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ACCURACY IN DETERMINING THE HIGHT OF A RADIOSONDE BY USING A TELEMETRIC ATTACHMENT TO -MALAKHIT- RADIOTHEODOLITE AT AEROLOGICAL STATIONS OF THE HYDROMETEOROLOGICAL SERVICE

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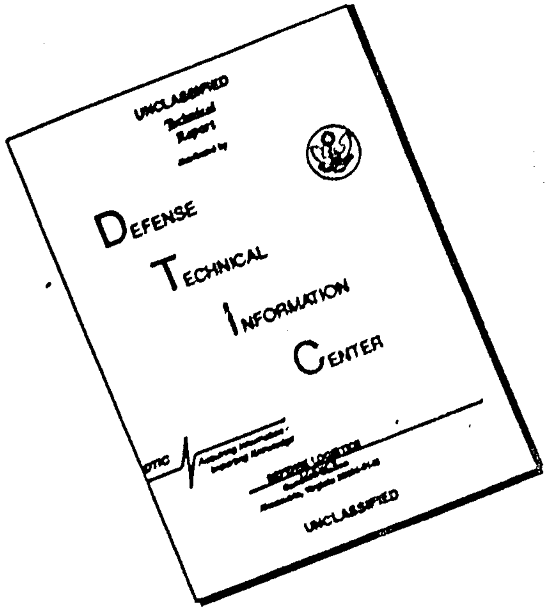

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TECHNICAL TRANSLATION

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ENGLISH TITLE: ACCURACY IN DETERMINING THE HIGHT OF A RADIOSONDE BY USING A TELEMETRIC ATTACHMENT TO -MALAKHIT- RADIOTHEODOLITE AT AEROLOGICAL STATIONS OF THE HYDROMETEOROLOGICAL SERVICE OF THE UZBEK SSR

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NOTICE

Cited below are the results of an altitude comparison based on a reading of a radiosonde pressure unit, and calculated by measuring the slant range with a range-finding attachment to a "Malachite" radio theodolite. The relationship between the altitude divergence and the balloon coordinates, the sheltered location of the horizontal site and the characteristics of the subjacent media has been established. The results of special base-line observations were used to calculate the systematic and mean square errors in altitude, made by every measuring means, using P. F. Zaichikov's triple control method.

"Malachite" radio theodolites with a range-finding attachment are used by all the aerological stations of the Uzbek Hydrometeorological Service. Observations involving the use of a "Malachite" radio theodolite with range-finding attachments were begun at the Aral Sea and Tamdy stations in April 1964, at the Termez station in September 1964 and at the Tashkent station in July 1965. The radio theodolites at the Aral Sea and Termez stations are stationary, their antenna systems measuring 10.9 and 7.6 meters in height, respectively. The terrain surrounding the radio theodolites at the mentioned points is open. The few obstacles in the path of the radio-wave propagation are due primarily to the negative angle of the horizon cover. Physical secondary reflectors under the 66 to 170° azimuth producing a horizon angle cover up to 0.6° are found only in Termez. The Aral Sea Aerological Station is located on the shore of a bay extending in a southeastern, southern and southwestern direction.

Mobile malachite-type radio theodolites with a 4.2 meter high antenna were installed at the Tandy and Tashkent Aerological Stations. A large number of obstacles in the way of radio-wave propagation was noted in Tashkent between 226 and 330°, but in the other directions the horizon cover is insignificant. The slope of the site from the center to the periphery in the area of the predominant balloon directions is 1-2 meters per 100 meters of horizontal distance. The "Malachite" radio theodolite is arranged at the highest point as compared to the adjacent areas. At the Tamdy station the largest number of secondary reflectors are arranged in the main direction of the balloon movement -- from 351 to 125°; some obstacles are encountered also in the

191-230° sector. The other directions, from 126 to 190° and from 231 to 350° are open.

The operating range of vertical angles at the stations under consideration was limited to the following minimum angles: at the Aral Sea station 14.0° in all directions: at the Termez station 14.5° in all directions: at the Tamdy station 14.5° in directions free from secondary reflectors; Tamdy station 16.0° in the sectors with a large horizon cover; Tashkent station 18.0° in the area with a large number of secondary reflectors; Tashkent station 17.0° in the direction of the predominant balloon movement: Tashkent station 16.0° in the other sectors free from secondary reflectors.

The mentioned magnitudes of the minimum vertical angles at all stations have been established without regard to the season.

The altitudes $H_{рл}$ and $H_{рз}$ compared in this study were calculated by the slant range and the reading of the radiosonde pressure unit for all the mentioned stations. The results of the following observations were used in this comparison: at the Tamdy station for September-October 1964, Tashkent station for August-September 1965, Aral Sea station August-September 1966, and at the Termez station for August-October 1966. A total of 208 ascents from the four stations, each lasting an average of 68 minutes, were used for the mentioned comparison. The plotting of an altitude graph to determine $H_{рл}$ and the introduction of altitude corrections for the earth curvature and radio wave refraction were made in accordance with (Ref. 5).

A comparative data processing produced the following altitude differences $\Delta H = H_{рл} - H_{рз}$. An analysis of the signs of these differences shows that $H_{рл}$ was predominant over $H_{рз}$ in the first minutes of observation. In the middle of the observation (12 - 40 minutes) the recurrence of the sign differences was approximately the same, and in the end the recurrence of $H_{рл} < H_{рз}$ cases was twice as frequent as the $H_{рл} > H_{рз}$ cases. At the Tamdy station $H_{рл} < H_{рз}$ is more frequent in the first 40 minutes, but no sharp differences in the recurrence of various ΔH signs are noted at that station. At the Termez station $H_{рл} > H_{рз}$, cases are predominant up to 40 minutes, but after 40 minutes the recurrence percentage of such differences is somewhat reduced but still remains predominant.

The difference in altitudes alone is not enough to estimate the divergence between $H_{рл}$ and $H_{рз}$. A clearer characteristic of the altitude convergence is provided by the following magnitude $z = \frac{H_{рл}\ H_{рз}}{H_{рз}} 100\%$. The percent ratio of the altitude differences ΔH was calculated from $H_{рз}$

because of the lesser possibility of accidental errors in the calculation of $H_{\nu\beta}$ as compared to $H_{\nu\beta}$.

Table 1

The Relation Between the Average /z/ Magnitudes and the Duration of the Observations

0-10 min.	12-40 min.	40 min.	Average
6	3	5	4
6	5	7	5
13	6	5	7
16	7	3	8
10	5	5	6

The absolute magnitude /z/, as determined by the duration of the observation, is shown in Table 1.

The large number of significant altitude differences seen in the first minutes of observation can be explained not only by errors in measuring the slant range but also by the small magnitude $H_{1/5}$ from which the percentage content of ΔH was calculated. In the following minutes of observation the /z/ magnitude is reduced on an average to 5 percent. At the Aral Sea and Tamdy stations the smallest /z/ magnitude (3 - 5%) is observed between 12 and 40 minutes, but it is somewhat increased later on (5-7%). At Tashkent and especially Termez the average /z/ magnitudes, noted between 12 and 20-30 minutes, amounts to 6 - 7%, and are then reduced to 5 - 3%.

The percentage recurrence of various /z/ magnitudes for various vertical angles and slant ranges has been calculated in order to estimate the relationship between /z/ and the changing balloon coordinates. Cited in tables 2 and 3 is the relation between the percentage recurrence of the /z/ gradations (0 - 5, 6 - 10, 11 - 20, 21 - 30, and 31 - 40%) and the vertical angle gradations from 0 to 90° in 5° intervals and a slant range from 0 to 120 kilometers in 10 kilometer intervals.

The total number of comparisons n from which the percentage recurrence of /z/ with various vertical angles and slant ranges was calculated, is cited in the last column of tables 2 and 3.

Recurrence of various /z/ gradations in relation to vertical angle Table 2.

Station	gradation [z]%	Vertical angle (gradations) 10-15	15-20	20-25	25-30	30-35	35-40	40-45	45-50	50-55	55-60	60-65	65-70	70-75	75-80	80-85	85-90	n
Aral Sea	0-5	2	9	14	17	16	12	9	7	6	3	2	1	1	1	-	-	1325
	6-10	6	26	22	11	7	10	6	4	4	4	-	-	-	-	-	-	476
	11-20	18	23	13	8	9	5	5	4	9	2	2	2	-	-	-	-	126
	21-30	23	47	-	7	-	7	3	-	3	10	-	-	-	-	-	-	30
	31-40	50	-	25	-	-	-	25	-	-	-	-	-	-	-	-	-	4
Tamday	0-5	21	17	13	12	10	5	5	5	6	3	2	1	-	-	-	-	612
	6-10	33	16	6	7	8	8	5	5	3	1	3	1	3	1	-	-	231
	11-20	28	24	8	8	3	4	4	2	4	2	3	3	4	3	-	-	156
	21-30	30	20	4	10	4	7	3	3	3	3	10	3	-	-	-	-	30
	31-40	-	-	-	-	-	-	-	100	-	-	-	-	-	-	-	-	1
Tashkent	0-5	12	11	14	10	8	9	9	6	4	4	4	4	3	1	1	-	1185
	6-10	11	13	15	13	9	6	4	4	4	4	4	4	4	3	1	1	895
	11-20	12	10	11	9	6	6	7	7	8	6	5	5	4	2	1	1	585
	21-30	11	8	8	6	8	5	4	10	14	8	9	4	5	-	-	-	99
	31-40	9	36	9	-	-	15	9	4	4	14	-	-	-	-	-	-	22
Termez	0-5	2	20	22	17	11	7	6	5	4	3	2	1	-	-	-	-	912
	6-10	2	10	3	8	12	14	11	8	8	8	8	5	3	1	1	-	355
	11-20	1	4	2	6	7	8	11	10	10	11	10	8	5	4	2	1	303
	21-30	-	-	1	4	7	9	6	7	8	10	15	13	6	7	7	-	134
	31-40	-	-	-	-	2	5	5	11	7	16	38	16	-	-	-	-	34

Recurrence of various /z/ gradations in relation to a slant range

Table 3.

Station	gradation [z] %	slant range, km 0–10	10–20	20–30	30–40	40–50	50–60	60–70	70–80	80–90	90–100	100–110	110–120	n
Aral Sea	0–5	39	25	14	9	9	2	1	1	-	-	-	-	1387
	6–10	29	5	16	23	13	10	2	1	-	-	-	-	442
	11–20	41	6	3	13	9	9	8	6	1	-	1	1	109
	21–30	40	-	-	10	5	-	5	-	3	10	5	5	20
	31–40	67	-	-	-	-	-	-	-	-	33	-	-	3
Tamday	0–5	35	16	11	8	6	4	8	4	3	1	3	1	639
	6–10	35	13	3	5	6	10	11	4	7	3	1	2	211
	11–20	29	4	8	8	4	9	16	8	8	2	1	3	148
	21–30	39	7	7	3	7	3	10	7	3	7	7	-	29
	31–40	33	-	-	-	-	-	-	-	-	-	33	34	3
Tashkent	0–5	14	22	19	15	14	7	3	3	1	1	1	-	1210
	6–10	33	18	14	11	10	5	5	2	1	1	-	-	890
	11–20	63	14	4	5	4	4	3	2	-	-	1	-	563
	21–30	77	12	7	2	1	-	1	-	-	-	-	-	101
	31–40	48	28	10	14	-	-	-	-	-	-	-	-	22
Termez	0–5	10	12	14	17	17	19	8	2	1	-	-	-	1087
	6–10	32	28	7	8	7	7	7	4	-	-	-	-	313
	11–20	65	11	7	3	5	1	7	1	-	-	-	-	225
	21–30	82	16	2	-	-	-	-	-	-	-	-	-	87
	31–40	100	-	-	-	-	-	-	-	-	-	-	-	26

An analysis of the recurrence of various /z/ gradations in relation to the vertical angle reveals the predominance of $/z/ < 5$ at the stations: for $25 \div 55^\circ$ angles at the Aral Sea, $20 \div 35^\circ$ and $45 \div 55^\circ$ at Tamdy, $35 \div 45^\circ$ at Tashkent, and $15 \div 30^\circ$ at Termez. There is a noticeable increase in the recurrence of $/z/ > 10$ for vertical angles larger than 55° at all stations, and less than 20° at the Aral Sea and Tamdy stations and over 45° at the Tashkent and Termez stations.

A comparison of the data obtained at the various stations has established that the greatest recurrence of $/z/ \leqslant 5$ is characteristic of $10 - 25^\circ$ angles at the Tamdy and Termez stations, and $25 - 55^\circ$ at the Aral Sea station. The lowest recurrence of $/z/ \leqslant 5$ is in Tashkent. The highest recurrence of the $5 < /z/ \leqslant 10$ interval with $10 - 25^\circ$ angles is noted at the Tamdy and Aral Sea stations, and with $25 - 70^\circ$ angles at Termez. $/z/ > 10$ most frequently occurs at the Aral Sea and Tamdy stations at $10 - 25^\circ$ angles. There is a marked predominance of such differences at angles exceeding 25° at Tashkent and Termez.

Thus the greatest convergence of $H_{a/f}$ and $H_{r/l}$ is noted at small vertical angles: 10 - 25° at the Termez station and 25 - 55° at the Aral Sea and Tamdy stations. The poorest convergence of the readings along the entire range of vertical angles was noted in Tashkent.

High /z/ values were frequently revealed for $D \leqslant 10 \div 15$ slant ranges at the Tamdy and Tashkent stations and for $D \leqslant 20 \div 25$ at the Termez station in the beginning of the observation (Table 3). The predominance of the lowest /z/ values is characteristic of Tashkent at $15 < D \leqslant 60$, Termez at $25 < D \leqslant 65$, Tadmy at $15 < D \leqslant 45$ and Aral Sea station at $0 < D \leqslant 25$. The recurrence of the other /z/ gradations is inversely proportional to their magnitudes at the Aral Sea, Tashkent and Termez stations, and at the Aral Sea station $/z/ = 6 \div 10$ is predominant at $25 < D \leqslant 55$. In the case of slant ranges larger than those shown above, the recurrence of larger /z/ values increased at the Aral Sea and Tamdy stations, and at Tashkent and Termez the magnitudes of such recurrences were smaller and there were no sharp differences between them. A comparison of the data applying to different stations revealed the highest recurrence of small /z/ for $D \leqslant 20 \div 25$ at the Aral Sea and Tamdy stations, and for $D > 25$ at Termez; $/z/ > 5$ was most frequently noted at $D \leqslant 20 \div 25$ at Tashkent and Termez, and at $D > 25$ at the Aral sea and Tamdy stations. Consequently, the greatest convergence of $H_{a/f}$ and $H_{r/l}$ when the balloon moved a short distance away (under 25 kilometer) at the Aral Sea and Tamdy stations, and at $D > 25$ at Termez. In the majority of the $D \leqslant 20$ cases in Tashkent the recurrence of low /z/ magnitudes was less frequent than at all the other stations.

The relation between the magnitude and recurrence of z and the combination of vertical angle and slant range gradations can be traced by the figures of Table 4. That table shows the z magnitude for five slant range and vertical angle gradations.

Slant range gradations: 0 - 10, 10 - 20, 20 - 40, 40 - 70, >70 km; vertical angle gradations: $90 \div 70$, $70 \div 50$, $50 \div 30°$, 30° - minimum angle, minimum angle - 0°.

The number of parallel altitude readings at each station for any gradation of the vertical angle and slant range is cited in Table 4. A reduction in the number of parallel readings is characteristic of the largest and smallest vertical angles and the large ($D > 70$) slant ranges. The table also includes information on the percentage content of $z < 0$ ($H_{a/f} < H_{r/l}$) cases in the total number of parallel altitude readings.

Information on the recurrence & magnitude of /z/ in relation to the vertical angle and slant range

Table 4.

Station	Vertical Angle Gradations (0)	Total Number Of Comparisons					Recurrence Of Z 0 (in percentage of total number of cases)					Average /Z/				
		Gradations of slant range (km)														
		0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70
Aral Sea	90-70	4	29	-	-	-	0	10	-	-	-	3	3	-	-	-
	70-50	56	125	51	5	-	18	30	4	0	-	6	2	8	10	-
	50-30	139	387	143	93	-	21	34	57	57	-	6	3	3	4	-
	30-m.y.	282	221	162	172	18	24	29	86	91	89	4	3	5	6	6
	m.y.-0	-	8	13	27	26	-	38	92	96	12	-	5	5	11	16
Tamdy	90-70	30	-	-	-	-	17	-	-	-	-	9	-	-	-	-
	70-50	109	-	-	-	-	36	-	-	-	-	6	-	-	-	-
	50-30	166	71	2	-	-	41	25	-	-	-	5	5	3	-	-
	30-m.y.	52	74	130	87	10	44	47	29	41	60	3	4	5	8	6
	m.y.-0	-	2	37	114	146	-	-	38	58	66	-	2	4	6	8
Tashkent	90-70	70	-	-	-	-	97	-	-	-	-	10	-	-	-	-
	70-50	209	36	-	2	-	99	100	-	100	-	11	5	-	4	-
	50-30	158	140	116	77	-	96	92	89	83	-	10	4	3	5	-
	30-m.y.	44	125	231	188	14	100	99	93	95	100	13	9	5	6	10
	m.y.-0	2	17	79	150	55	100	100	85	79	49	48	14	6	5	7
Termez	90-70	77	5	3	-	-	1		-	-	-	14	25	14	-	-
	70-50	152	54	50	2	-	9	2	16	100	-	23	11	6	2	-
	50-30	153	167	126	99	-	25	15	24	7	-	11	6	3	5	-
	30-m.y.	13	20	286	459	53	23	30	28	34	40	10	18	3	3	4
	m.y.-0	-	-	1	17	1	-	-	100	71	-	-	-	4	5	6

m.y. -- minimum angle

Cases of $H_{рл} < H_{рз}$ are predominant in Tashkent. In Termez below the D = 40 in the working range of vertical angles the number of $z < 0$ cases does not exceed 30% of the total number of readings. With $D > 40$, $z < 0$ is found in 40% of the cases at this station, and with small vertical angles in 70 - 100% of the cases. At the Aral Sea and Tamdy stations the recurrence of $z < 0$ cases also increase with large slant ranges and small vertical angles. In the other cases, various signs of z are equiprobable.

The average magnitude of /z/ is also shown in Table 4. A rising /z/ value was noted at the beginning of the observation at all stations. The lowest mean values of /z/ were found at the Aral Sea and Tamdy stations with $10 < D < 40$ for any vertical angle, and at Tashkent and Termez with $20 < D < 70$, while at Tashkent /z/ increased in the area of small vertical angles, and at Termez in the area of large angles, especially with $\beta = 70 \div 90°$.

The figures shown in Table 4 characterize the altitude divergence in the direction of the predominant balloon movement as the majority of parallel altitude readings apply to this sector of observations. To characterize the relations between /z/ and the conditions of the surrounding terrain, /z/ magnitudes were selected for the areas not included in the sector of the predominant wind direction: at Tashkent and Tamdy it applied to a section free from secondary reflectors, and at the Aral Sea station to sea and land (Table 5).

A comparison of the figures cited in Tables 4 and 5 shows that at the Aral Sea station the average /z/ magnitude above the sea is considerably smaller than above the land. It does not exceed 4 - 5% of the radiosonde altitude in all the slant range and vertical angle gradations. In the section above the land opposite to the prevailing direction of the winds the figures in Table 5 are similar to those shown in Table 4; they increase only at small vertical angles and $\beta = 50 \div 70°$ angles at distances over 20 kilometers.

The average /z/ magnitude for an open section in Tamdy is somewhat smaller than in Table 4. An increasing /z/ magnitude was noted only in cases of small ($D < 10$) and large ($D > 70$) slant ranges for vertical angles of $30 \div 16°$. In the area with a large number of secondary reflectors similarly located in the opposite direction of the prevailing winds, all the average /z/ magnitudes are larger than the appropriate values shown in Table 4.

Table 5.

The relation between /z/ and available secondary reflectors and characteristics of the radiotheodolite platform-stand

Vertical angle gradations	Aral Sea										Tashkent					Tamdy									
	sea					land					open section					open section					closed section				
	slant range gradations (km)																								
	0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70	0-10	10-20	20-40	40-70	>70
90-70	3	3	0	-	-	2	3	-	-	-	-	-	-	-	-	9	-	-	-	-	16	-	-	-	-
70-50	3	2	3	-	-	4	1	11	22	-	11	6	-	4	-	4	-	-	-	-	7	-	-	-	-
50-30	4	3	4	4	-	7	2	2	4	-	12	4	4	4	-	4	2	2	-	-	6	1	-	-	-
30-m.y.	5	3	4	-	-	4	4	5	6	6	14	8	6	7	-	6	-	3	10	-	4	-	-	-	-
m.y.-0	-	4	2	-	-	-	7	9	17	43	22	13	8	14	-	-	-	-	-	-	-	-	-	-	-

There is no marked difference between the figures of Table 4 and 5 for Tashkent. This obviously depends on the similarity of the conditions in the prevailing directions of the wind and the free additional sector. With small angles at $D > 10$, the figures in Table 4 are larger than the analogical values in Table 5. The average /s/ magnitudes for the sector in Tashkent with a large horizon cover are not given because of the insignificant number of comparative readings.

It appears from the results of the above-shown altitude comparisons that in the majority of cases the figures for the Aral Sea and Tamdy stations (with sandy soil), and Tashkent and Termez (with clay soil) are similar in pairs. The altitude divergence apparently depends to a large extent on the characteristic features of the subjacent media and their electrical properties (for example, electric conductivity) as compared to to the effect of secondary reflectors and the height of the antenna above the ground surface. We know from the theory of radio-wave propagation in stratified media (1) that the field strength of the areas with a good electric conductivity (the sea and clay soil) is higher than the media with a poor conductivity (land, sandy soil, limestones). There is a better convergence of the $H_{р/л}$ and $H_{р/з}$ altitudes above the media characterized by a higher field strength, especially at the end of the observation when the power of the incoming signal grows weaker because of the great distance from the balloon.

The specialist engaged in the numerical methods of forecasting might be interested in the accuracy of determining the altitude of the major isobaric surfaces. The altitude of the isobaric surfaces was calculated on the basis of the radar measured altitude in accordance with (10) for the purpose of comparing the altitudes at the mentioned levels. A comparison of the $H_{р/л}$ and $H_{р/з}$ altitudes on the isobaric levels shows that at the Aral Sea, Tamdy and Termez stations /z/ does not exceed 1 - 2% beyond 700 - 600 millibars, and at Tashkent it does not exceed 3% beyond 600 millibars and 2% beyond 300 - 400 millibars.

A comparison of the signs of the difference revealed a predominance of $H_{р/з}$ over $H_{р/л}$ at the Aral Sea and Tashkent stations in 100% of the cases, at Tamdy in 90% and at Termez in 79% of the cases.

It would thus be wrong to extend the divergence of the $H_{р/л}$ and $H_{р/з}$ altitudes during the specific readings to the altitude difference of the main isobaric surfaces found by the two mentioned processing methods. The divergencies between the altitudes of the main isobaric surfaces are less than at certain moments of time because of the averaging-out method used in the processing.

To calculate the errors permissible in the determination of the $H_{a/l}$ and $H_{a/s}$ altitudes, the latter were compared to the H_b altitudes found by the simultaneous base-line pilot balloon observations at the Aral Sea, Tashkent and Termez stations.

The base-line observations were made and processed according to the requirements in (8). The length of the base line at the Aral Sea station was 1050 meters, at Tashkent 490 and 1250 meters, and at Termez 430 meters.

A total of 27 base-line observations of the radiosondes and 10 observations of the radio pilots, each lasting an average of 21-22 minutes, were carried out at the three stations. The total number of parallel readings resulting from the radiosonde observations was 336, and radio pilot observations 143. The simultaneous measurements of $H_{a/l}$ and $H_{a/s}$ were taken from the altitude-time ratio graphs. The H_b altitude defined by the analytical method was not averaged out but included in the treatment in the form it had been found during the calculations made for certain minutes of observations. Consequently, it was not the averaged value of the H_b altitude that was used for comparison purposes but the actual value reflecting the vertical currents which are considerable in the atmospheric layer under consideration.

The following differences were calculated for every three parallel readings of the altitude:

$$H_b - H_{r/s}$$
$$H_b - H_{r/p}$$
$$H_{r/s} - H_{r/p}$$

where H_b is the altitude calculated by the results of the base-line pilot balloon observations. An analysis of the signs of the resulting differences reveals that $H_b < H_{a/s}$ in 85 - 89% of the cases at all stations. $H_b < H_{a/l}$ at the Aral Sea station in most cases throughout the observation (an average of 80%). A different picture was observable at the Tashkent and Termez stations: $H_b > H_{a/s}$ in about 53 - 61% of the cases. $H_{a/l} < H_{a/s}$ at the Aral Sea, Tashkent and Termez stations in 69, 88 and 95% of the cases, respectively.

In the case of the base-line observations of the transponder, $H_{a/s}$ exceeded H_b in most of the cases (85%), a reverse altitude correlation was noted in 14% of the cases, and $H_{a/l} = H_b$ in 1% of the cases.

The triple control method proposed by P. F. Zaichikov (2, 3) was used for calculating the systematic and random errors in the determination of the altitude by various methods.

Every minute of observation was processed by the triple control method. Magnitudes of the simultaneous altitude measurements were selected by the mentioned three methods for each of the three stations as well as for all the stations together (Table 6). The observation data for the Termez station are conditional because of the small number of cases.

The systematic error in each measuring method was determined on the basis of the recommendations in (3) by the use of arithmetic mean differences. Assuming that the systematic error of one of the measuring methods equals zero, it is possible to find the systematic errors of the other two ΔH methods. In the case under consideration it would be more natural to assume the absence of a systematic error in the base-line method of altitude measurement. To determine the systematic error in measuring $H_{r/l}$ and $H_{a/s}$, such an error in base-line observations was assumed to be the nonexistent $\Delta H_s = 0$.

The random error for each method of measurement was calculated according to (3) by the following formula

$$\sigma_i^2 = \frac{1}{N-2}\sum_{j=1}^{N}\sigma_{i,j}^2 - \frac{1}{(N-1)(N-2)}\sum_{i=1}^{N-1}\sum_{j=1}^{N-j}\sigma^2_{j-(i+j)}$$

where N is the number of methods of simultaneous measurements, σ_i^2 the dispersion magnitude (the square of the average quadratic error) of each of the N methods of simultaneous measurements, $\sigma_{i,j}$ the mean quadratic difference of the simultaneous altitude measurements by two methods.

The reliability of the determination of errors, depending on the accuracy of calculating the mean quadratic error (2, 3), was calculated in addition to the systematic ΔH and the mean quadratic with σ of errors,

$$\Delta\Delta H_i = \sqrt{\frac{1}{(N-2)(n-1)}\sum_{i=1}^{n}\sigma_i^2}$$

The average ΔH, the mean quadratic errors σ in determining the altitude, and the reliability of determining the $\Delta\Delta H$ errors by the three measuring methods are cited in Table 6. The systematic error in defining $H_{a/s}$ at all stations is markedly greater than the similar error in measuring $H_{r/l}$. In the case of $H_{r/l}$ and $H_{a/s}$ the systematic error increases with time, while the increase of $\Delta H_{a/s}$ begins in the first minutes of observation, and $\Delta H_{r/l}$ reveals a marked increase after 10 minutes. The systematic $\Delta H_{a/s}$ errors were negative throughout the observations, and approximately similar in magnitude at all the three stations. $\Delta H_{r/l}$ is preceded primarily by a positive sign in Tashkent and Termez, and by a negative sign at the Aral Sea station.

Mean and mean quadratic errors (m) in determining the altitude measurements (r/l) according to the base-line pilot balloon, radio sounding (r/s) and radar data

Table 6.

Station	Method of Measurement Min.	min. angle								
		1			2			3		
		ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔH
Aral Sea	6a3	0	67	±57	0	26	±29	0	64	±48
	p/3	-12	17	±41	-44	51	±34	-71	49	±45
	p/л	-7	20	±45	-23	30	±29	-48	76	±50
Tashkent	6a3	0	22	±19	0	33	±28	0	0	±33
	p/3	-25	0	±16	-22	39	±29	-62	56	±38
	p/л	-11	41	±22	0	54	±33	- 8	100	±45
Termez	6a3	0	0	±95	0	78	±94	0	87	±119
	p/3	65	103	±114	-30	0	±62	-77	0	±80
	p/л	12	142	±128	90	96	±102	11	140	±142
General	6a3	0	51	±29	0	39	±22	0	48	±28
	p/3	1	52	±29	-32	36	±22	-67	35	±26
	p/л	-4	67	±31	6	70	±26	-7	104	±33

Station	Measuring Method									
		9			10			12		
		ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔH
Aral Sea	6a3	0	110	±62	0	84	±60	0	60	±75
	p/3	-197	0	±44	-215	54	±53	-203	94	±81
	p/л	-121	58	±50	-102	44	±51	-98	108	±85
Tashkent	6a3	0	126	±95	0	184	±82	0	182	±105
	p/3	-174	0	±81	-190	169	±79	-187	82	±68
	p/л	52	214	±113	23	238	±95	81	126	±94
Termez	6a3	0	87	±96	0	58	±87	0	147	±168
	p/3	-170	0	±67	-247	66	±86	-220	121	±158
	p/л	60	74	±91	-30	122	±79	63	0	±131
General	6a3	0	121	±52	0	109	±51	0	132	±60
	p/3	-183	0	±42	-206	64	±48	-198	92	±56
	p/л	-16	168	±59	-22	154	±57	18	135	±61

Table 6 -- continued

Tbl														
4			5			6			7			8		
ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔH
0	73	±42	0	94	±35	0	158	±88	0	52	±36	0	68	±42
-70	0	±35	-95	0	±28	-121	0	±46	-104	17	±30	-126	10	±33
-53	61	±40	-82	93	±35	-86	141	±84	-56	49	±35	-48	52	±39
0	142	±71	0	60	±31	0	0	±62	0	65	±59	0	22	±68
-84	70	±60	-127	109	±31	-111	100	±71	-152	76	±60	-143	77	±73
25	120	±67	-2	124	±36	93	199	±88	43	157	±73	72	176	±92
0	74	±107	0	0	±33	0	0	±68	0	0	±61	0	66	±89
-103	10	±93	-153	66	±47	-160	21	±89	-190	52	±76	-177	0	±68
100	108	±119	57	88	±53	57	100	±104	40	87	±91	37	101	±105
0	116	±42	0	57	±21	0	0	±42	0	47	±36	0	53	±20
-81	44	±35	-120	91	±39	-116	0	±40	-142	73	±39	-142	50	±20
6	113	±42	-22	125	±43	46	133	±55	11	135	±45	19	0	±14

Tbl											
14			16			18			20		
ΔH	σ	ΔΔH	ΔH	σ	ΔΔH	ΔH	σ	ΔΔHH	ΔH	σ	ΔΔH
0	80	±87	0	-	-	0	-	-	0	-	-
-333	20	±80	-292	-	-	-172	-	-	-297	-	-
-193	158	±106	-212	-	-	110	-	-	-160	-	-
0	254	±131	0	172	±92	0	105	±81	0	-	-
-144	98	±108	-322	48	±78	-194	77	±76	-215	-	-
154	179	±118	35	181	±94	113	110	±82	130	-	-
0	40	-	0	-	-	-	-	-	-	-	-
-190	155	-	-205	-	-	-	-	-	-	-	-
170	0	-	160	-	-	-	-	-	-	-	-
0	236	±93	0	161	±72	0	150	±75	0	271	±170
-220	97	±79	302	165	±73	-218	72	±64	-250	0	±125
98	192	±88	-1	100	±66	94	111	±68	6	186	±150

As was to be expected, a review of the mean quadratic magnitudes of the random altitude deviations from the mean value reveals that $\sigma_{n/l}$ exceeds $\sigma_{n/s}$ in most cases. σ_{δ} is a fairly large magnitude but it does not basically exceed $\sigma_{n/l}$. This fact is not subject to any doubt in view of the characteristic method of defining H_{δ} used for each minute without averaging them out. An analysis of the magnitudes characterizing the reliability of the average or mean quadratic differences shows that the maximum error of an average $\Delta\Delta h$ at all the stations is approximately the same at certain moments of time for all the three measuring methods. The $\Delta\Delta H$ values increase toward the end of the observation, and in most cases $\Delta\Delta H < \sigma$ and $\Delta\Delta H < \Delta H$ for each method of measurement.

In view of the above, it may be concluded that the radar method of altitude determination produces a smaller systematic error than $H_{n/s}$. The considerable magnitudes of the random errors in determining $H_{n/s}$ are due to the method of radiowind observations whereby the accuracy of the readings of the slant range and the angle coordinates depends in large measure on subjective factors: the simultaneousness of the readings, the experience of the observer and the extent of his concentration.

In conclusion, a simultaneous processing of two radiowind observations of the radiosonde was carried out by three methods:

1) the processing of A = 30 = D on a drawing table based on the slant range and the interpolation for standard altitudes of wind velocity and direction for the $H_{n/s}$ altitude;

2) the processing of A = 30 = D on a drawing board based on the slant range and interpolation for the $H_{n/l}$ altitude;

3) the processing based on a conditional vertical speed and interpolation for the $H_{n/s}$ altitude.

The following differences were calculated in the comparison of the three above-indicated processing methods:

$$\Delta V_1 = V_1 - V_2; \quad \Delta d_1 = d_1 - d_2;$$
$$\Delta V_2 = V_1 - V_3; \quad \Delta d_2 = d_1 - d_3;$$
$$\Delta V_3 = V_2 - V_3; \quad \Delta d_3 = d_2 - d_3;$$

where V_1 and d_1 are the speed and direction of the wind defined by the first processing method, and V_2 and d_2, V_3 and d_3 are the same magnitude found by the second and third methods respectively.

The average divergencies of the wind velocity between the data computed by various methods are small for all the altitudes, and do not exceed 2 m/sec. for ΔV_1, ΔV_2 and ΔV_3. The maximum differences are: $\Delta V_{1max} = 5$ m/sec, $\Delta V_{2max} = 3 \div 5$ m/sec. and $\Delta V_{3max} = 4 \div 6$ m/sec.

The divergencies between the wind directions computed by the first and second, second and third methods are of considerable magnitude: $\Delta d_1 = 37 \div 62^o$; $\Delta d_3 = 40 \div 62^o$. These divergencies are not large for the direction values determined by the first and third methods where the interpolation is fulfilled for $H_{a/s}$, $\Delta d_2 = 6 \div 7^o$.

The changes of the maximum differences in the wind direction $\Delta d_{1max} = 98 \div 205^o$, $\Delta d_{2max} = 23 \div 38^o$, $\Delta d_{3max} = 90 \div 188^o$ are similar to those of the average differences.

Thus the large $H_{a/l}$ and $H_{a/s}$ altitude divergencies account for the considerable Δd magnitudos, and in this connection it is recommended that the interpolation of the windage for standard altitudes during the processing of the wind data be carried out between the altitudes of the middle parts of the layers determined by $H_{a/l}$.

Conclusions

1. A comparison of the $H_{a/l}$ and $H_{a/s}$ altitudes reveals that $H_{a/l} < H_{a/s}$ in most cases in Tashkent, and $H_{a/l} > H_{a/s}$ in Termez; at the Aral Sea and Tamdy stations different signs of the altitude differences are equiprobable.

2. At the Aral Sea and Tamdy stations the /z/ magnitude did not exceed 5% in the middle of the observation (under 40 minutes), and increased to 5 - 7% by the end of it. In Tashkent and Termez /z/ amounted to 6 - 7% for 20 - 30 minutes, and then dropped to 5 - 3%.

3. The difference between the $H_{a/s}$ and $H_{a/l}$ altitudes depends on the balloon coordinates (δ, D), and increases in the direction of the smallest and largest vertical angles and large slant ranges.

4. The altitude convergence above the sea is better than above land, which is explained by the greater field strength above a water surface.

5. The divergence between the $H_{n/k}$ and $H_{n/s}$ altitudes depends on the characteristic features of the subjacent media and their electrical properties. Similar data on the changing altitudes were noted at the Aral Sea and Tamdy stations (with sandy soil) and Tashkent and Termez (with clay soil).

6. The altitude divergence is greater in the observation sectors with a large number of secondary reflectors.

7. The systematic space $\Delta H_{n/s}$ error always exceeds $\Delta H_{n/k}$. The sign of $\Delta H_{n/s}$ is always negative. In Tashkent and Termez the sign of $\Delta H_{n/k}$ is mostly positive, and at the Aral Sea station negative.

8. The mean quadratic errors made in the altitude measurements are smallest for $H_{n/s}$ and largest for $H_{n/k}$.

9. At fixed moments of observation the reliability of determining the errors at all stations is approximately the same for the various observation methods.

10. The tendency of every type of error is to increase with time.

11. When processing the windage data for a slant range it is advisable to interpolate the wind only between the $H_{n/k}$ altitudes.

* * * * *

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13. ABSTRACT

Cited in this article are the results of an altitude comparison based on a reading of a radiosonde pressure unit, and calculated by measuring the slant range with a range-finding, attachement to a "malachite" radio theodolite. The relationship between the altitude divergence and the ballon coordinates, the sheltered location of the horizontal site and the characteristics of the subjacent media has been established. The results of special base-line observations were used to calculated the systematic and mean square errors in altitude, made by every measuring means, using P. F. Zaichikov's triple control method.

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