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# SEASONAL TRENDS OF TEMPERATURE, DENSITY, AND PRESSURE TO 67.6 KM OBTAINED WITH THE SEARCHLIGHT PROBING TECHNIQUE

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ABSTRACT

During the period 29 May to 23 October 1952, 90 sets of measurements were acquired using the searchlight probing technique. Treatment of the data yielded density, temperature, and pressure information to 67.6 km. These results are discussed relative to seasonal trends. An over-all average for the period is submitted for the three parameters.

The temperature profile obtained for pre-dawn, 22 October 1952, is compared with rocket, anomalous sound, and radiosonde temperature measurements, all carried out within a 14-hour period and a 300-mile radius. Good agreement is evident among the four methods.

## 1. INTRODUCTION

Light-scattering measurements from a searchlight beam were carried out in the vicinity of Albuquerque, New Mexico, during the period 29 May through 23 October 1952. The data acquired yield distributions of density, temperature, and pressure to an altitude of 67.6 km. The density information is obtained from

$$N = \frac{E_0}{C(1 + \cos^2 \beta)} \qquad (1)$$

where $N$ is the number density (cm$^{-3}$), $E_0$ is the instrumentation response (microvolts) at a known altitude, $\beta$ is the angle of light-scatter determined from the searchlight scene geometry, and $C$ is a constant evaluated from radiosonde data taken during the same night and in the same vicinity of the searchlight-scattering measurements. The derivation of equation (1) is based on Rayleigh scattering, the searchlight scene geometry, attenuation in the atmosphere, and the characteristics of the instrumentation. The method of derivation has been treated previously [see 1 of "References" at end of paper].

The density-temperature equation is based on the hydrostatic equation, the equation of state combined with an expression for the mean density of an atmospheric layer, so that

$$T_2 = T_1 \frac{N_1}{N_2} - \frac{mg}{k} \Delta h \frac{\left(\frac{N_1}{N_2} - 1\right)}{\ln\left(\frac{N_1}{N_2}\right)} \qquad (2)$$

where $T_1$ = temperature at the bottom of the layer (°K)
$T_2$ = temperature at the top of the layer (°K)
$N_1$ = number density at the bottom of the layer ($cm^{-3}$)
$N_2$ = number density at the top of the layer ($cm^{-3}$)
$m$ = mean molecular mass ($4.8 \times 10^{-23}$ gm)
$g$ = apparent gravity (cm $sec^{-2}$)
$h$ = layer thickness (cm)
$k$ = Boltzmann's constant ($1.372 \times 10^{-16}$ erg $deg^{-1}$)

With the density and temperature established for the altitudes probed by the searchlight, the corresponding pressures are readily determined.

The derivation of equation (2) is carried in a recent issue of this JOURNAL [2]. It was shown that the factor $N_1T_1$ is a constant of integration which can be determined from radiosonde pressure measurements, and that this factor must be known to a high degree of accuracy in order to develop the temperature profile to high altitudes. Since the radiosonde pressure is accurate within $\pm 4$ mb, various pressures chosen within these error limits lead to a family of profiles. The treatment of the problem indicated that a pressure value should be chosen which results in a profile characterized by a temperature gradient of 5°C/km in the atmospheric region 57.87 to 60.74 km.

The basis for using this lapse rate can be supported further with direct measurements from rocket soundings. According to Havens, Koll, and LaGow [3], the lapse rate between 60 to 70 km obtained from the average temperatures from ten rocket flights is 5°C/km. Also three Aerobee rockets, instrumented by Michigan University [4], yielded lapse rates as follows:

| Date | Layer | Lapse rate |
|---|---|---|
| | *km* | *°C/km* |
| 20 June 1950 | 57.5 to 68.0 | 5.0 |
| 25 Sep. 1951 | 56.0 to 60.0 | 4.5 |
| 22 Oct. 1952 | 55.0 to 68.0 | 4.8* |

The weighted average based on the 13 rockets yields 4.95°C/km as lapse rate covering the region 57.87 to 60.74 km, which compares very closely to the lapse rate for this region used in the searchlight calculations.

Ninety sets of measurements were obtained, representing 18 nights when the sky was clear and moonless (Table 1). During July and August, thunderstorms are particularly frequent in New Mexico, so that these months were almost unproductive. June, September, and October were most profitable. The averages for the three months are submitted in order that seasonal trends may be considered. Also included is an over-all representation of stratosphere conditions based on the average of the 90 sets of measurements.

## 2. DISCUSSION OF RESULTS

2.1 *Method of presentation*—The density distributions and temperature profiles are presented as monthly averages. The monthly density distribution was obtained

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by averaging the daily densities for each searchlight altitude (Table 2 and Fig. 2). The monthly temperature profile was obtained by calculation from the monthly density distribution rather than by averaging the temperatures at each searchlight altitude (Table 2 and Fig. 3). Monthly results are submitted for June, September, and October only, since the degree of activity for May, July, and August is insufficient for an average presentation.

The over-all density distribution for the period 29 May to 23 October 1953

TABLE 1—*Activity of 1952 season*

| Date | Sets of measurements acquired |
|---|---|
| *1952* | |
| May 29 | 1 |
| June 13 | 1 |
| 15 | 7 |
| 21 | 8 |
| 22 | 6 |
| July — | 0 |
| Aug. 3 | 3 |
| Sep. 17 | 6 |
| 18 | 5 |
| 24 | 6 |
| 25 | 6 |
| 26 | 6 |
| Oct. 10 | 6 |
| 11 | 4 |
| 16 | 3 |
| 18 | 5 |
| 22 (pre-dawn) | 6 |
| 22 (post-twilight) | 6 |
| 23 | 5 |
| 18 nights | 90 sets |

(Fig. 4) was obtained from a weighted average of the monthly distributions. As seen from Table 1, the May distribution was given a weight of 1; the June distribution a weight of 22; the August distribution a weight of 3; etc. The over-all temperature profile (Fig. 5) was obtained from the over-all density distribution. From these, the over-all pressure distribution (Fig. 4) can be readily calculated.

The results of this investigation can be discussed conveniently by considering three regions of the atmosphere, that is, 9.5 to 20 km, 20 to 45 km, and 45.0 to 67.6 km. These regions are established primarily because of their different characteristics. The presentation of day-by-day density distributions and temperature

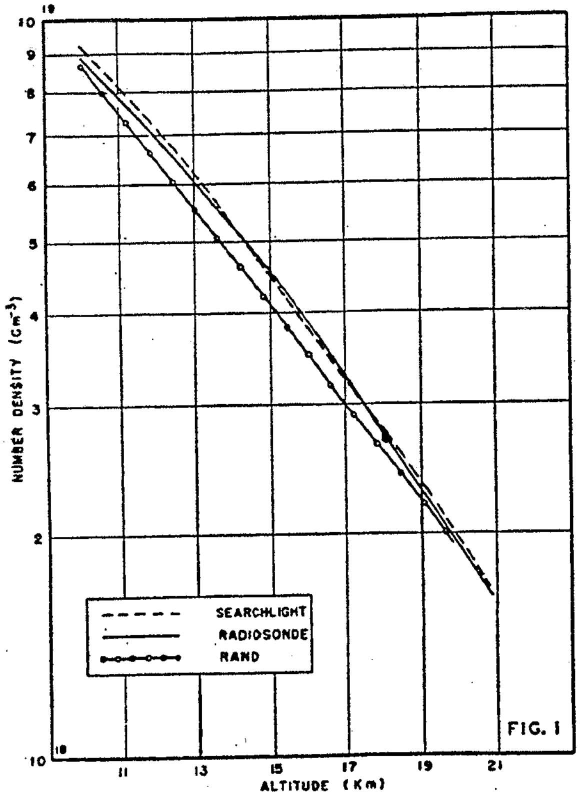


FIG. 1—Comparison of densities, searchlight, radiosonde and Rand, New Mexico, Oct. 1952

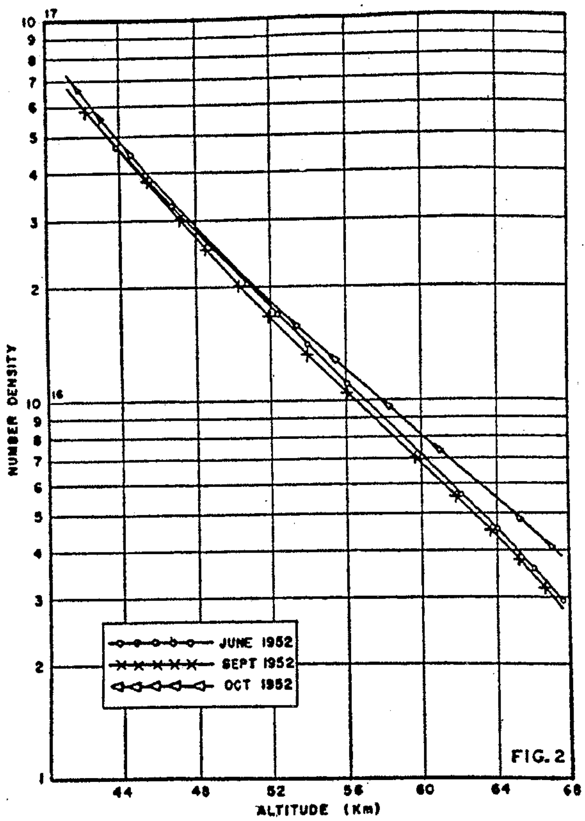


FIG. 2—Comparison of monthly density distributions, New Mexico

TABLE 2—*Monthly and over-all average of searchlight densities, temperature, and pressures*

| $h$ | June 1952 | | | September 1952 | | | October 1952 | | | 29 May to 23 October 1952 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | $N$ | $T$ | $P$ | $N$ | $T$ | $P$ | $N$ | $T$ | $P$ | $N$ | $T$ | $P$ |
| 9.50 | $9.28 \times 10^{18}$ | 241 | 306.8 | $9.61 \times 10^{18}$ | 232 | 305.9 | $9.82 \times 10^{18}$ | 229 | 308.5 | $9.60 \times 10^{18}$ | 233 | 306.9 |
| 10.82 | 8.10 | 228 | 253.4 | 8.20 | 223 | 250.9 | 8.38 | 219 | 251.8 | 8.24 | 223 | 252.1 |
| 12.12 | 6.96 | 217 | 207.2 | 6.93 | 216 | 205.4 | 7.09 | 211 | 205.2 | 6.97 | 215 | 205.6 |
| 13.42 | 5.83 | 210 | 168.0 | 5.79 | 210 | 166.8 | 5.82 | 208 | 166.1 | 5.82 | 209 | 166.9 |
| 14.74 | 4.83 | 204 | 135.2 | 4.75 | 206 | 134.3 | 4.68 | 208 | 133.6 | 4.77 | 205 | 134.2 |
| 16.10 | 3.94 | 198 | 107.0 | 3.83 | 203 | 106.7 | 3.77 | 206 | 106.6 | 3.83 | 203 | 106.7 |
| 17.53 | 3.07 | 199 | 83.82 | 3.01 | 203 | 83.83 | 3.00 | 204 | 83.97 | 3.01 | 204 | 84.25 |
| 19.06 | 2.34 | 201 | 64.53 | 2.31 | 205 | 64.97 | 2.31 | 206 | 65.29 | 2.31 | 205 | 64.97 |
| 20.70 | 1.74 | 206 | 49.18 | 1.74 | 207 | 49.42 | 1.72 | 211 | 49.79 | 1.73 | 209 | 49.60 |
| 22.53 | 1.26 | 210 | 36.30 | 1.26 | 213 | 36.82 | 1.25 | 217 | 37.22 | 1.27 | 212 | 36.94 |
| 24.60 | $8.76 \times 10^{17}$ | 218 | 26.20 | $8.90 \times 10^{17}$ | 217 | 26.50 | $8.97 \times 10^{17}$ | 219 | 26.95 | $8.93 \times 10^{17}$ | 217 | 26.59 |
| 25.98 | 6.92 | 223 | 21.17 | 7.07 | 220 | 21.34 | 7.06 | 225 | 21.79 | 7.08 | 221 | 21.47 |
| 27.51 | 5.40 | 226 | 16.74 | 5.50 | 223 | 16.83 | 5.52 | 229 | 17.34 | 5.48 | 226 | 16.99 |
| 29.83 | 3.72 | 232 | 11.84 | 3.78 | 229 | 11.88 | 3.81 | 237 | 12.39 | 3.78 | 232 | 12.03 |
| 31.85 | 2.73 | 236 | 8.840 | 2.74 | 235 | 8.834 | 2.77 | 244 | 9.273 | 2.75 | 238 | 8.98 |
| 34.16 | 1.90 | 245 | 6.387 | 1.93 | 240 | 6.355 | 1.96 | 252 | 6.777 | 1.93 | 246 | 6.51 |
| 37.87 | 1.09 | 259 | 3.873 | 1.10 | 252 | 3.803 | 1.15 | 263 | 4.150 | 1.11 | 259 | 3.94 |
| 41.29 | $6.70 \times 10^{16}$ | 272 | 2.500 | $6.72 \times 10^{16}$ | 263 | 2.425 | $7.14 \times 10^{16}$ | 274 | 2.684 | $6.76 \times 10^{16}$ | 275 | 2.550 |
| 45.51 | 3.80 | 287 | 1.496 | 3.75 | 278 | 1.430 | 3.95 | 301 | 1.631 | 3.84 | 293 | 1.544 |
| 50.84 | 2.00 | 284 | 0.779 | 1.90 | 289 | 0.753 | 2.07 | 312 | 0.886 | 2.00 | 299 | 0.820 |
| 55.28 | 1.20 | 278 | 0.458 | 1.14 | 285 | 0.446 | 1.28 | 313 | 0.550 | 1.23 | 293 | 0.494 |
| 57.87 | $8.97 \times 10^{15}$ | 270 | 0.332 | $8.57 \times 10^{15}$ | 278 | 0.327 | $9.94 \times 10^{15}$ | 303 | 0.413 | $9.35 \times 10^{15}$ | 285 | 0.366 |
| 60.74 | 6.56 | 256 | 0.230 | 6.33 | 264 | 0.229 | 7.53 | 289 | 0.299 | 6.95 | 270 | 0.257 |
| 63.97 | 4.55 | 238 | 0.149 | 4.42 | 247 | 0.150 | 5.53 | 266 | 0.202 | 4.89 | 254 | 0.170 |
| 67.60 | 2.89 | 220 | 0.087 | 2.86 | 229 | 0.090 | 3.86 | 235 | 0.124 | 3.20 | 236 | 0.104 |

$h$ = altitude (km)
$N$ = number density ($cm^{-3}$)
$T$ = temperature (°$K$)
$P$ = pressure (mb)

profiles must be omitted, since much space would be required.* However, reference to the day-by-day results will be made in the discussion that follows.

2.2 *The 9.5- to 20-km region*—An examination of the density distributions indicates little day-by-day variation throughout the season. October 1952 may be taken as typical for this atmospheric region, and demonstrates the close agreement between the searchlight and radiosonde densities (Fig. 1). The gradient is curved concave downward to about 17 km, where the gradient reaches a point of inflection. The searchlight densities are slightly higher than those of the radiosonde, the difference decreasing with higher altitudes. This is attributed to non-Rayleigh conditions which exist in this region. Since the searchlight densities are slightly

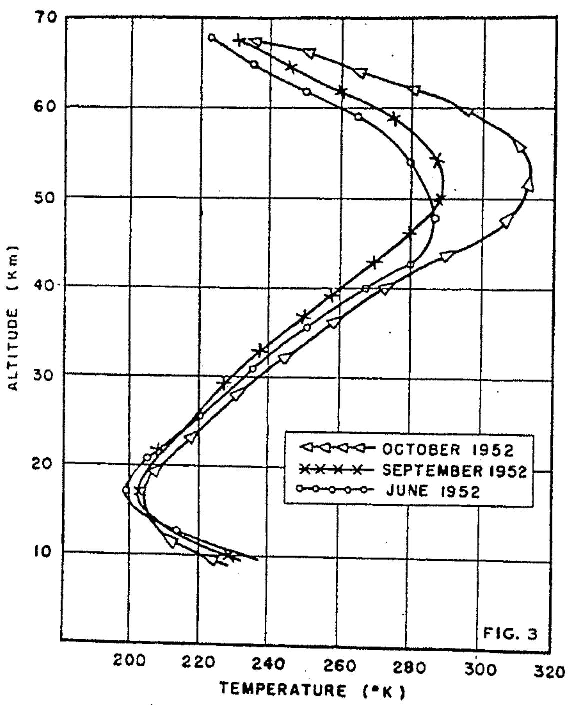


Fig. 3—Comparison of monthly profiles, New Mexico

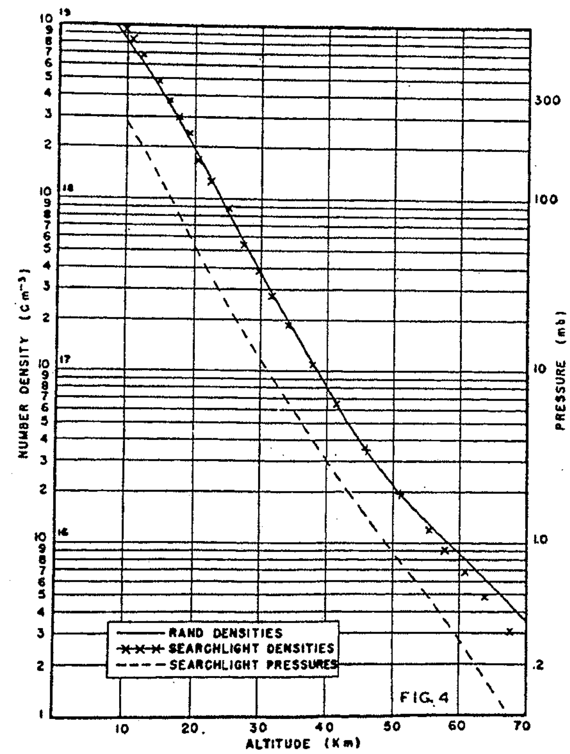


Fig. 4—Average density and pressure distributions, 29 May - 23 October 1952, New Mexico

higher than the radiosonde, the calculation results in searchlight temperatures being somewhat lower than those of the radiosonde. This difference is evident in the daily temperature profiles throughout the season.

The monthly profiles in the vicinity of the tropopause (Fig. 3) agree with each other to within 5°C, and this spread is not sufficiently large to assert a seasonal trend. The results show that the tropopause tends to persist at 17 km (Figs. 3 and 5), with a corresponding temperature of 204°K. Below the tropopause, the temperature spread of the monthly profiles is more significant, the spread being

*For a full presentation (including data, density curves, and temperature profiles for 18 individual nights) refer to Geophysical Research Paper No. 29, "Seasonal trends of temperature, density and pressure in the stratosphere obtained with the searchlight probing technique," scheduled for publication September 1954 by Geophysical Research Division, Air Force Cambridge Research Center, Cambridge, Massachusetts.

12°C at 10 km. The seasonal trend at this altitude is for progressively cooler temperatures from June through October.

2.3 *The 20- to 45-km region*—The searchlight measurements show the densities to be relatively dormant in this region. The daily searchlight densities are in close agreement with the Rand densities. Little benefit would be derived in graphically presenting the average monthly distributions, since the three curves very nearly coincide.

For the entire period of measurement, the daily profiles show a spread of about 30°C at 45 km and about 15°C at 35 km. However, for any two successive nights,

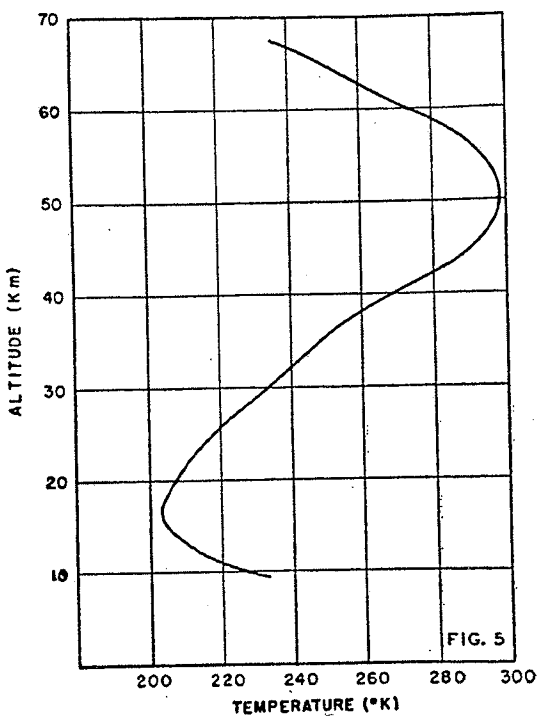


Fig. 5—Average profile, New Mexico, 29 May - 23 Oct. 1952

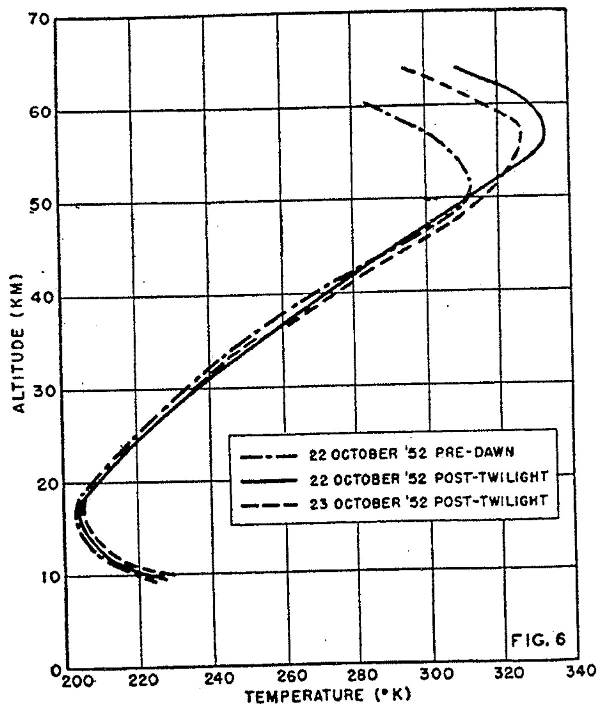


Fig. 6—Searchlight temperature profiles obtained within 48 hours

the temperatures are in satisfactory agreement (Fig. 6). The monthly temperature profiles (Fig. 3) show relatively little temperature variation for the period June through October 1952, so that the absence of a substantial seasonal trend in this region is indicated. The lapse rate is reasonably constant, approximating −3°C/km.

2.4 *The* 45.0- *to* 67.6-*km region*—In contrast, the searchlight measurements indicate this region to be in a state of flux. The daily distributions show significant change from one day to the next, and possibly within shorter periods. Of the 18 daily density distributions obtained, one runs higher than the Rand distribution, three approximate Rand, and 14 fall below that of Rand. Figure 2 compares the monthly density distributions in the region 41.3 to 67.6 km. As mentioned above, the distributions run almost concurrently to about 45 km. Beyond this altitude, they begin to spread. Thus, the tail of the density distribution (45.0 to 67.6 km) shows an undulation of about 16 per cent at 60 km. The over-all average of the densities (Fig. 4) swings lower than the Rand distribution beyond 50 km.

The monthly and over-all curves indicate a point of inflection in the vicinity of 62 km.

As with the densities, the temperatures in this region can change significantly from one day to the next, but the general shape of the temperature curve tends to persist (Fig. 6). The pre-dawn temperatures in this region are lower than the post-twilight temperatures, and, correspondingly, the temperature maximum at pre-dawn is lower than at post-twilight (Fig. 6).

The similarity between the June and September density distributions is reflected in their corresponding temperature profiles (Fig. 3). The difference in the slopes of the densities in the region 46 to 56 km results in the temperature maxima occurring at different altitudes. Above 50 km, a seasonal trend in temperature is manifested in the monthly profiles, the temperatures increasing from June through October. The height of the temperature maximum for June is 48 km; for September, 52 km; and for October, 53 km. An elevation of the temperature maximum, therefore, is indicated roughly at the rate of 1 km for each month for this period. The over-all profile for the season (Fig. 5) shows the temperature maximum to be 298°K at 51 km.

2.5 *Pressure distribution*—Since searchlight probing yields densities and temperatures, corresponding pressures can be determined readily. The average pressure distributions for June, September, and October are provided in Table 2. The average pressure for the period 29 May to 23 October 1952 is shown in Figure 4 and Table 2.

2.6 *Comparison of radiosonde, searchlight, anomalous sound, and rocket temperatures for 22 October* 1952—On 22 October, an Aerobee rocket, instrumented by Michigan University, determined temperatures to an altitude of 89 km*. Temperature measurements by anomalous sound propagation were also conducted on this day.* This permits comparison of four different methods, tabulated as follows:

| Method | Location | Date and time of measurement (MST) | Range of measurement |
|---|---|---|---|
| | | | *km* |
| Searchlight | Albuquerque, N.Mex. | 22 Oct. 1952<br>01:20 to 05:30 | 9.50 to 60.74 |
| Radiosonde | Albuquerque, N.Mex. | 21 Oct. 1952<br>20:00 | 0 to 22 |
| Rocket | White Sands, N.Mex. | 22 Oct. 1952<br>07:00 | 45 to 89 |
| Anomalous sound | White Sands, N.Mex. | 22 Oct. 1952<br>06:00 to 10:20 | 25 to 50 |

It is seen that all methods were conducted within a 14-hour period and within a distance of approximately 300 miles. The results of the four methods are compared in Figure 7. Between 30 and 50 km, anomalous sound measurements are higher by about 17° than searchlight temperatures. Rocket and radiosonde temperatures compare very favorably with those of the searchlight.

*Unpublished at this date.

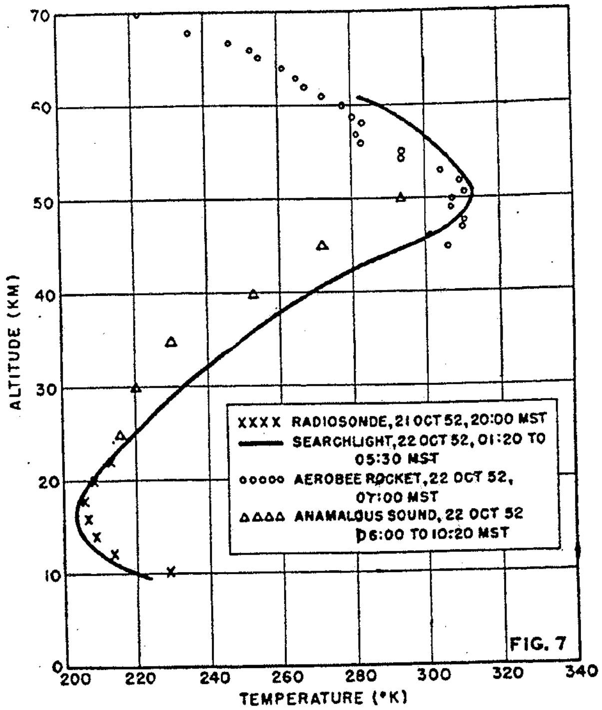


FIG. 7—Results of four methods of temperature measurement, New Mexico, 22 October 1952

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