwin	300	0.6	0.6	0.6	8	8	8	0.6	0.6	0.6	8	8	8
	200	1.3	0.9	0.7	45	38	34	1.1	0.9	0.7	42	38	34
	100	2.6	1.9	1.3	178	133	101	2.4	1.7	1.3	162	126	101
	80	3.2	2.2	1.6	245	179	135	3.2	2.2	2.0	226	172	140
	60	4.2	3.2	2.1	336	247	172	4.0	3.0	1.5	320	240	187
Guildford	300	0.6	0.6	0.6	8	8	8	0.6	0.6	0.6	8	8	8
	200	1.3	1.0	0.7	46	40	34	1.2	0.9	0.7	44	33	34
	100	3.5	2.2	1.4	210	148	105	2.3	1.7	1.2	162	126	99
	80	4.2	2.9	1.7				3.1	2.0	1.5			
	60	5.5	4.3	2.7				4.0	2.8	1.9			
Hobart	300	0.6	0.6	0.6	8	8	8	0.4	0.4	0.4	8	8	8
	200	1.2	1.0	0.7	44	40	34	0.6	0.5	0.4	28	26	24
	100	2.8	1.8	1.3	179	128	92	1.3	0.9	0.6	94	74	57
	80	3.8	2.4	1.6				1.8	1.1	0.9			
	60	4.1	3.5	2.3				2.4	1.6	1.2			

The error for any Australian station would be within the range given by the three representative stations.

From the table it can be seen that quite large errors can be expected at pressures of 100 mb. and lower. However for one rate of ascent the differences between the errors at any one pressure level are not large, and construction of 100 mb. C.P. charts would not be affected, but differences between the rates of ascent can produce quite large variations in the error.

Graphs of the radiation error as a function of pressure are given in Figures 1 and 2, for the present time of release of 0400Z and for the former time of 0700Z. Of the release times in the past the errors for 0730Z release will be slightly smaller than at 0700Z, and the errors for 0830Z will be nil except for Western Australian stations in midsummer when small errors (maximum 1° at 100 mb.) are possible. For Western Australian stations in winter and other stations throughout the year the errors for 0830Z release are nil. At any other release times (1600Z, 1400Z, 1100Z) the error is zero for any station at any time of the year.

5. RATES OF ASCENT OF THE RADIOSONDE

A graph of the radiation error as a function of the rate of ascent for one station, pressure and time, is shown in Figure 3. The average amount of gas required to achieve this rate of ascent with standard radiosonde equipment is also shown. These graphs show that whilst high rates of ascent (e.g. 600 metres min^{-1}) would make the error small, the quantities of gas required make this solution impracticable. Also variations in rates of ascent are largely outside the observers' control due to changes in the shape of the balloon and to variations in Reynold's number (Stewart, 1945). Also the observer must vary the rate of ascent to meet such conditions as icing, strong or light winds, and the requirements of sowin and rawin flights.

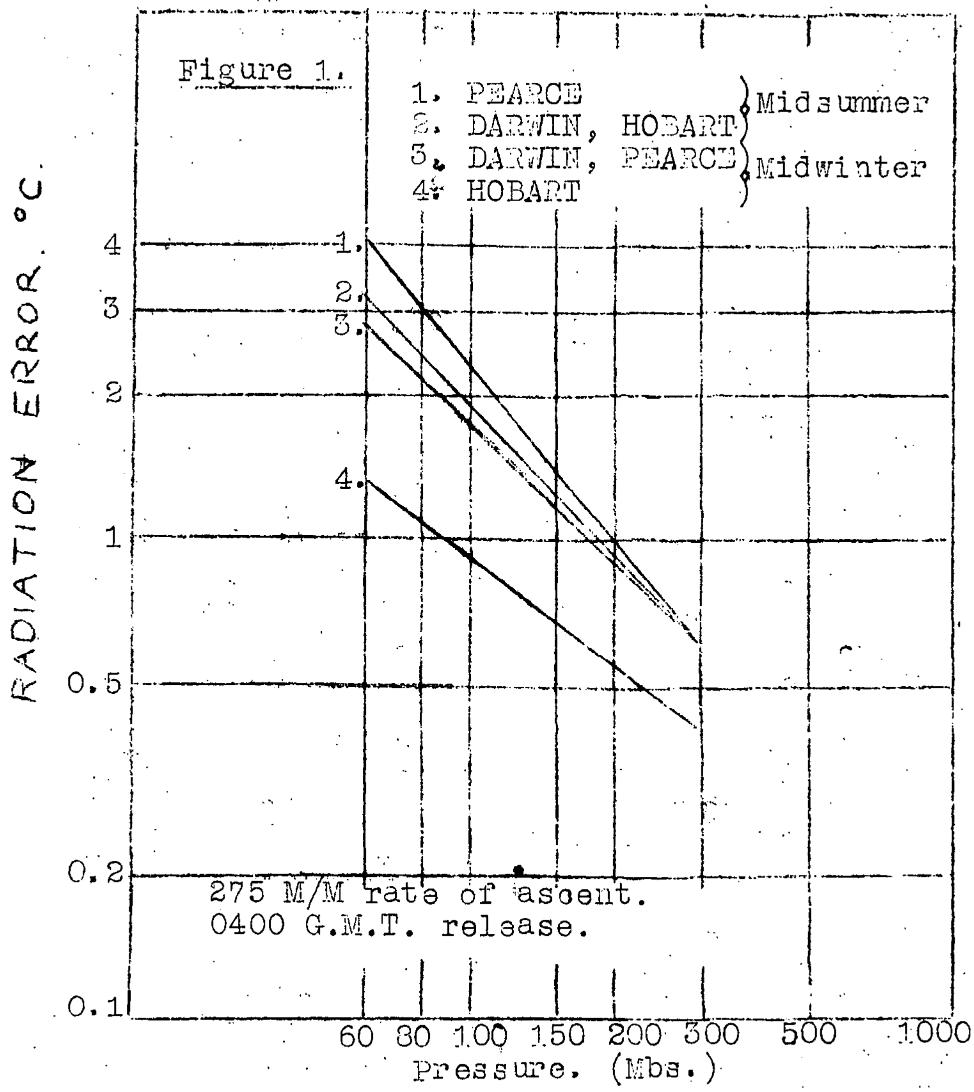
In view of this the rates of ascent between 200 and 100 mb. were studied to find what variation could be expected. Twenty-five flights from each of the selected stations were examined, and their frequency distributions are shown in Figure 4. Most stations have a rate of ascent of 230 ± 50 metres min^{-1} but individual flights can have much faster rates of ascent and large variations from station to station and flight to flight are possible. The change in the error in the height of the 100 mb. pressure surface for a change of the rate of ascent from 200 to 400 metres min^{-1} can be of the order of 180 ft. and this must be borne in mind when attempting 100 mb. C.P. analysis with observational data desired as at present.

6. DIURNAL VARIATION OF THE RADIATION ERROR

An example of this variation is shown in Figure 5. Curves for other stations differ little from this in summer but in winter the amplitude of the curve for Hobart is only half that of the curve for Pearce (or Guildford).

7. VERIFICATION OF THE RADIATION ERROR

The U.S.W.B. in their preliminary investigation adopted an indirect method of verification by comparing the differences between the radiosonde and a separate radiosonde resistor exposed



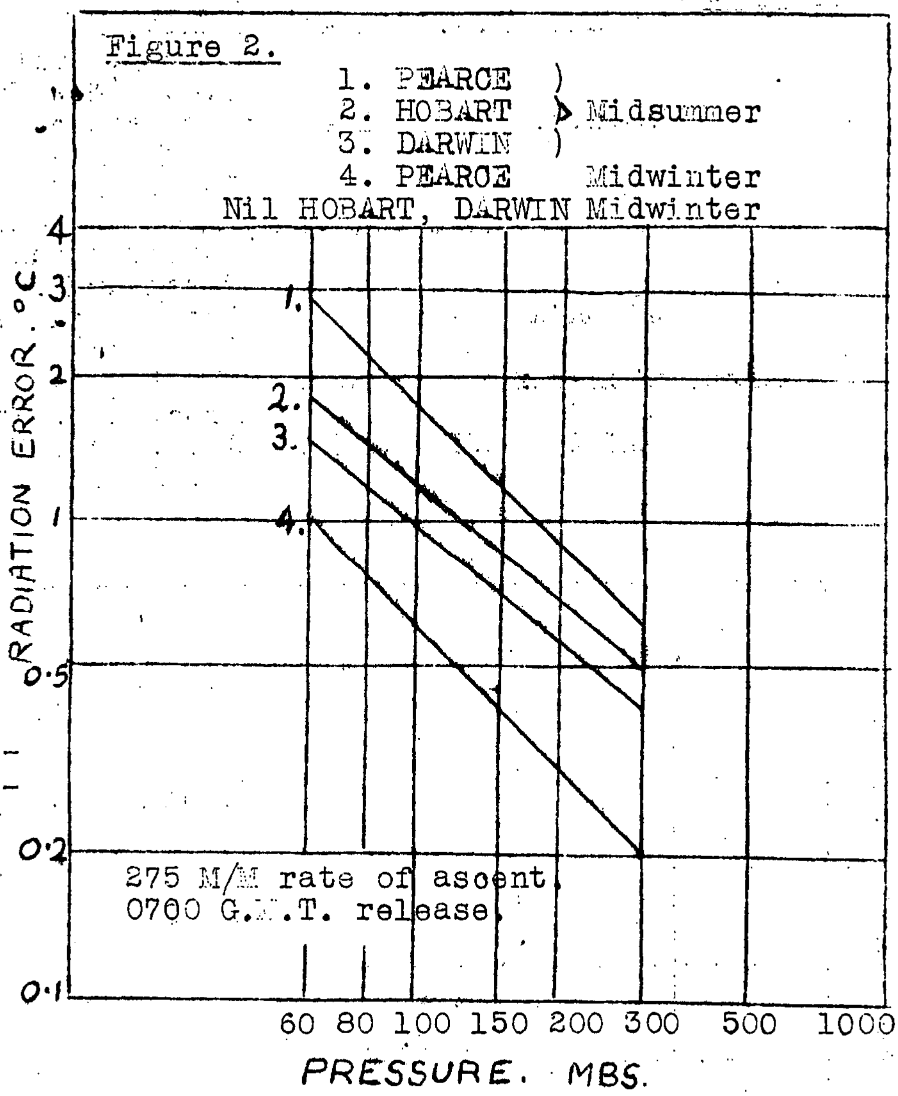
to the radiation, both in the wind tunnel and in actual flights. In the latter case the exposed resistor was wired to record in the humidity interval of the radiosonde. It was found that there was generally good agreement in the temperature differences measured by the two methods.

The writer has attempted to verify the error by using actual flights and comparing ascent and descent values at the same pressures. However it has been found that the other errors - ventilation, reproducability, and sampling - mask the radiation effect.

8. CONCLUSION.

The investigation has shown that errors are produced in the radiosonde temperature measurements by solar radiation and that these errors are important above 200 mb. and will make the construction of accurate 100 mb. analyses difficult unless corrections are used.

Figure 2.



The U.S.W.B. nomogram makes it possible for the error to be corrected during the radiosonde flight. The Australian radiosonde, although of the same design as the U.S.W.B. radiosonde, uses different materials for the outer covering of the case for the louvres and for the duct, and this may produce differences in the error. Experimental work is necessary to ascertain whether the U.S.W.B. corrections are directly applicable to the Australian radiosonde.

Acknowledgment

The writer desires to acknowledge with thanks the assistance of Mr. H. N. Brann, Supervising Meteorologist, Instruments Section, Central Weather Bureau, Melbourne, under whose guidance the investigation was carried out.

References

STEWART, H. J.	1945	Handbook of Meteorology, (Berry, Bollay & Beers) p.450 (New York)
U.S.W.B.	1947	Performance Characteristics of the Radiosonde, U.S. Dept. of Commerce.
U.S.W.B.	1950	Manual of Radiosonde Observations, W.B.A.N. Circular P.
VAISZALA	1948	Geophysica, Vol. 1, No. 3 (Finland)

Also, with reference to Reynolds' number :-

ALLOCK	1908	Proc. Roy. Soc. p.80.
CLARKE & KARFF	1914	Jour. Franklin Inst. pp. 232, 341.

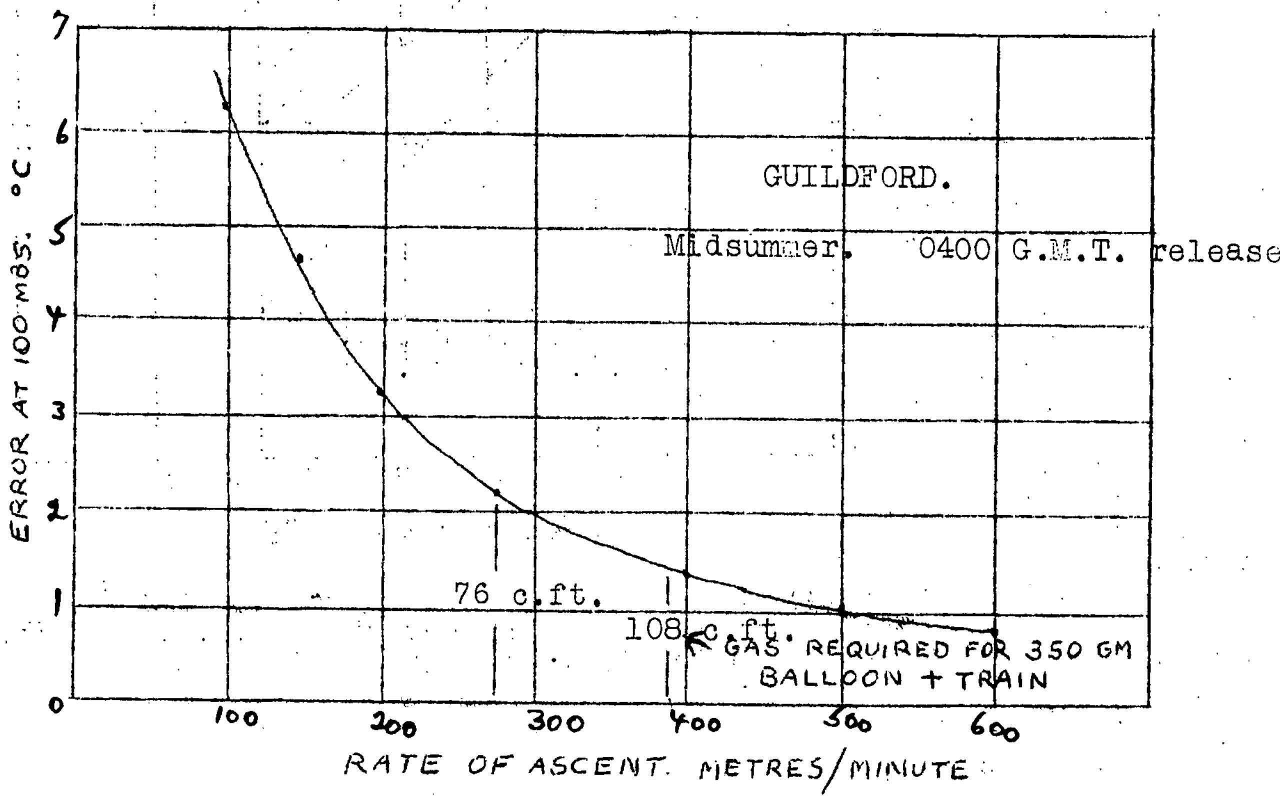


Figure 3.

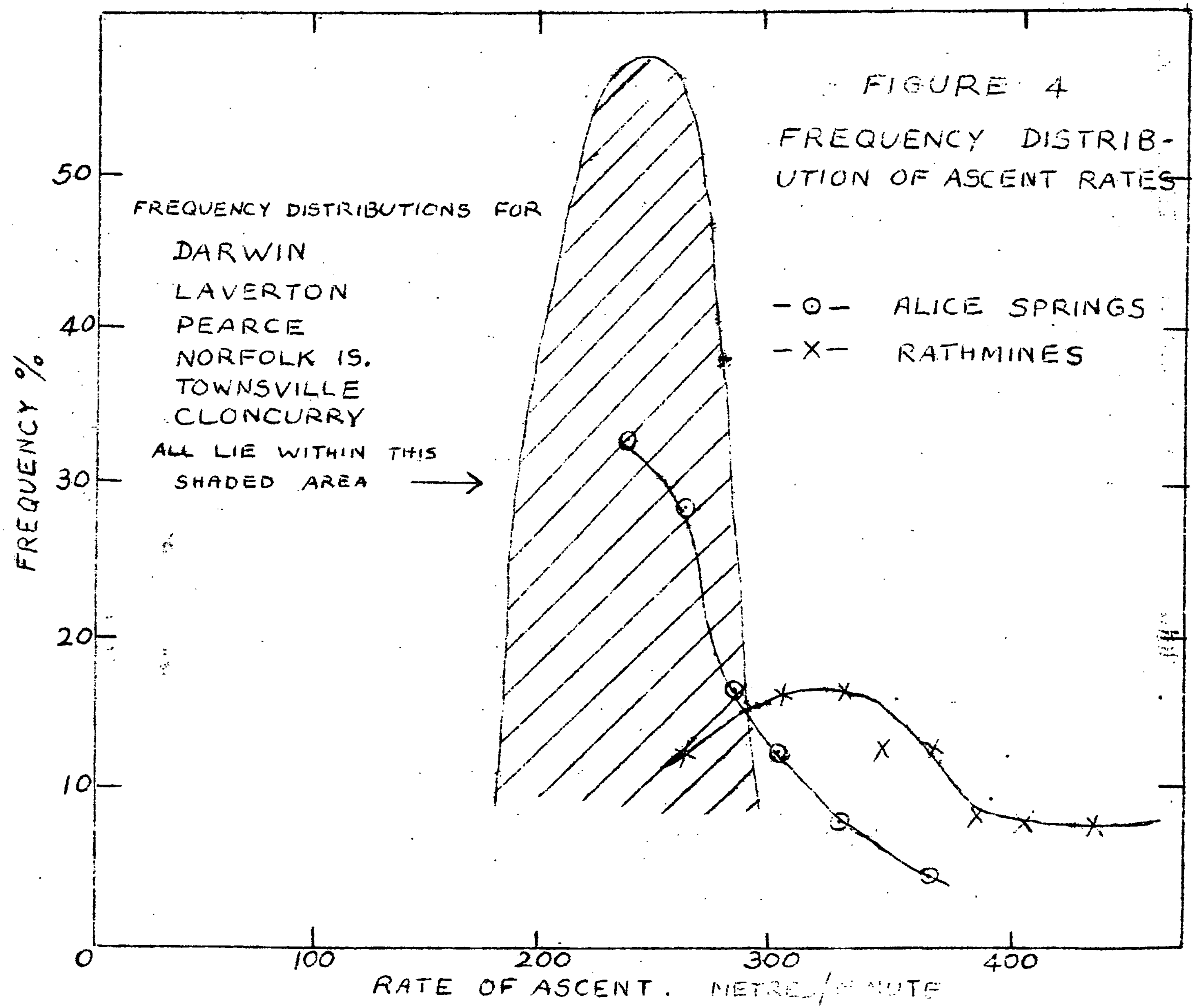


FIGURE 4
FREQUENCY DISTRIBUTION OF ASCENT RATES
-O- ALICE SPRINGS
-X- RATHMINES
FREQUENCY DISTRIBUTIONS FOR
DARWIN
LAVERTON
PEARCE
NORFOLK IS.
TOWNSVILLE
CLONCURRY
ALL LIE WITHIN THIS SHADED AREA
FREQUENCY %
50
40
30
20
10
0
100
200
300
400
RATE OF ASCENT. METRE/MINUTE

Figure 5.

DIURNAL VARIATION OF RADIATION ERROR AT PEARCE.

Midsummer. Rate of Ascent 275 M/M/