ROYAL OBSERVATORY, HONG KONG.

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RESULTS OF THE EXPERIMENTAL RADIOSONDE ASCENTS MADE AT HONG KONG DURING THE SOLAR ECLIPSE APRIL 19TH 1958

BY

R.F. APPS

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INTRODUCTION.

The radiation corrections which are applied to the Kew type radiosonde in normal work have been checked at Hong Kong for the layers between 6.5 and 16.5 kms. above Mean Sea Level.(1) The results of the Payerne trials (1956) and various anomalies in the routine Hong Kong upper air results have been discussed (2) and suggestions for the modification of the normal lag and radiation corrections have been made. The purpose of these trial ascents made at Hong Kong during the solar eclipse of April 19th, 1958, was two-fold :-

(a) To check whether a change in the shielding of the magnetic circuit (without altering the shielding of the bi-metallic thermometer element) would alter the temperature recorded at any given level. If the ideas put forward in (2) are correct, then a shield arranged to give better ventilation of the magnetic circuit would cause the temperature recorded to be higher than that recorded with a thermometer element with a normal shield.

(b) To check the radiation corrections at levels below 6.5 kms. and below cloud if possible. The effect of cloud cover on the corrections to be applied to a sonde beneath the layer has been estimated previously. (2)

INSTRUMENTATION.

The solar eclipse of April 19th, 1958, was 94% total at Hong Kong and instantaneously annular at its maximum phase at the Royal Observatory. The time progression of the eclipse was photographed through a telescope by Mr. J.C.H. Lui near Sheung Shui village in the New Territories. This position is a few miles to the north of the Observatory and the eclipse was not annular there at its maximum phase. Ho ever, these photographs enable a fairly accurate estimate to be made of the proportion of the sun's disc which was covered at any time. The difference in the phase of the eclipse at the Royal Observatory and at the position of the balloon during the trials is equivalent to one minute difference in timing and is negligible for our purpose. The eclipse commenced at the Royal Observatory at 1012 hrs., H.K. Summer Time;* the maximum phase occurred at 1145 hrs. and the eclipse ended at 1351 hrs.

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* All times are in Hong Kong Summer Time, which is 9 hours ahead of Greenwich Mean Time.

In order to check the effect of the modified shield, two radiosondes were flown on the same balloon. One of these was a standard sonde, and the other was a sonde fitted with a modified shield to the magnetic circuit of the temperature measuring element. The modification gave better ventilation of the core in the magnetic circuit and better clearance between core and shield. The modified sonde was set to record temperature continuously. A 1250 gram balloon was used and carried the following in order below it :-

> a parachute, radar target, modified sonde at the end of 25 m. suspension and an unmodified sonde at the end of a further 20 m. suspension.

This type of assembly was flown on balloons released at 1129 hrs and at 1400 hrs. The routine ascent at 0910 hrs was made with the normal assembly, except that the suspension between the sonde and the target was increased to 45 m. Thus in all three ascents the unmodified sonde was the same distance below the balloon. The modified sonde, when used, was at the distance below the balloon which is used in normal sounding. This is generally accepted as reducing to negligible proportions errors due to the warm wake of the balloon.

The three ascents were tracked by radar which was carefully set up and checked before the trials. All time readings were taken from the same clock so that errors due to different clock rating were eliminated. The same operators were used throughout the trials. Two sets of radiosonde ground equipment were used and these were calibrated against a common frequency standard. In addition, a sonde was checked prior to flight on the same ground equipment as was used to follow it during flight.

VALIDITY OF THE NORMAL LAG CORRECTION.

Modification was made only to that part of the shield of the thermometer element which does not enter into the calculation of normal corrections. Therefore, the same theoretical radiation corrections should apply to both modified and unmodified sonde. Thus any differences in temperature at the same height between modified and unmodified sonde flown on the same balloon must be due to the alteration in the shielding of the magnetic circuit, this being the only point of difference between the two sondes. Let us now suppose that this variation in shielding allows the temperature of the whole temperature measuring element to be uniform. Then the modified sonde needs the application of the normal lag correction in addition to the normal radiation correction to give the true

air temperature at any given level. The unmodified sonde, however, needs no lag correction if it is assumed that the heating of its magnetic circuit results in a total lag correction of zero as postulated in (2). Then in the case of the ascent in full sunlight at 1400 hrs, the difference obtained by subtracting the temperature recorded by the unmodified sonde from that recorded by the modified sonde at the same level should equal the normal lag error at that level. The ascent at 1129 hrs, which was made when the incoming radiation was reduced considerably, should show differences of the same sign but approaching zero. As the calculation of the normal lag correction depends on the apparent lapse of temperature, the results in the troposphere are considered first.

The records of the soundings were reduced in the following way :- The temperature at each exact minute was found from the records of the sondes. The corresponding height above M.S.L. was found from the radar readings. These heights were corrected for earth's curvature and difference in position between the target and the modified sonde. Since there was a difference in the height above M.S.L. of the two sondes at these times, corrections were applied to the readings of the unmodified sonde. These were obtained from the difference in the length of the suspension of the sondes below the balloon, the rate of ascent of the assembly and the lapse rate of temperature. Differences Δ given by (temperature from the modified sonde minus unmodified sonde values at the same height) were found. These are shown in Figure I B for the 1129 hr. ascent and in Figure I C for the 1400 hrs. Values (B) for the 1400 hr. ascent were then found by adding the normal lag correction to the values of Δ and are given in Figure I A. For the reasons explained above these values of B should be zero if the postulates are correct. For the 35 values (plotted with dots in Figure I B) obtained in the layers up to the tropopause (16 kms.) a mean value of $-0.17^{\circ}C$ and an adjusted standard deviation $0.3^{\circ}C$ were obtained for B. The application of "Student's" "t" test to this sample shows that it is unlikely to originate from a normal population with zero mean. The coefficient of regression of B on height is +0.01 and there is no reason to suspect that the distribution of B is other than normal. The normal lag correction is therefore not completely nullified. There is substantial modification, however, since the normal lag correction at the tropopause level is $-1.1^{\circ}C$. This trial would suggest that the normal lag correction should be reduced to $-0.2^{\circ}C$ at all heights up to the tropopause for ascents in daytime. This is equivalent to saying that the temperature of the magnetic circuit is lagging by $6^{\circ}C$ on that of the air at all levels up to the tropopause.

The results of the ascent at 1129 hrs are complicated by the fact that the amount of radiation received directly was varying with time. However, Mr. Lui's photographs (Figure II) enable the proportion of the sun's disc uncovered to be estimated at any time. Treating the sun as an isotropic radiator, an estimate can be made of the amount of direct radiation received at the sonde. To find the maximum possible radiation during the partial eclipse, consider the angle between (a) a line from the centre of the sun to the observer, and (b) the normal to the sun's surface at the nearest point on the sun visible to the observer. Multiplying the cosine of this angle by the proportion of the sun's disc uncovered gives the maximum proportion of the sun's radiation which could be received. Figure I B shows this estimate of the proportion of full solar radiation for various levels and the proportion of the sun's disc uncovered. These figures show that, for the flight in the troposphere of the 1129 hrs balloon, the amounts of radiation being received were considerably reduced. For our purpose the ascent can be treated as having been made almost in darkness. The values of Δ for this ascent should be small and positive if the postulates in (2) are correct. It can be seen from Figure I B (dotted points) that this is certainly so at levels above about 5 kms. These results suggest that in the troposphere

(i) the normal lag corrections are valid for ascents of unmodified sondes in darkness, and

(ii) the normal lag corrections should be reduced to $-0.2^{\circ}C$ at all levels for ascents using unmodified sondes in daytime.

The normal lag corrections in the stratosphere are calculated from the apparent lapse of temperature recorded by the sonde (i.e. calculated from the results of the sounding without radiation corrections having been applied). In the case of these trials there was a well marked and continued reversal of lapse at the tropopause on all ascents. The curve of uncorrected temperature against height for the 1129 hrs ascent is shown in Figure I D. Values of Δ and B for the 1400 hrs ascent and values of Δ for the 1129 hrs ascent were found using the appropriate rate of ascent and apparent lapse of temperature. These are shown in Figures IA, B and C by means of crosses. Continuing with the comparison of Figures I A and I B, it will be seen that at the tropopause on the former there is a marked discontinuity in the values, whereas there is good continuity in Figure I B. However, there is also good continuity in Figure I C. That is, the actual difference in temperatures recorded by the sondes are preserved in spite of the reversal of lapse rate. The difference in the case of the 1129 hrs is near zero, and in the case of the 1400 hr ascent is equal to the normal lag correction at levels

just below the tropopause. Consider what has happened here. Just below the tropopause it has been shown that the normal lag correction is applicable to the ascent at 1129 hrs. No difference is to be expected in the temperatures recorded by the sondes on this balloon since the incident radiation is practically nil, and the normal lag correction should still apply. There should be continuity in the small differences on this ascent in spite of the fact that the lapse rate has been reversed in passing the tropopause. In the case of the ascent at 1400 hrs, however, it has been shown that there is an additional correction of +C.9°C to be applied to the unmodified sonde (i.e. the difference between the normal error 1.1°C and the mean value of 0.2°C just found). We have assumed that this error is due only to the incoming radiation and is not dependent on the lapse rate (i.e. due to a wrong coefficient). Thus just above the tropopause it should continue with the same magnitude and sign. The value of the normal correction just above the tropopause in this trial is +1.5°C. The value of B must therefore jump from zero to +2.4°C just above the tropopause. This is clearly shown on Figure I A and is probably the strongest support for the proposal that the normal lag corrections need modification in daytime. At levels above 22 kms. there is a marked similarity between the values of Δ on the two ascents (Figures I B and I C). This is probably due to the fact that conditions for both ascents were becoming similar.

RADIATION CORRECTIONS.

The results of the 1955 trials at Hong Kong [1] were assessed without taking the variation of the lag correction with insolation into account. If the values in Table I of the 1955 report are adjusted, the values of the mean and standard deviation change from -0.2°C and 0.4°C respectively to +0.2°C and 0.4°C. The validity of the normal radiation corrections is still supported.

In assessing the results of the present trials, it was clear that the routine sounding at 0910 hrs was unreliable at levels about 10.5 kms. due to instrumental faults, there being several instantaneous discontinuities in the temperature record. It was also apparent that there was a real difference in the ascents at 1129 hrs and 1400 hrs in the layers between 13.8 kms. and 16.2 kms. (Figure I D). That the difference was real is shown by the fact that the difference in shape is also shown by the modified sondes. A similar difference in the levels just below the tropopause was observed during the 1955 trials (see the footnote on page one of the 1955 report [1]). The comparison was therefore limited to checking the radiation corrections at the lower levels, and additional confirmation at the higher levels was not sought.

The local cloud reports obtained from aircraft flying over Hong Kong during the trials show that the main cloud was confined to the layer below 2 kms. From the results of the unmodified sonde on each ascent the temperature at 0.25 kms. intervals from 2.24 kms. to 10.5 kms. was found. These temperatures were corrected for lag using the results of the previous paragraphs to modify the corrections where necessary. The ascent at 0910 hrs was made with solar angle of 35° to 40°, that at 1129 hrs at 70° to 71°, and at 1400 hrs at 60° to 65°. However, the radiation correction varies continuously and steadily with increasing solar angle, so that the mean of the temperatures for a given level obtained from the temperatures corrected for lag on the 0910 and 1400 hrs ascents may be taken to refer to a solar angle of 50° approximately. It has already been shown that the amount of radiation reaching the sonde on the 1129 hrs ascent is negligible. The radiation corrections to be applied to the results of this sounding estimated from the amount of radiation at the sonde (which was unlikely to be exceeded) were 0.1° or less at all levels. The high solar angle during this ascent was therefore unimportant. Mean temperatures for each level were found as indicated above, and differences (D) were obtained by subtracting these mean temperatures from the temperature at the same level from the 1129 hrs ascent. The temperatures and corrections used are shown in Table I. Values of normal radiation correction for solar angle 50° minus D were then found for each level. From the 31 values thus obtained, a mean value of $-0.05^{\circ}C$ was found and a corrected standard deviation of $0.3^{\circ}C$. All these levels were above the prevailing cloud layers and the figures confirm that the normal radiation corrections are valid between 2.25 kms. and 10.5 kms.

RADIATION CORRECTIONS BENEATH CLOUD LAYERS.

From observations taken by aircraft flying over Hong Kong on the day of the trials it is known that the general cloud base was generally below 700 m. and tops at about 2 kms. There was insufficient data to check the radiation corrections below cloud, especially as the cloud was broken. However, this trial shows that the radiation corrections need no modification at levels from 2.25 kms. up to 10.5 kms. when the ascent is made above cloud. The Payerne trials (1956) showed low values for the radiation corrections at 850, 800 and 700 mbs.(when there was probably considerable cloud cover), and confirmed the normal corrections at higher levels. It can be inferred that the calculation of the corrections is not in error, but that the cloud cover is an additional factor which should be allowed for in applying the corrections to routine soundings.

CONCLUSIONS.

LAG CORRECTIONS.

This trial suggests that, in order to use the normal lag corrections, the shielding over the magnetic circuit of the temperature element should be modified. The modification used in the trial is not wholly satisfactory as can be seen from the results at levels above 22 kms. A modified and effective shield is better than attempting to modify the correction to be applied, since the latter method is complicated at levels in the stratosphere.

RADIATION CORRECTIONS.

The normal (calculated) radiation corrections are confirmed for the levels from 2.25 kms. to 10.5 kms. on the assumption that the effective lag correction is $-0.2^{\circ}C$ in these layers in daytime during the trial, and normal lag corrections are necessary in darkness. That is, the normal radiation corrections in these layers are adequate, but errors are introduced into the results of soundings by the use of wrong lag corrections. The low values for the radiation corrections at the 850, 800, 700 mbs obtained at Payerne are not confirmed, and the postulate that the amount of cloud cover above the sonde must be considered when these corrections are applied is supported.

ACKNOWLEDGEMENTS.

I am indebted to Mr. J. Darling, Meteorological Office, Air Ministry, London, and the Royal Air Force in Hong Kong for information on cloud tops and cover during the trials; to Mr. J.C. Lui for a set of photographs of the various stages of the eclipse, and to the staff of the Radiosonde section of the Royal Observatory for radiosonde and radar observations taken during the trial.

REFERENCES

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(2) APPS R.F. Modification to Lag and Radiation Corrections for the Kew type Radiosonde in the Troposphere. Technical Note No.18, Royal Observatory, Hong Kong. 1958.

(3) PERLAT and MARC. Report Preliminaire de la Meteorologie Francaise sur les Experiences de Comparison de Radiosondes a Payerne (Mai-Juin 1956) Paris. 1956.

Height above M.S.L. (kms)	0910 hr. T°C	0910 hr. Corrected for lag (°C)	1400 hr. T°C	1400 hr. Corrected for lag. (°C)	Mean T°C	1129 hr. T°C	1129 hr. Corrected for lag. (°C)	D	Normal Radiation Correction for Solar Angle 50°	Normal Radiation Correction (50°) minus D
2¼	16.6	16.4	15.2	15.0	15.7	15.2	14.9	-0.8	-0.8	0.0
2½	15.0	14.8	15.2	15.0	14.9	14.2	13.9	-1.0	-0.8	+0.2
2¾	13.5	13.3	14.0	13.8	13.5	12.8	12.5	-1.0	-0.9	+0.1
3	11.8	11.6	12.5	12.3	12.0	11.5	11.2	-0.8	-0.9	-0.1
3¼	10.4	10.2	11.1	10.9	10.5	10.2	9.9	-0.6	-0.9	-0.3
3½	8.9	8.7	9.3	9.1	8.9	8.2	7.9	-1.0	-1.0	0.0
3¾	6.9	6.7	7.4	7.2	6.9	6.3	6.0	-0.9	-1.0	-0.1
4	5.0	4.8	5.4	5.2	5.0	5.0	4.3	-1.0	-1.0	0.0
4¼	3.1	2.9	4.2	4.0	3.5	2.4	2.1	-1.4	-1.0	+0.4
4½	1.5	1.3	2.5	2.3	1.8	0.8	0.4	-1.4	-1.0	+0.4
4¾	0.3	0.1	0.7	0.5	0.3	-0.6	-1.0	-1.3	-1.0	+0.3
5	-1.5	-1.7	-1.1	-1.3	-1.3	-2.4	-2.8	-1.3	-1.1	+0.2
5¼	-5.0	-3.2	-2.4	-2.6	-2.9	-3.7	-4.1	-1.2	-1.1	+0.1
5½	-4.4	-4.6	-3.1	-3.3	-3.9	-4.8	-5.2	-1.3	-1.1	+0.2
5¾	-5.3	-5.5	-4.3	-4.5	-5.0	-5.7	-6.1	-1.1	-1.1	+0.0
6	-6.2	-6.4	-6.3	-6.5	-6.4	-6.9	-7.3	-0.9	-1.1	-0.2
6¼	-6.8	-7.0	-7.4	-7.6	-7.3	-8.3	-8.7	-1.4	-1.1	+0.3
6½	-8.6	-8.8	-8.7	-8.9	-8.8	-9.6	-10.0	-1.2	-1.2	+0.0
6¾	-10.2	-10.4	-9.9	-10.1	-10.2	-11.3	-11.7	-1.5	-1.2	+0.3
7	-11.8	-12.0	-11.8	-12.0	-12.0	-13.0	-13.4	-1.4	-1.2	+0.2
7¼	-13.5	-13.7	-13.7	-13.9	-13.8	-14.8	-15.2	-1.4	-1.3	+0.1
7½	-15.1	-15.3	-15.7	-15.9	-15.6	-16.3	-16.7	-0.9	-1.3	-0.4
7¾	-16.7	-16.9	-17.7	-17.9	-17.4	-17.8	-18.2	-0.8	-1.3	-0.5
8	-18.4	-18.6	-19.0	-19.2	-18.9	-19.4	-19.8	-0.9	-1.3	-0.4
8¼	-20.7	-20.9	-20.5	-20.7	-20.8	-21.5	-21.9	-1.1	-1.4	-0.3
8½	-22.7	-22.9	-22.3	-22.5	-22.7	-23.5	-23.9	-1.2	-1.4	-0.2
8¾	-24.6	-24.8	-24.1	-24.3	-24.5	-25.5	-26.0	-1.5	-1.4	+0.1
9	-26.6	-26.8	-25.8	-26.0	-26.4	-27.6	-28.1	-1.7	-1.5	+0.2
9¼	-28.5	-28.7	-27.6	-27.8	-28.2	-29.6	-30.1	-1.9	-1.5	+0.4
9½	-30.4	-30.6	-29.5	-29.7	-30.1	-31.0	-31.6	-1.5	-1.6	-0.1
9¾	-32.3	-32.5	-31.5	-31.7	-32.1	-32.5	-33.1	-1.0	-1.6	-0.6
10	-34.2	-24.4	-33.7	-33.9	-34.1	-34.4	-35.0	0.9	-1.6	-0.7
10¼	-36.0	-36.2	-35.8	-36.0	-36.1	-36.5	-37.0	-0.9	-1.7	-0.8
10½	-37.9	-38.1	-37.9	-38.1	-38.1	-38.9	-39.4	-1.3	-1.8	-0.5

Mean = -0.05°C

Adjusted standard deviation = 0.3°C

TABLE I.

Comparison of calculated and observed radiation corrections for solar angle 50°.

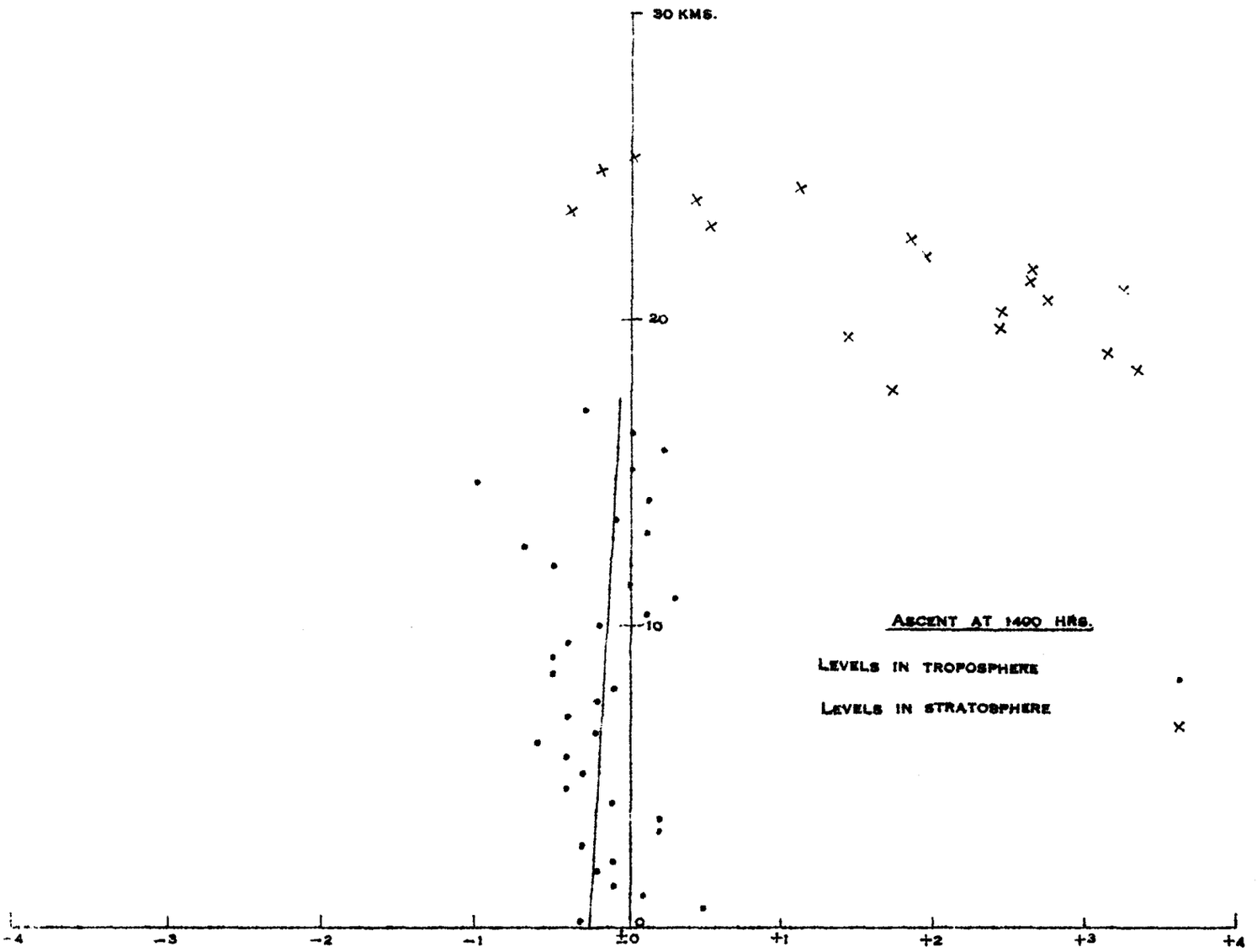


FIGURE 1A VALUES OF B(°C) AGAINST HEIGHT

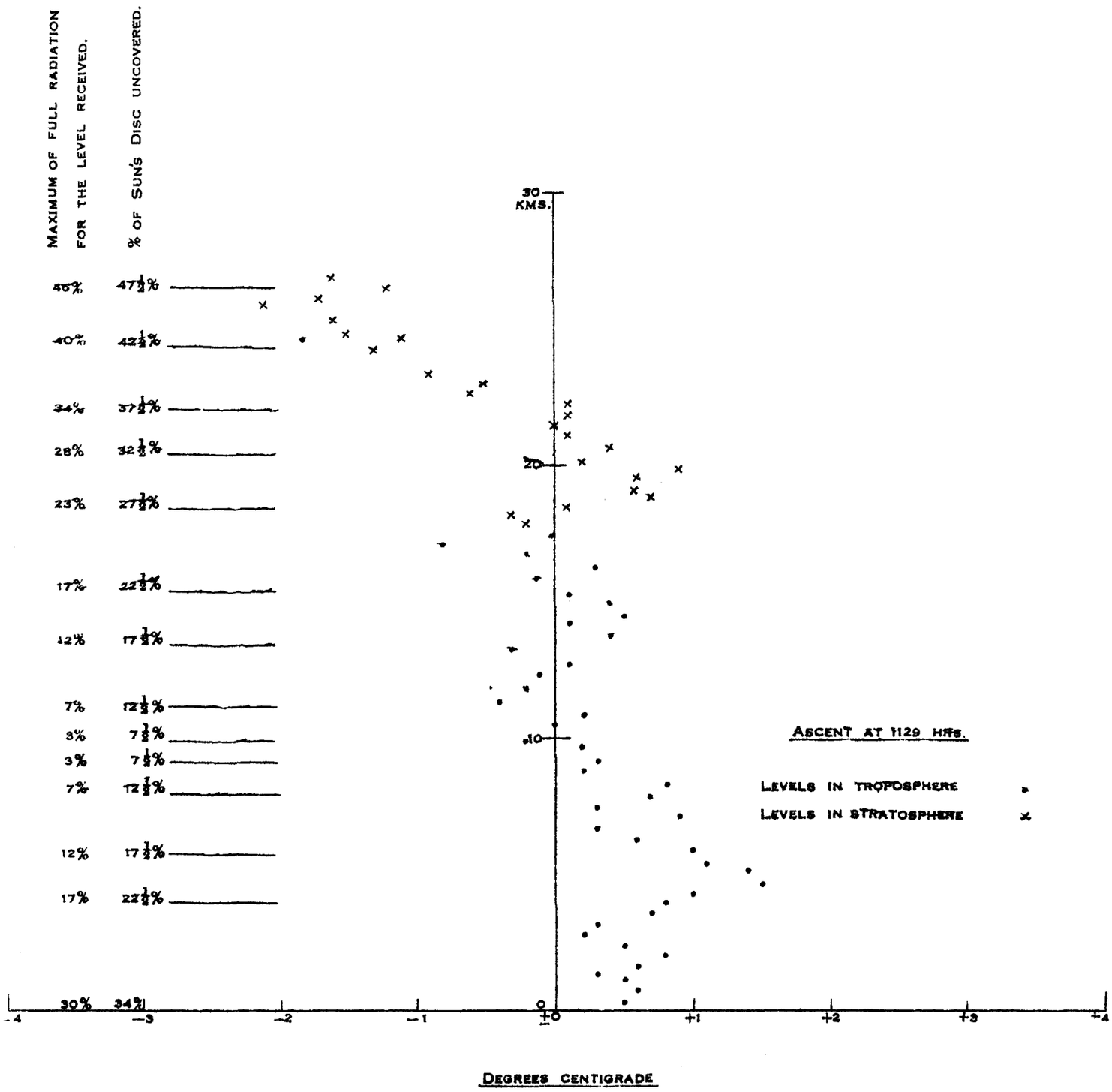


FIGURE 1 B DIFFERENCES (Δ) IN TEMPERATURE (°C)

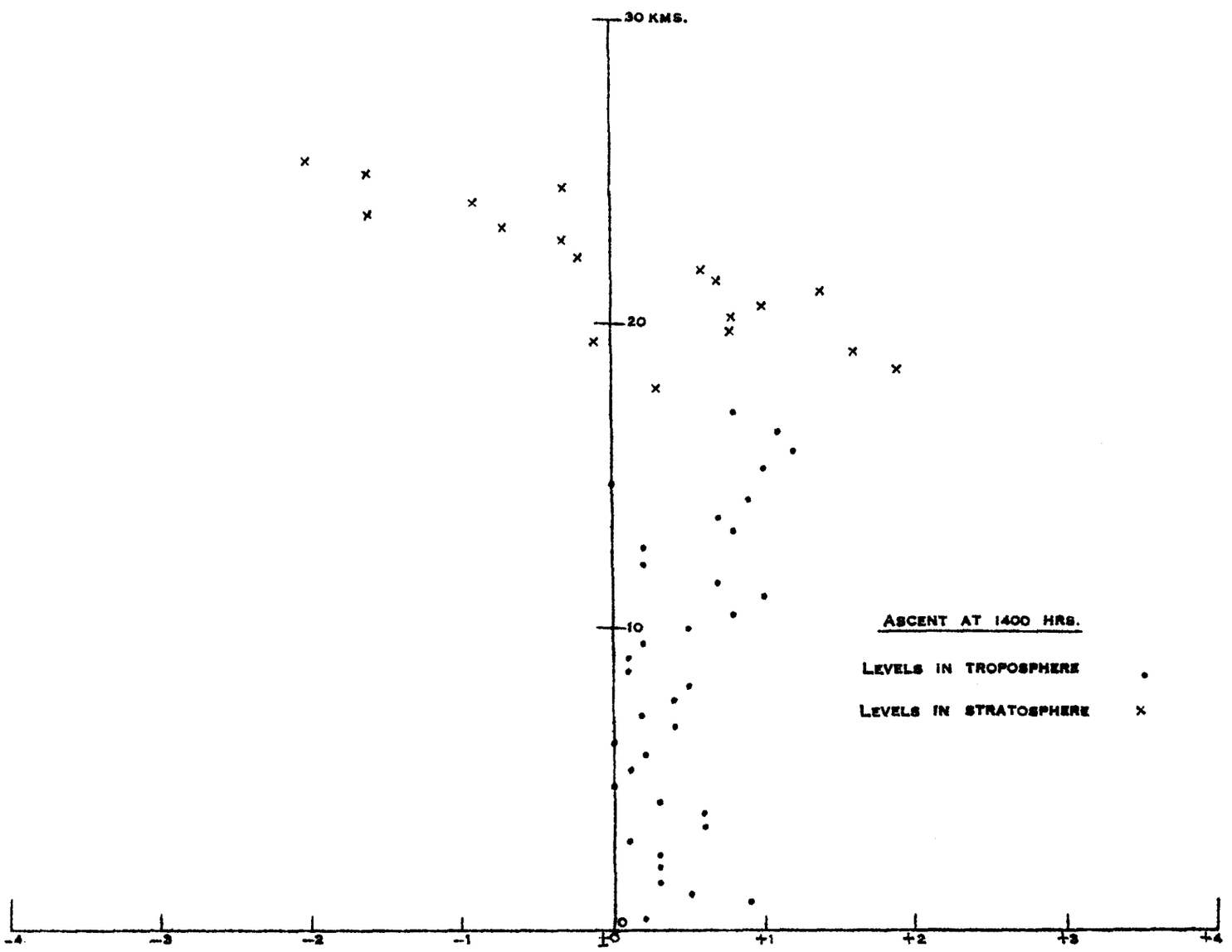


FIGURE IC DIFFERENCES (Δ) IN TEMPERATURE (°C) AGAINST HEIGHT

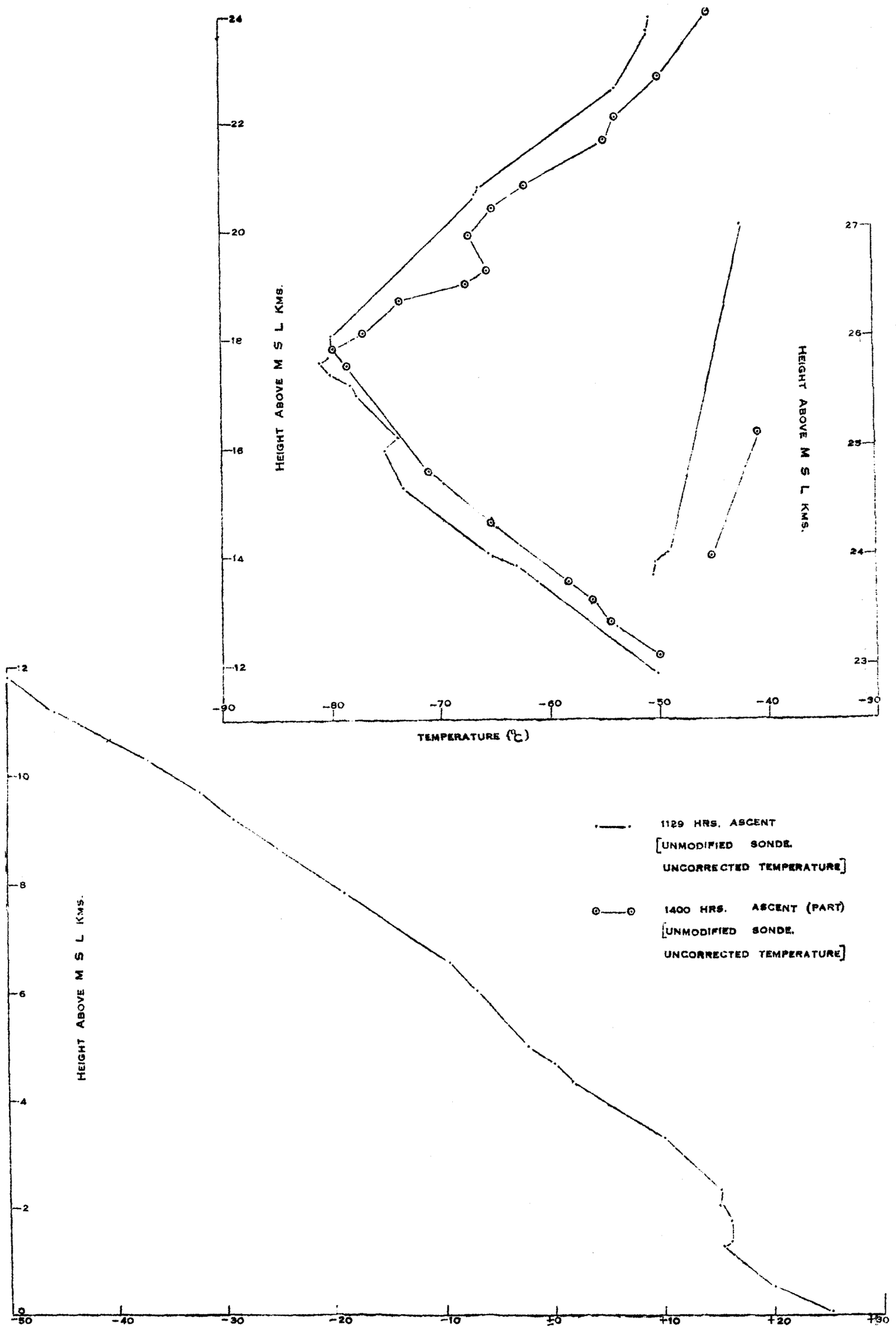
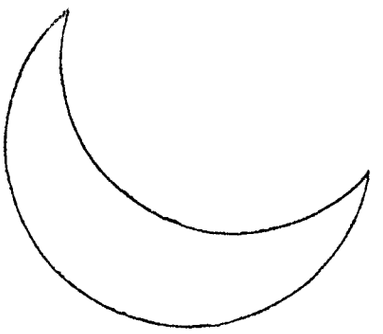

HEIGHT ABOVE M S L KMS.
TEMPERATURE (°C)
1129 HRS. ASCENT
[UNMODIFIED SONDE.
UNCORRECTED TEMPERATURE]
1400 HRS. ASCENT (PART)
[UNMODIFIED SONDE.
UNCORRECTED TEMPERATURE]

FIGURE 1 D



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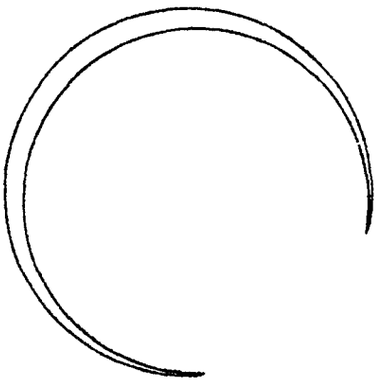

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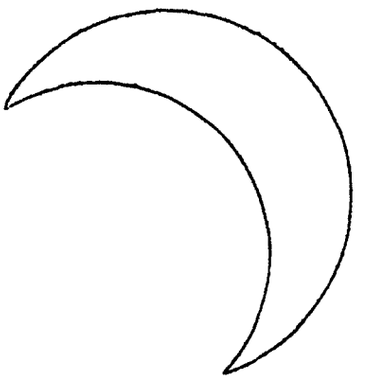

12:23 P.M.

TIME PROGRESSION OF THE ECLIPSE

FIGURE II (SHOWING UNCOVERED PORTION OF THE SUN'S DISC)