SOUNDING-BALLOON OBSERVATIONS MADE AT OMAHA, NEBR., DURING THE INTERNATIONAL MONTHS JUNE 1935, NOVEMBER 1936, AND AUGUST 1937, AND WINDS OBSERVED DURING JULY 1938

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The sounding-balloon observations made at Omaha, Nebr., by the Weather Bureau during the international months June 1935, November 1936, and August 1937, were a part of the worldwide system of observations made in cooperation with the International Aerological Commission. They were similar in character and schedule to sounding-balloon observations made during previous international months. That is, one observation was made each day about an hour and a half before sunset and, in addition, on 3 days during June 1935, 3 during November 1936, and 6 days during August 1937 an observation was made daily just after sunrise.

All of the sounding-balloon data for various standard and the significant levels have been furnished to the International Aerological Commission along with airplane, pilot-balloon, and cloud observation data obtained during the 3- or 6-day international periods each month; the detailed data will be published by that Commission.

However, for the convenience of those who might be interested in knowing just what data are available, tables 1, 2, and 3 have been prepared and are presented here. A few statistical data and a discussion of them are also given.

Fergusson sounding-balloon meteorographs were used in all the flights and only one balloon was used in each ascension. The arrangement of equipment was in the order: balloon, parachute, 75 to 100 feet of cord, and meteorograph. The balloons used in June 1935 were the same type as those used in the previous several series of observations. Those used in November 1936 and August 1937 were a newer type recently developed and, as the heights attained indicate, were quite satisfactory. The balloons averaged about 350 g in weight, and about 40 inches in diameter, uninflated. The parachutes were made with pieces of silk or rayon about a yard square for all equipment weighing 300 to 400 g. Parachutes about 54 inches square were uesd with heavier equipment.

In June 1935 and November 1936 the balloons were filled to give them an average free lift, after all equipment was attached, of about 650 g. Such a filling gave the balloons a diameter of around 5 feet. During November 1936 pieces of additional experimental equipment were attached at various times so that the weight of equipment carried by the balloon was usually about 300 g (the weight of the apparatus using a Fergusson instrument only), 950 g, or 1,700 g. The average height at bursting of the balloons carrying 300 g of equipment was roughly 23 km, of the 9 balloons carrying 950 g about 21 km, and of the 4 carrying 1,700 g also about 21 km. Three of the balloons carrying 950 g of apparatus reached heights of 26.5, 26.2, and 25.7 km. The average diameter of the balloons at the average bursting altitude was computed to be about 14 feet. Many of the balloons reached 15 feet in diameter and some 17 or so feet.

In August 1937 15 meteorographs of the Jaumotte type (manufactured in the United States) were also used. One of these instruments in each case was attached to the same balloon with a Fergusson meteorograph; the object, of course, being to compare the performance of the two types of meteorograph. Twelve of the Jaumotte type instruments were found and returned; six of these and approximately the top half of a seventh carried computable records. The agreement between the two records in each case and a comparison with the two-theodolite observations indicated that only one of the seven Jaumotte type instruments performed satisfactorily. This is in agreement with the performance shown by these instruments in other observations made during the summer of 1937. These two sets of observations are the first in which the Weather Bureau has had an opportunity to observe the performance of this type of instrument under actual working conditions. The excessive number of lost records due to obliteration can, no doubt, be reduced in the future by the method of smoking the record plate and by the use of a baffle plate in front of the record plate. This instrument is much less costly to manufacture than the Fergusson instrument and, while it has disadvantages, if it can be made satisfactory for use it will result in a great saving where a large number of observations, with a large loss of instruments, is required. Forty-nine of these meteorographs were released during the international month July 1938, each attached to the same balloon with a Fergusson meteorograph. Twelve of the observations were made with the view of studying the effect of insolation on the two instruments. Some very valuable data should be obtained when the records of those flights have been computed.

A higher rate of ascent was used in the August series than had been used previously. During that month the balloons were given a free-lift, after attaching equipment, of about 1,000 g. The average altitude at bursting during the August series (of those balloons which did not burst prematurely) was 23.5 km as compared to 22.9 km for those balloons carrying only one instrument during the November series and having a free-lift of about 650 g. It is generally believed that the greatest height would be reached by a balloon carrying a given weight when it has about the smallest free-lift which will cause it to rise. This would be expected from the fact that the maximum height reached is a direct function of the maximum possible size of the balloon; this maximum will be reached at a higher altitude the lower the free-lift at bursting. It is also known that at the low temperatures in the stratosphere the rate of flow of the rubber in the balloons is considerably decreased. Hence, a slow rate of ascent should allow the balloon to expand more before bursting than would be possible with a rapid rate of ascent. Another temperature factor which would be expected to operate in favor of a low rate of ascent is the insolation effect on a balloon during daylight flights. A nearly floating balloon would be ventilated very little so that its temperature might be expected to be raised by insolation to a value considerably higher than that of the surrounding air. A rapidly-rising balloon would be cooled on the outside by ventilation and on the inside by the nearly adiabatically expanding hydrogen, the temperature of which would tend to be considerably lower than that of the surrounding air in the stratosphere.

On the other hand, there are other factors which favor a rapid rate of ascent for the best altitude performance. Ozone, for example, has a pronounced deleterious effect on rubber. Hence, if it is present in important quantities in the upper atmosphere a balloon would be expected to rise farther through a layer containing ozone if it rose rapidly. Another factor is that of the effect of time upon a highly expanded balloon. It may be that a balloon will expand to a given diameter if the expansion is accomplished in a given time, whereas if the time is increased (rate of expansion decreased) the balloon will burst at a smaller diameter. This factor would operate in a direction opposite to that of the effect of temperature on the rate of flow of the rubber and both are believed to be important.

Greater altitudes would be expected to be reached when the rate of ascent is such that the most favorable balance

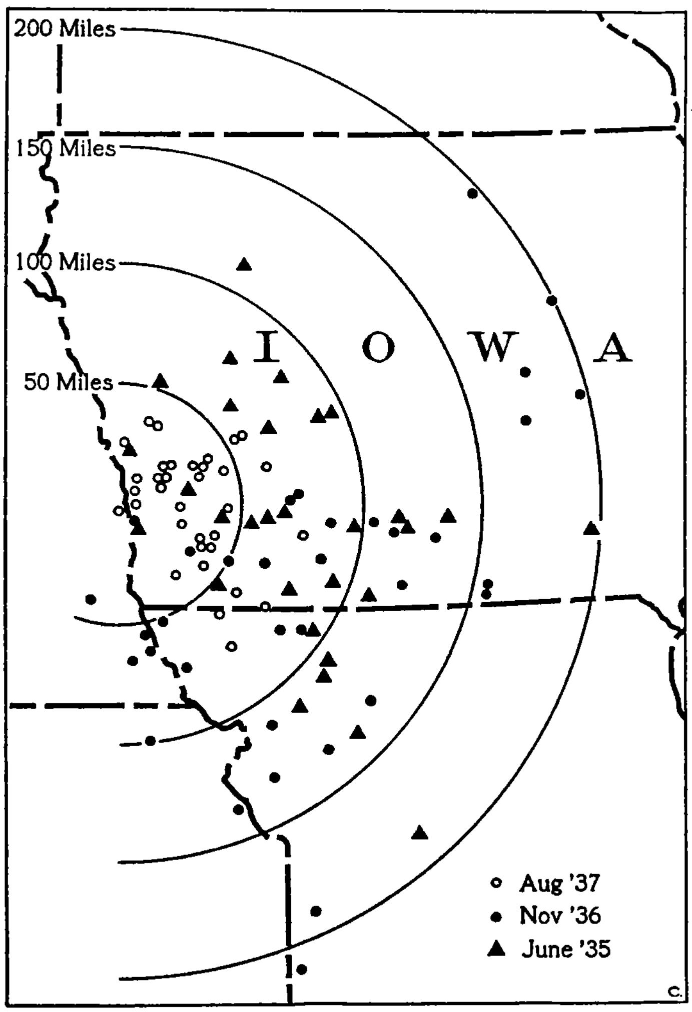

FIGURE 1.—Landing places of instruments released at Omaha, Nebr., in June 1935 (triangles), November 1936 (solid circles), and August 1937 (open circles).

between the various factors is struck. Experience has actually shown that the best altitude performance is obtained by using a fairly rapid rate of ascent—certainly not a very slow rate. Experience has also shown that the average heights reached on daytime flights are considerably greater than those reached at night. These two facts seem to indicate that the heating effect of insolation is important but that it is not the only important factor involved.

Figure 1 shows the landing places of the instruments released during the June, November, and August series of observations. The distances of the landing places from Omaha indicate in a general way the average wind velocities during each of the three months. It will be noted that 9 of the 35 recovered instruments of the November series were found more than 150 miles from Omaha. The only one of these 9 which could be followed to a fair altitude with theodolites was that released on the 26th, which was followed to 10 km. Attention is called to the strong winds observed on that date. (See table 5.) The instrument was found 192 miles from Omaha. The balloon released on the 6th was followed to 6 km at which altitude the wind velocity was 45 m. p. s. This instrument was found 168 miles from Omaha. Such instances are indicative of the strong winds which would undoubtedly be frequently observed if the observations could be made in all kinds of weather to high altitudes.

One very favorable result of the use of a comparatively high rate of ascent during the August series was that most of the balloons could be followed to the bursting point with two-theodolites. Twenty-four balloons were followed with two theodolites to heights of 20 km or higher. Nineteen observations of wind direction and velocity were made to 23 km, 13 to 24 km, 4 to 25 km, and 2 to 26 km. During July 1938 a still greater ascensional rate was used as well as larger balloons (700 g balloons) and observations of wind extended to considerably higher altitudes. During the latter month 15 observations of wind were made at 26 km and 4 at 29 km. The highest altitude to which a wind observation extended was 29,540 m., m. s. l. The balloon released on July 13, 1938, at 6:24 p. m. was observed with two theodolites to burst at that altitude. The wind data obtained during these series of observations constitute a large percentage of all wind data available for this country for heights above 20 km.

It is interesting to note at this point in connection with the observation of balloons at high altitudes that nearly all of the balloons followed with theodolites during the August and July series could be plainly seen with the naked eye at the bursting point. Some of the balloons became invisible to the unaided eye during part of the ascent on account of distance and low elevation angle but became visible again at high levels after a decrease in the distance out (due to being carried back in easterly winds) and an increase in the elevation angle. It was found that the balloons could nearly always be seen with the unaided eye when the elevation angle was about 25° or higher. After sunset at the ground the balloons rapidly grow brighter until they disappear in darkness 20 to 30 minutes later. A balloon cut off by darkness fades out quite rapidly, being completely obscured a minute or so after it begins to grow dim.

Tables 4, 5, 6, and 7 show the wind directions and velocities observed at the surface and each standard kilometric level during the June, November, August, and July series, respectively. The June and November series were not summarized on account of the small number of observations. The August and July observations, however, were summarized and the results are shown in figure 2 where the average wind velocities and directions have each been plotted against height. The average velocities were computed by the well-known "difference" method. The average directions were computed as resultants, giving each observed direction a weight of one, i. e., disregarding velocity.

It will be noted that the maximum velocity occurred at an altitude about 2 km lower than the mean observed height of the tropopause during August 1937. The mean height of the tropopause during July 1938 has not yet been computed but will probably be about 15 km, or somewhat lower than in August 1937.

This occurrence of the maximum mean velocity at an altitude somewhat below the mean height of the tropopause is in agreement with the results of previous observations. The steady increase in velocity with altitude of the easterly winds above 21 km is worthy of note since it is a real phenomenon. That is, it is not caused by the frequent extension of westerly winds to altitudes in this range with hte resultant low velocities in the region of the shift from westerly to easterly and the consequent reduction of the mean velocities at the first few standard heights above 21 km.

The prevailing easterly wind directions observed in the region of 20 km and above during the August and July series are especially worthy of note. Easterly winds at these altitudes and latitudes have been occasionally observed in the past but these are the first series of observations in which sufficient data have been gathered in this country to fully substantiate the theory of their prevalence. The two observations made during June 1935 at 21, 22, and 23 km likewise show easterly winds at these altitudes. On the other hand, during November 1936 five observations were made at 21 and 22 km, four at 23 km, and one at 24 km. Of all these observations none indicated easterly winds at 21 km, only one (NNE) at 22 km and one (ESE) at 23 km. The one observation at 24 km showed a NW wind. It would be interesting to know whether this reversal of wind direction, and of pressure gradient, is characteristic of the season or was true only during November 1936. It seems likely that the effect is seasonal in that easterly winds, if they occur at all, come in at higher altitudes in winter than in summer.

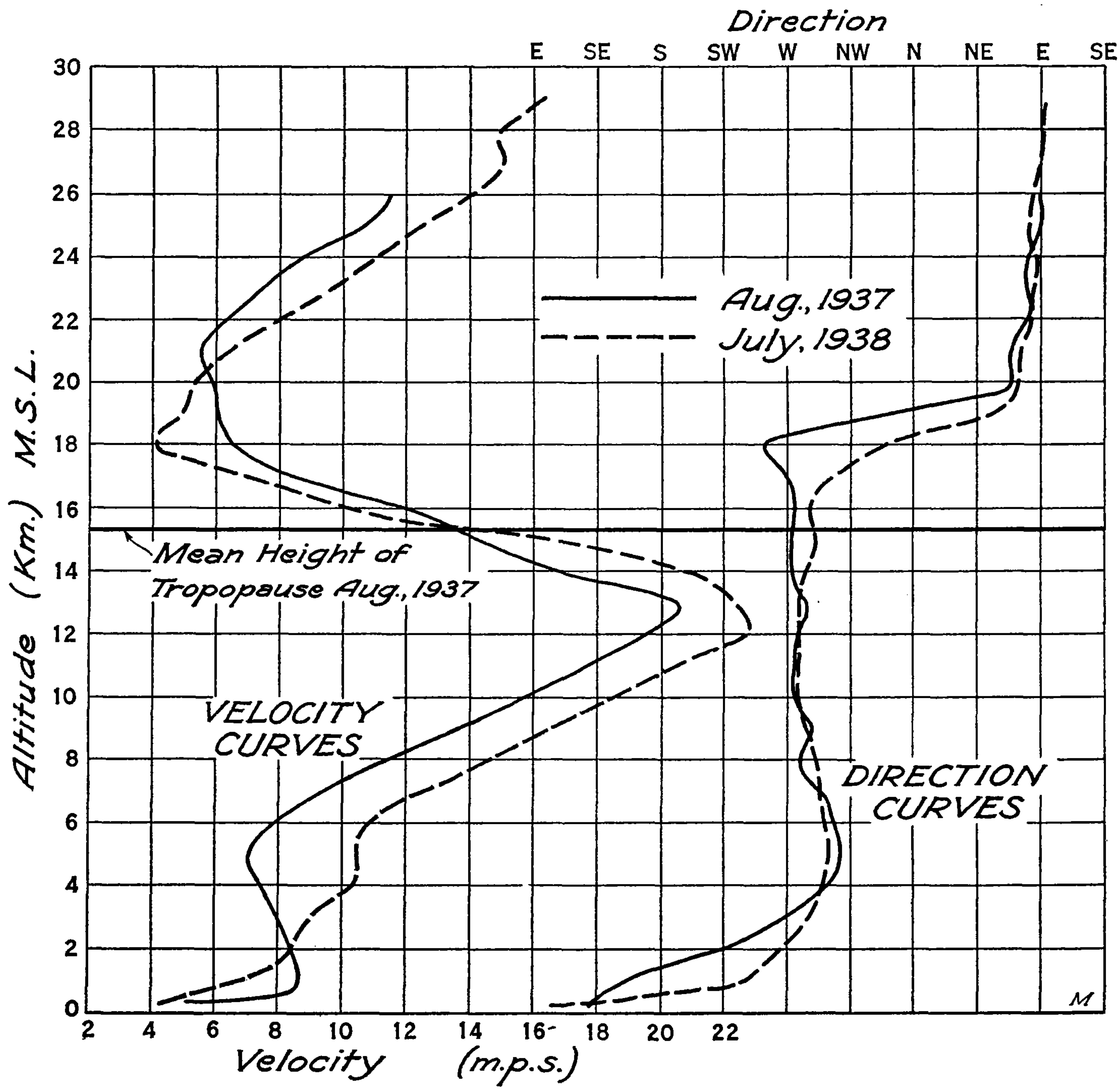

FIGURE 2.—Mean wind velocity (v) and direction (d) from sounding-balloon observations at Omaha, Nebr. (solid lines, August 1937, dashed lines, July 1938).

Figure 3 shows the mean temperatures for each of the three (June, November, and August) series plotted against height. November was the coldest of the three months from the surface up to 13 km and above 19 km. From 14 km to 19 km inclusive, however, August 1937 was the coldest of the 3 months. June 1935 was the warmest of the 3 months from 9 km to 20 km while August was the warmest from the surface to 8 km and above 20 km. It is very interesting to note the apparent seasonal trend in the mean temperatures at levels above 20 km, at which levels the temperatures, as at the surface and up to 8 km, were lowest in November and highest in August.

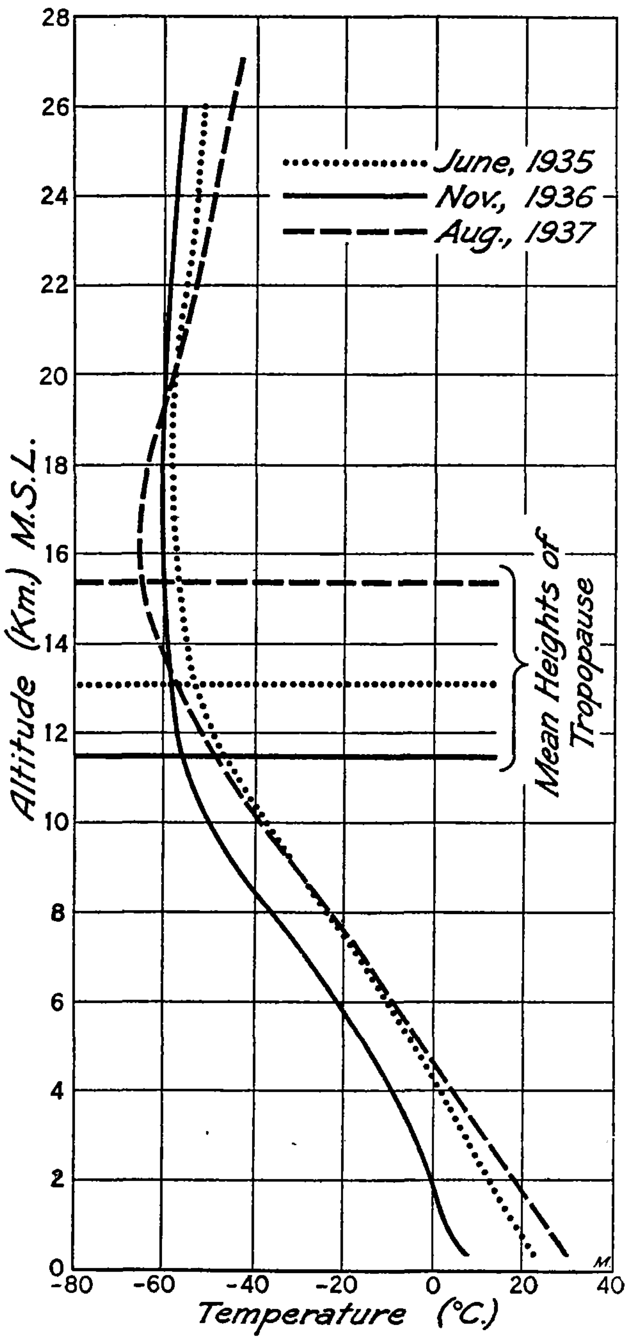

FIGURE 3.—Mean temperature from sounding-balloon observations at Omaha, Nebr.

The large inversion indicated by the August means at high levels is likewise worthy of note. This inversion amounted to 20.7° between the −65.7° C. mean at 16 km and the −45.0° C. mean at 26 km. The November inversion amounted to 5.3° between 17 and 26 km and the June inversion to 7.3° between 18 and 26 km. It is generally assumed that there is considerable error in the temperatures recorded at high levels on daytime flights due to the effect of insolation on the instrument. However, in this set of observations the same type of instrument was used throughout and the flights were all begun when the sun was about the same height in the sky. Hence, it would be expected that nearly the same insolation effect would be present in all three sets of means. Then, it would follow that all the higher level means indicate mean air temperatures which are higher than the true values but by about the same amounts, level for level. The insolation effect probably increases with altitude so that the shape of each of the three curves in figure 3 would be altered if the mean temperatures were corrected for insolation effect but their positions relative to each other would remain the same. Such a correction would reduce the magnitude of each of the inversions cited above and possibly to such an extent that the November inversion might be reduced to an isothermal or positive lapse rate.

It is believed, however, that a comparatively large inversion would remain in the August means. The magnitude and possibly even the existence of the inversion at the given time, a short time before sunset, probably has an annual variation. Inspection of the July 1938 records indicates that the inversion during that month was at least as large as during August 1937 and that it underwent a diurnal variation. However, the latter records have not yet been computed and it is not possible at present to present conclusive evidence.

TABLE 1

Date June 1935	Time of release 90th mer.	Maximum altitude of record M. S. L.
		m
1	7:29 p.	22,030
2	7:08 p.	19,580
3	6:56 p.	22,340
4	7:05 p.	24,980
5	7:01 p.	8,340
6	7:04 p.	(1)
7	7:01 p.	21,030
8	6:56 p.	21,630
9	6:46 p.	26,100
10	7:01 p.	23,870
11	4:56 a.	[3] 9,420
11	6:57 p.	26,180
12	4:43 a.	[3] 8,290
12	6:56 p.	22,890
13	5:04 a.	(4)
13	6:50 p.	23,240
14	6:42 p.	22,900
15	6:44 p.	23,760
16	6:52 p.	(4)
17	6:52 p.	17,470
18	7:02 p.	(1)
19	6:40 p.	21,550
20	6:58 p.	19,940
21	6:39 p.	26,970
22	6:29 p.	17,940
23	6:36 p.	(2)
24	6:48 p.	19,800
25	6:31 p.	25,740
26	6:31 p.	26,330
27	6:47 p.	(1)
28	6:18 p.	23,280
29	6:41 p.	24,210
30	6:49 p.	25,970

TABLE 2

Date Nov. 1936	Time of release 90th mer.	Maximum altitude of record M. S. L.
		m
1	4:32 p.	(3)
2	4:21 p.	(3)
3	4:24 p.	21,900
4	4:12 p.	18,820
5	4:25 p.	[2] 10,440
6	4:25 p.	25,440
7	4:27 p.	[3] 5,920
8	4:00 p.	22,600
9	4:13 p.	22,430
10	4:20 p.	26,560
11	4:06 p.	23,390
12	3:55 p.	24,860
13	3:57 p.	[2] 7,070
14	4:13 p.	24,520
15	4:08 p.	21,640
16	4:16 p.	19,780
17	7:15 a.	22,960
17	1:16 p.	5,610
17	4:36 p.	15,040
18	7:22 a.	26,190
18	4:41 p.	21,160
19	7:30 a.	24,990
19	4:28 p.	26,530
20	4:37 p.	2,270
21	4:21 p.	(1)
22	4:13 p.	(3)
23	4:10 p.	21,180
24	2:45 p.	14,470
25	11:43 a.	24,350
25	1:35 p.	18,420
25	4:12 p.	14,450
26	3:54 p.	18,180
27	2:16 p.	22,550
27	4:07 p.	25,700
28	3:49 p.	(1)
29	4:00 p.	19,950
30	3:45 p.	19,820

TABLE 3

Date Aug. 1937	Time of release 90th mer.	Maximum altitude of record M. S. L.
		m
1	6:44 p.	[3] 6,190
2	6:16 p.	[3] 12,770
3	6:20 p.	22,400
4	6:10 p.	22,790
5	6:05 p.	[2] 14,010
6	6:00 p.	23,080
7	5:39 p.	6,200
8	6:03 p.	22,130
9	6:09 p.	19,570
10	6:00 p.	25,030
11	6:02 p.	(4)
12	6:05 p.	24,940
13	5:57 p.	(1)
14	5:50 p.	23,060
15	6:02 p.	24,490
16	5:40 a.	25,510
16	5:57 p.	22,470
17	5:43 a.	9,750
17	6:04 p.	20,040
18	5:45 a.	25,440
18	6:00 p.	23,530
19	5:43 a.	28,660
19	5:56 p.	21,790
20	5:46 a.	22,980
20	6:02 p.	22,740
21	5:51 a.	25,690
21	5:55 p.	22,330
22	5:56 p.	(1)
23	6:03 p.	(1)
24	5:59 p.	24,210
25	5:59 p.	23,870
26	6:02 p.	2,650
26	6:29 p.	20,820
27	6:00 p.	21,370
28	6:03 p.	[3] 11,000
29	5:50 p.	23,900
30	5:50 p.	[5] 2,920
31	5:51 p.	23,690

[1] Instrument not returned.
[2] Pressure pen failure.
[3] Clock stopped.
[4] Record obliterated.
[5] Pens tangled.

TABLE 4.—*Wind directions and velocities from sounding-balloon observations at Omaha, Nebr., during June 1935*

Date	ALTITUDE (KM, M. S. L.)											
	Surface	1	2	3	4	5	6	7	8	9	10	11
7	W 2	SW 5	WSW 6	WNW 7	WNW 14	WNW 23	WNW 30	W 32	W 39	W 39	W 39	W 42
8	S 5	S 7	WNW 7	NW 12	WNW 20	NW 18	NW 20	NW 23	NW 24	NW 25	NW 29	NW 30
12	SE 6	S 7	SW 5	WSW 6	W 9	NW 5	W 8	WSW 9	WNW 8	W 7	W 14	W 11
14	SE 6	ESE 6	SE 3	S 2	WSW 5	WSW 5	SSW 3	WSW 5	SW 9	SSW 13	SSW 13	SSW 15
15	S 6	S 12	SSW 15	S 11	SSW 14	SW 4	SSE 5	SSW 5	SSW 7	W 10	SW 12	WSW 15
20	N 3	N 4	NNW 5	NW 8	WNW 8	WNW 20	W 22	WNW 24	W 26	W 27	W 25	W 42
22	N 4	NNW 5	WNW 7	NNW 13	NNW 18	NW 21	NNW 24	NNW 24	NNW 22	NW 12	NW 15	-----
25	NE 2	NE 5	NE 3	W 7	W 17	WSW 19	WSW 21	WSW 21	WSW 24	SW 19	WSW 25	WSW 26
26	SW 2	WSW 6	WNW 12	WNW 14	W 11	WNW 19	WNW 26	WNW 30	W 30	W 36	W 34	W 26
28	NE 2	NE 3	NW 6	WNW 7	NNW 10	NW 8	NNW 6	NNW 5	N 6	W 7	WSW 10	W 14

Date	ALTITUDE (KM, M. S. L.)											
	Surface	12	13	14	15	16	17	18	19	20	21	22	23
7	W 2	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
8	S 5	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
12	SE 6	W 19	W 20	W 28	WNW 30	W 29	WNW 25	NW 27	-----	-----	-----	-----	-----
14	SE 6	S 17	S 17	S 18	S 19	SSW 13	S 21	SSW 16	-----	-----	-----	-----	-----
15	S 6	WSW 21	WSW 24	W 22	W 15	WSW 17	WSW 19	WSW 18	WSW 6	WSW 6	-----	-----	-----
20	N 3	WNW 33	WNW 26	W 25	W 17	W 17	-----	-----	-----	-----	-----	-----	-----
22	N 4	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
25	NE 2	SW 39	SSW 46	SW 42	SW 44	WSW 31	WSW 25	WSW 12	W 5	W 12	S 4	ESE 12	SE 4
26	SW 2	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
28	NE 2	WSW 23	WSW 23	W 21	W 21	WSW 12	NE 4	NNW 6	ENE 2	NE 4	E 8	NE 7	E 7

TABLE 5.—*Wind directions and velocities from sounding-balloon observations at Omaha, Nebr., during November 1936*

Date	ALTITUDE (KM, M. S. L.)												
	Surface	1	2	3	4	5	6	7	8	9	10	11	12
3	NW 6	NW 7	NW 9	NW 11	NNW 8	N 9	N 15	NNE 29	NNE 31	NNE 19	W 10	WSW 21	SW 27
8	SW 4	WSW 12	WNW 15	NW 16	NW 17	NW 14	WNW 19	WNW 15	WNW 22	WNW 19	WNW 19	WNW 26	W 33
10	SSW 7	SW 16	WSW 13	W 14	W 11	W 11	WNW 11	WNW 14	WNW 11	NW 12	WNW 14	WNW 17	WNW 17
12	NNW 4	N 7	NW 9	NW 10	NNW 7	NE 11	NE 14	NE 15	NNE 18	NNE 20	N 12	NNW 11	NW 11
15	N 3	NNW 4	NW 7	NW 14	NNW 20	NNW 26	NNW 26	NNW 34	NNW 34	NNW 42	NNW 44	NNW 37	NNW 41
17	NW 1	NW 12	WNW 11	WNW 13	WNW 9	NW 11	WNW 14	W 18	W 17	WNW 15	W 12	W 13	WNW 11
18	N 4	NE 8	NNE 9	N 7	NNE 2	NNW 4	WNW 5	WNW 3	SSW 5	SW 4	W 8	W 13	W 16
19	SW 7	WSW 15	W 18	WNW 17	WNW 14	WNW 12	WNW 12	WNW 11	NW 8	NNW 15	N 9	NNW 14	-----
26	NNW 6	NW 10	NW 14	NNW 21	NNW 28	NNW 53	NNW 60	NNW 64	NNW 67	NNW 52	NNW 66	-----	-----
27	SE 11	W 17	WNW 21	WNW 22	NW 23	NW 21	NW 20	NW 16	NW 21	NW 22	NW 27	NW 25	NW 31
29	SSE 4	SSE 4	WSW 3	WNW 8	W 15	W 15	WNW 16	WNW 15	WNW 19	WNW 18	WNW 20	WNW 15	WNW 21
30	SE 6	SSE 8	SW 8	WSW 9	W 13	W 17	W 19	W 19	W 21	W 22	W 27	W 23	W 28

Date	ALTITUDE (KM, M. S. L.)												
	Surface	13	14	15	16	17	18	19	20	21	22	23	24
3	NW 6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
8	SW 4	WNW 35	W 38	W 34	W 28	W 25	W 20	W 22	W 16	-----	-----	-----	-----
10	SSW 7	W 20	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
12	NNW 4	WNW 12	NW 11	WNW 13	WNW 14	NW 11	NW 10	NNW 7	NW 6	NW 10	WNW 5	WNW 8	-----
15	N 3	NNW 54	NNW 41	NNW 42	NNW 30	NW 33	-----	-----	-----	-----	-----	-----	-----
17	NW 1	W 11	WNW 13	NW 8	WNW 7	NW 14	N 6	WNW 3	NNE 3	NW 2	NNE 7	ESE 2	-----
18	N 4	W 17	WNW 12	WNW 10	NW 13	NW 9	NW 10	NW 7	N 6	WNW 9	N 6	NNW 6	NW 4
19	SW 7	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
26	NNW 6	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
27	SE 11	NW 24	NW 23	WNW 23	NW 22	NNW 15	NW 18	NW 20	NW 29	NW 25	NW 22	WNW 25	-----
29	SSE 4	WNW 24	WNW 27	-----	-----	-----	-----	-----	-----	-----	-----	-----	-----
30	SE 6	W 28	W 20	W 27	W 25	W 26	W 21	W 10	W 14	W 18	WNW 17	-----	-----

TABLE 6.—*Wind directions and velocities from sounding-balloon observations at Omaha, Nebr., during August 1937*

Date	ALTITUDE (KM, M. S. L.)													
	Surface	1	2	3	4	5	6	7	8	9	10	11	12	13
1	SE 9	SSE 15	SSW 24	SW 13	SW 5	W 10	W 11	WSW 7	WSW 7	NW 5	W 7	W 10	WNW 15	NW 16
2	SE 4	SSE 11	SW 13	WSW 14	W 14	WNW 9	W 6	W 10	W 11	WSW 12	WSW 13	WSW 14	WSW 22	
3	N 4	NNE 6	N 4	NW 5	NW 8	WNW 11	W 17	W 21	WSW 31	WSW 31	WSW 31	WSW 30	WSW 31	WSW 28
4	SE 3	S 2	WNW 5	NW 13	NNW 16	NNW 13	NNW 17	NNW 20	NNW 17	NNW 14	NNW 18	NW 22	NW 32	NW 45
5	SE 7	SSE 12	SW 9	WNW 6	NNW 6	NNW 15	NNW 14	NNW 12	NW 13	NW 25	NW 34			
6	SE 5	SE 9	SSW 11	SW 7	WNW 6	NW 4	NNW 8	NW 12	NW 16	NW 20	NW 21	NW 29	NW 24	WNW 25
8	NW 2	N 5	NNE 6	N 16	NNW 16	NNW 13	NNW 8	NW 8	NW 14	WNW 14	WNW 22	WNW 26	WNW 26	WNW 20
10	SE 5	SSW 4	SW 4	WNW 2	NW 7	NW 10	NW 6	WNW 6	W 11	W 20	W 29	W 35	W 35	W 33
11	NW 4	N 7	NNW 12	NW 16	WNW 18	WNW 17	NW 21	NW 21	NW 22	NW 22	NW 21	NNW 23	NNW 24	NNW 29
12	S 6	SW 8	WSW 12	NW 14	NNW 16	NW 17	NW 19	NW 19	WNW 21	WNW 19	WNW 23	WNW 26	W 29	WNW 34
13	S 4	SSW 9	SW 6	W 1	WNW 5	NW 7	NNW 14	NNW 10	NNW 8	NW 10	NW 13	NW 14	NNW 16	NW 18
14	SE 9	SSE 13	SSW 12	WSW 7	WSW 6	WNW 5	W 5	WNW 2	S 7	WSW 6	WSW 8	W 8	WSW 11	WSW 12
15	S 6	S 12	SSW 15	SSW 15	WSW 7	NW 2	WNW 2	NW 2	WNW 6	W 9	WNW 10	W 10	W 7	NW 4
16	S 4	SW 18	SW 11	WSW 4	NE 5	W 1	E 2	NW 2	SSW 3	NNE 1	NNE 2	NNE 6	NE 4	NW 5
16	SE 4	S 11	SSW 8	WSW 4	ENE 3	NNE 6	E 2	NNW 2	NE 4	NNE 4	ESE 3	SSE 2	SSW 4	SW 6
17	NE 7	ESE 8	SSW 3	NW 5	NW 6	N 5	NNW 3	WNW 3	W 6	WNW 12	W 13	WSW 17	WSW 18	WSW 17
18	S 7	SSE 11	SW 12	SW 8	WSW 7	WSW 7	WSW 8	SW 14	WSW 13	WSW 14	WSW 20	WSW 21		
19	E 6	SSE 6	SSW 4	SE 5	SSE 5	NW 1	WSW 7	W 13	WSW 19	WSW 24	SW 24	SW 21	SW 23	WSW 20
20	N 4	NNE 8	N 8	NNW 16	N 13	WNW 5	WNW 7	WSW 9	WSW 19	WSW 28	SW 24	SW 34	WSW 31	WSW 27
21	N 4	NE 8	NNW 11	NNW 12	N 11	NNW 5	NNW 6	NNW 7	NNW 7	NW 8	WSW 16	W 23	W 29	WSW 34
21	E 2	ENE 2	NNE 5	N 6	N 8	NNW 9	NNW 8	NW 9	NNW 8	NNW 11	WNW 11	W 12	W 24	W 28
22	SE 6	SE 7	SE 4	ESE 8	E 7	ENE 8	NNW 4	NNW 5	WNW 6	WNW 8	WNW 9	NW 13	WNW 10	W 16
23	SE 6	SSE 9	S 9	SSE 7	S 3	NW 3	NNW 6	NW 7	WNW 5	NW 3	WNW 4	NW 13	NW 23	NW 23
24	SE 8	SSE 11	SSW 10	SSW 3	S 1	E 1	W 1	NNW 2	W 3	WNW 5	WNW 13	NW 16	NW 17	NW 16
25	SE 4	SSE 6	SW 3	NW 4	NW 10	NW 8	NW 12	W 21	WNW 16	W 17	WNW 18	WNW 16	WNW 17	WNW 18
26	E 1	NE 1	NW 3	NW 9	N 7	N 6	NNW 9	NW 8	NW 20	NW 28	WNW 28	WNW 29	WNW 27	NW 23
27	S 3	SSE 5	W 3	SW 1	WNW 2	NW 3	NNW 8	NW 11	NW 14	NNW 17	NW 17	NW 24	NW 21	NW 24
28	SE 8	S 14	S 13	SW 10	W 1	SW 3	SSW 1	WSW 4	WSW 8	WSW 8	W 11	WNW 12	WNW 11	WNW 11
29	SE 6	SSE 11	SSW 7	WSW 8	SW 6	SSW 7	SSW 7	SW 7	SW 9	SW 8	SW 6	WSW 3	WSW 6	WSW 6
30	SE 6	SSE 10	SSW 9	SW 5	SW 3	W 5	SW 4	S 7	SSW 3	SSE 2	SE 3	SE 5	ESE 3	SSW 6
31	SE 5	SSE 9	S 4	SSW 4	S 3	WSW 2	S 4	SSW 6	SSW 6	S 6	S 8	SSE 3	S 4	WNW 2

Date	ALTITUDE (KM, M. S. L.)													
	Surface	14	15	16	17	18	19	20	21	22	23	24	25	26
1	SE 9	NW 14	N 13	NNE 7	SE 7	SE 5	SSE 7	E 5	ENE 7	ENE 9	ENE 7	ENE 7		
2	SE 4													
3	N 4	SW 19	W 12	WSW 5	W 7	W 3	NNW 1	ENE 9	ENE 7	ENE 11				
4	SE 3	NW 38	WNW 27	W 22	N 8	NW 3	ENE 11	NE 4	NE 8	E 7	ENE 8	NNE 11		
5	SE 7													
6	SE 5	WNW 17	W 13	W 11	SSW 7	SW 8	WNW 3	ESE 6	E 6	E 8	E 7			
8	NW 2	W 18	W 18	WNW 10	SW 6	W 3	E 1	E 7						
10	SE 5	W 22												
11	NW 4	NW 20	NW 11	W 5	WNW 10	NW 7	N 4	ESE 2	ESE 7	SE 3	E 8	E 8		
12	S 6	NW 23	NW 17	WNW 18	WNW 10	WNW 11	NW 12	NW 9	N 5	NNW 2	NE 5	ENE 6	E 9	E 8
13	S 4	NW 13	WNW 10	NW 17	NNE 1	SW 6	NW 5	NNE 4	NE 4	E 5	ENE 4	NE 7	ENE 9	
14	SE 9	WSW 12	WSW 11	W 11	NW 4	SW 5	NE 4	SE 3	NE 1	E 6	E 5	E 6		
15	S 6	W 6	WSW 9	WSW 5	S 5	SSE 4	W 4	NNW 2	NE 7	ENE 7	E 5			
16	S 4	SW 4	W 5	WSW 7	WSW 9	SW 2	NW 5	SSE 4	N 4	NE 8	NE 6	ESE 7	E 10	
16	SE 4	W 6	WSW 5	W 6	WNW 5	SW 3	N 4	SE 3	NNW 3	NNE 5	NE 9			
17	NE 7	W 11	WSW 6	WNW 11	WNW 7	WNW 9	NNW 6	NW 3						
18	S 7													
19	E 6	SW 18	SW 7	W 8	WNW 4	SW 9	NE 4	SW 10	W 6	S 6	S 5			
20	N 4	WSW 25	WSW 20	WSW 7	WSW 8	WSW 5	WNW 9	SSW 7	E 2	E 5	ENE 11			
21	N 4	WSW 30	W 26	W 15	WSW 16	W 9	W 7	W 5	NNE 4	SSE 1	ESE 6	ESE 5	ESE 6	E 8
21	E 2	W 20	W 18	W 11	W 8	W 5	W 5	NNW 4	N 2	E 6	E 4			
22	SE 6	W 19	WNW 15	WNW 13	WNW 9	WNW 5	N 4	NW 3						
23	SE 6	WNW 17	W 11	W 14	W 2	S 3	SSW 4	WNW 4	SSE 1	ENE 6	E 6	NE 8		
24	SE 8	WNW 15	WNW 12	WNW 12	WNW 7	SW 4	WSW 4	W 4	SE 3	NNE 3	NE 8	E 10		
25	SE 4	WNW 17	NW 11	WNW 13	WNW 7	WNW 5	N 7	NE 4	NE 5	E 4				
26	E 1	WNW 19	WNW 23	NW 13	WSW 7									
27	S 3	NW 15	NW 21	NW 11	NNW 5	NNW 2	N 1	NE 5	E 6					
28	SE 8	WNW 8	NW 6	WNW 7	SSW 4	WSW 3	ESE 2	E 4	SSE 4	ENE 3				
29	SE 6	SW 7	SSW 6	SSW 8	SSW 12	W 4	S 3	SSE 7	ESE 6	ESE 2	SE 5	E 5		
30	SE 6	WSW 6	SSW 11	SW 12	WSW 8	S 11	WSW 6	ENE 3	E 3	ESE 5	ESE 5	SE 8		
31	SE 5	SSE 3	SW 8	WSW 10	WSW 4	W 7	ENE 4	ESE 1	SE 2	NE; 4	NE 5	ENE 7		

TABLE 7.—*Wind directions and velocities from sounding-balloon observations at Omaha, Nebr., during July 1938*

Date	Surface	1	2	3	4	5	6	7	8	9	10	11	12	13	14
	ALTITUDE (KM, M. S. L.)														
2	E 6	SE 12	SSE 10	SSW 4	WSW 6	W 10	W 10	WSW 10	WSW 14	WSW 17	WSW 19	WSW 23	WSW 29	WSW 30	SW 29
3	SE 6	SSE 9	SSW 9	SW 3	WSW 4	SW 5	WSW 4	WSW 5	WSW 6	WSW 10	WSW 14	WSW 19	SW 22	SW 23	SW 23
4	S 4	S 10	S 9	SSW 7	SSW 4	SSW 4	SSW 6	WSW 6	W 12	SW 14	SW 16	SW 18	SW 26	SW 19	SW 21
5	S 4	S 12	S 8	S 3	W 3	WSW 6	SW 11	SW 8	WSW 14	SW 17	SW 24	WSW 21	SW 26	SW 28	----
7	W 4	WSW 4	W 8	W 10	WSW 14	WSW 15	W 15	W 17	WSW 25	SW 34	SSW 37	SSW 44	SW 45	SW 32	SW 25
8	NW 3	WNW 3	WNW 8	NW 13	NW 12	NW 13	NW 18	NNW 18	NNW 22	NNW 21	NNW 25	NW 23	WNW 19	WNW 21	WNW 16
9	S 6	S 12	SW 16	W 14	WNW 12	NW 9	NW 15	WNW 15	WNW 18	WNW 20	WNW 24	WNW 26	WNW 22	WNW 17	W 18
10	E 2	E 2	SSW 5	W 3	WNW 7	WNW 11	NW 13	NW 13	NW 17	NW 21	WNW 24	W 25	W 30	W 30	WNW 22
11	S 3	SW 8	SW 9	WSW 9	SW 8	W 5	W 4	W 6	W 9	W 7	W 7	W 10	WNW 13	W 13	WNW 17
12	S 4	SW 10	SW 9	W 10	NW 7	N 6	NW 7	WNW 10	W 12	WSW 14	W 17	W 17	WNW 21	W 18	WNW 16
13	N 8	N 10	NW 13	NW 20	NW 21	NW 17	NW 16	NW 16	NW 19	WNW 17	WNW 16	W 12	WNW 15	W 15	WNW 28
14	N 4	N 6	NW 8	NNW 9	NNW 11	NNW 16	NW 13	NW 14	NW 12	WNW 14	WNW 17	WNW 20	WNW 22	NW 25	NW 23
15	SE 4	SSW 5	WSW 6	NW 6	NW 7	NW 8	NW 10	W 9	WNW 11	WNW 12	W 12	W 15	WNW 16	WNW 20	WNW 22
17	E 4	ENE 6	NNE 9	NNE 11	N 8	NNE 6	NNW 6	NNW 8	NW 9	WNW 11	W 12	WNW 13	WNW 14	NW 16	WNW 14
18	S 2	SSW 3	SW 2	S 2	WSW 4	W 4	WNW 6	WNW 8	WNW 13	WNW 17	WNW 15	WNW 18	WNW 23	WNW 23	W 18
19	N 6	N 7	N 5	NW 8	NW 12	NW 8	NNW 11	NW 13	NW 14	NW 14	WNW 15	W 20	W 29	WNW 25	WNW 25
20	NE 3	ENE 4	NNE 4	NNW 6	NW 10	NW 12	NW 12	NW 15	WNW 15	W 19	W 20	W 24	W 26	W 29	W 25
21	E 4	W 4	WNW 11	WNW 17	WNW 20	WNW 12	WNW 9	WNW 21	WNW 24	WNW 19	WSW 17	----	----	----	----
22	N 4	NW 6	NW 9	NW 11	NNW 15	NW 18	NW 16	NW 15	NW 19	NW 19	WNW 20	WNW 22	WNW 26	WNW 30	NW 20
23	SE 7	S 11	SW 9	WSW 10	WNW 8	NW 7	WNW 6	NW 9	NW 8	NNW 6	NNW 8	NNW 8	NW 10	WNW 18	WNW 15
24	S 5	SW 12	SW 10	WNW 8	WNW 8	WNW 8	W 4	W 9	WSW 9	WSW 10	SW 9	WNW 9	WNW 16	WNW 18	W 14
25	N 6	ENE 4	WSW 6	SW 6	WSW 11	WSW 11	W 8	WNW 11	W 12	WNW 18	WNW 19	W 16	WNW 22	WNW 19	WNW 19
27	N 2	NNW 3	NW 9	NNW 12	NW 15	NW 11	NW 15	WNW 16	WNW 18	W 21	W 24	W 28	W 24	W 24	W 22
30	N 7	NNW 7	NNW 9	NNW 11	NNW 14	NNW 22	NNW 21	NNW 19	NW 13	NW 12	NW 16	NW 18	NW 17	NW 16	NW 22
31	SE 2	NNW 4	N 9	N 11	NNW 16	NNW 18	NNW 14	NNW 16	NNW 21	NNW 26	NNW 37	NNW 39	NNW 35	NNW 27	NW 24

Date	Surface	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29
	ALTITUDE (KM, M. S. L.)															
2	E 6	NE 16	WSW 6	NW 3	ESE 2	ENE 9	E 10	ESE 6	ESE 5	ENE 6	E 9	ENE 11	----	----	----	----
3	SE 6	WSW 20	SSW 3	SW 3	W 2	ESE 9	ENE 4	E 4	E 9	----	----	----	----	----	----	----
4	S 4	SW 15	WSW 11	SSW 6	SE 3	E 4	E 7	ENE 10	E 8	E 12	E 12	----	----	----	----	----
5	S 4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
7	W 4	SW 17	SW 10	WSW 6	S 8	NE 2	ENE 3	E 6	ESE 5	E 7	E 10	ENE 12	ENE 15	E 15	ESE 15	----
8	NW 3	WNW 7	WNW 6	WNW 3	N 5	NE 7	ENE 6	ENE 7	ENE 6	ENE 6	ENE 11	E 15	E 17	E 16	ESE 15	E 14
9	S 6	WNW 13	NW 10	NNW 4	NNE 1	NE 3	ESE 7	E 7	E 9	E 14	E 12	E 11	E 14	E 14	E 11	E 15
10	E 2	NW 14	NW 9	NE 2	ENE 1	E 5	E 3	ENE 7	E 12	ESE 7	E 8	ENE 10	E 11	E 14	ENE 13	----
11	S 3	NW 8	SSW 3	N 4	NE 2	ENE 8	ENE 7	----	----	----	----	----	----	----	----	----
12	S 4	NW 13	WNW 8	NW 7	NE 6	SE 6	NE 5	ENE 9	E 12	ENE 6	E 12	ENE 13	E 12	E 11	----	----
13	N 8	NW 21	WNW 6	NW 10	SE 5	NNW 10	ENE 8	E 6	ENE 6	E 8	E 9	ENE 12	ENE 16	ENE 14	E 18	E 19
14	N 4	NW 23	NW 13	NW 7	NNW 3	NE 5	WSW 6	NNE 5	NE 7	E 8	E 8	ENE 13	----	----	----	----
15	SE 4	WNW 18	NW 16	WNW 10	WNW 7	NNE 4	NE 7	ESE 4	NE 5	E 7	ENE 9	E 10	E 12	E 10	----	----
17	E 4	NW 11	WNW 8	NW 7	NNW 5	WNW 4	NNE 5	ENE 5	ENE 12	----	----	----	----	----	----	----
18	S 2	W 24	WNW 12	WNW 11	NW 6	E 2	ENE 4	ENE 6	NE 7	E 13	E 12	E 13	E 14	E 14	ENE 12	----
19	N 6	WNW 14	W 12	NW 9	W 3	NE 3	ENE 3	E 5	ENE 7	E 10	E 10	E 11	----	----	----	----
20	NE 3	WNW 24	WNW 13	WSW 10	WNW 4	W 6	NW 5	NE 7	E 10	ENE 11	E 12	E 14	E 14	E 17	E 19	----
21	E 4	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----
22	N 4	WNW 19	NW 12	WNW 6	WNW 7	NNE 4	E 4	NE 5	E 8	ENE 10	E 12	ESE 14	E 13	E 16	E 15	E 16
23	SE 7	WNW 15	NW 10	NW 7	WNW 4	NNE 3	E 4	ENE 6	ESE 7	ENE 8	E 12	E 12	E 11	E 12	----	----
24	S 5	W 10	W 7	NW 6	NNE 2	ENE 4	E 5	E 5	E 6	E 10	E 10	ENE 8	E 13	E 18	----	----
25	N 6	W 7	W 11	WNW 8	SSW 2	ENE 1	E 3	----	----	----	----	----	----	----	----	----
27	N 2	WNW 20	W 21	WNW 12	NNW 1	NNE 1	E 2	NE 5	NE 10	ENE 13	E 15	E 10	E 18	----	----	----
30	N 7	NW 23	NE 7	NW 7	E 7	----	----	----	----	----	NNE 13	NE 12	NNE 12	NE 17	NE 16	----
31	SE 2	W 10	NW 11	WNW 8	W 4	E 2	ENE 3	NE 7	ENE 7	E 10	E 11	ENE 14	E 15	ESE 13	ESE 14	----