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On the Accuracy of the Finnish Radiosonde

By

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The accuracy of the Finnish radiosonde is under continuous investigation at the Ilmala observatory. The investigations are based on observations made partly in the laboratory, partly in nature. Here, the latest investigation results will be presented and it is hoped they will give a clear picture of the accuracy of the radiosonde.

This investigation partly conforms with what was presented at the meeting of the director generals of the meterological institutes of the Scandinavian countries in Copenhagen in May 1950. The investigations made seperately with each radiosonde type serve to complete the international research work which has for its object to shed light on the properties and accuracy of the different types of radiosondes. The results of the first international comparison of radiosondes in May 8—26, 1950 have been discussed in many different papers (1, 3, 5, 10, 11, 12, 13). Among others e.g. MALET (4), HENRY (2) and U. S. committee (14) have intercompared different radiosondes.

Observations method

The taking of observations with the Finnish radiosonde is carried on so that the observer brings by means of the lowest sound sent from the loudspeaker the receiver wave and the transmitter wave into resonance with each other. The thus made observation is then recorded, by perforations made with thin needle, onto a strip of paper in the receiver. The accuracy here attained by the observer determines the accuracy of the method. Naturally different observers attain somewhat personal accuracies but long practise and experience tend to render these differences between observers minute.

At Ilmala, the sounding staff composed in part of experienced workers made laboratory observations of the waves of the larger and smaller constant condensers. On the hyperbolic scale the standard deviation as computed from the observations was 0.22 for the smaller constant condenser and 0.09 for the larger constant condenser.

Because the hyperbolic scale is so devised that one scale part by the larger constant condenser trebles that part by the smaller constant condenser, obviously the accuracy will, upon employing an equally divided measuring scale (e.g. a millimeter scale), be the same over the whole measurement area for the reason that the ratio of the first mentioned is very nearly 1/3. The hyperbolic scale is devised for the purpose of obtaining the calibration curves of the different elements as straight lines, which means that one hyperbolic scale part correspondes approximately to one and the same pressure and temperature value within the whole wave area. Because accuracy varies in different scale parts *the accuracy of the Finnish method is dependent upon the order of the degree spacings of the hyperbolic scale.*

In measuring the radiosonde record the basic lines of the hyperbolic scale are placed upon the waves of the two constant condensers and coincident values of the elements are read off the scale. In doing this, standard deviation occurs at the basic lines (σ_k) and at the different elements (σ_e). Because two basic lines are employed we can assume that the basic line standard deviation is half the standard deviation of one wave (σ_k). In this way the standard deviation for measurement is

$$\sigma_m^2 = \sigma_e^2 + \tfrac{1}{2}\,\sigma_k^2.$$

When the element wave falls within the vicinity of the constant condensers, then σ_e will equal σ_k, wherefor e$\sigma_m^2 = 1\tfrac{1}{2}\,\sigma_k^2$. Taking into consideration the mentioned values the standard deviation (σ_m) will be 0.27 and 0.11 near to the smaller constant condenser and to the larger constant condenser, respectively.

When the mean values of the temperature and pressure calibrations are taken into consideration the foregoing hyperbolic scale accuracies will, in pressure measurement, represent accuracies of 4 mb, 3 mb and 1 mb respectively under pressures 1 000 mb, 500 mb and 100 mb, and in temperature measurement the accuracies of 0.3 C°, 0.2 C° and 0.1 C° respectively at temperatures +20° C, —20° C and —60° C. Hence the method gives values of elements with less accuracy in the vicinity of the smaller constant condenser than in that of the larger constant condenser. Because the earth surface values are close to the smaller constant condenser while the stratosphere values are close to the larger constant condenser the observations of lower air levels will be had with less accuracy than those of higher air levels.

Successive calibrations and accuracy of calibration

The radiosonde measurements are based on the individual calibration of thermometers, barometers and hygrometers. Thus, by studying calibration accuracy light will also be shed on the accuracy with which the different elements are measured. Calibration accuracy can be studied by means of successive calibrations. If the time interval between calibrations varies in length it is also possible to study changes occuring in the elements to be measured during different periods of time, and in this way information will be obtained as to basic corrections to be applied and the part they play in measurement accuracy.

Measurement accuracy was checked by successive calibrations carried on both at the factory and Ilmala observatory. Here, the results of an observation series carried on at Ilmala will be given. In this series 5 successive calibrations were made with 16 radiosondes during a period of about 5 months duration in 1951. The calibrations were made in a device adapted to house 8 radiosondes and a mercury manometer for measuring pressure, the temperature being observed by two different methods, viz. employing a thermoelement disposed inside the recipient and a thermometer located in the bath as also a thermoelement adapted to indicate the temperature difference between the bath and the inside air.

On the basis of each calibration a calibration curve was drawn for each radiosonde by employing the generally used method. The thus obtained calibration curves were then used in computing the hyperbolic scale difference between the first calibration and the second, third etc. calibration under certain pressures (for +20° C and —60° C pressure calibration) and certain temperatures. From the thus obtained differences the mean values and the standard deviation were computed. The standard deviation σ_d computed from the difference (Δ) gives the standard deviation σ_c of each calibration upon employing the equation $\sigma_d^2 = 2\sigma_c^2$.

PRESSURE. The mean difference values in Table 1 clearly show a shift taking place under pressure, said shift obviously being due to the aneroid box being gradually compressed. This shows that the employed *aneorid is a relative measuring element* and that it should be further developed and improved. A study of the mean shift under different pressures will show the same to be fairly uniform wherefore *the calibration curve of the barometer appears upon the whole to retain its shape and direction during the shift.* Taking into consideration the shift in barometer a basic correction should be applied to the pressure so the pressure calibration curves shift parallel with the original calibration curves.

The standard deviation here employed serves to give a picture of accuracy. First, we observe accuracy to be poorer under high pressure than under low pressure. When the time interval between calibrations is short and barometer shift smallish the standard deviation is twice as great under a pressure of 1 000 mb than under a pressure of 50 mb. Obviously this is, in part at least, due to the accuracy of the measuring method. Under a pressure of 1 000 mb the standard deviation of the measuring method is 0.27 and under a pressure of 50 mb it is 0.10 wherefore the standard deviation shown by the element itself is, according to column 1 of Table I, 0.47 and 0.16 respectively. Secondly, we ascertain that when the time interval between calibrations lengthens the standard deviation grows to some extent especially under low pressures. Obviously, this must be construed as due to aneroid changes not shifting the calibration curve quite parallel with the original calibration curve.

TEMPERATURE. The thermometer calibration curve shows no clear shift in a certain direction because the algebraic sign of the mean difference changes. Thus, application of basic corrections due to shifting of calibration curve does not here seem necessary.

The standard deviation in temperature calibrations is of the same order as that in pressure calibrations and the maximum and minimum values of standard deviation occur respectively at temperatures of + 20° C and —60° C. Even in this case the order of standard deviation depends partly upon the standard deviation caused by the observation method itself.

Effect of basic corrections on accuracy

The successive calibrations available were also treated so that for each radiosonde the basic correction was determined according to the first calibration while using as comparison observations data the readings of the

Table 1. Mean difference ($\varDelta$) and standard deviation (σ_c) as computed by means of successive calibrations (hyperbolic scale).

Time interval between calibrations		Pressure								Temperature		
		+20° C				—60° C						
		1000	500	200	50	1000	500	200	50	+20°	—20°	—60°
7 days	$\varDelta$	—0.12	—0.09	—0.11	—0.21	—0.02	—0.17	—0.29	—0.37	—0.11	—0.11	—0.08
	σ_c	0.54	0.29	0.31	0.28	0.43	0.25	0.32	0.17	0.55	0.45	0.40
23 »	$\varDelta$	—0.39	—0.33	—0.43	—0.51	—0.42	—0.62	—0.64	—0.69	0.21	—0.05	0.28
	σ_c	0.54	0.30	0.27	0.30	0.65	0.39	0.26	0.27	0.57	0.39	0.28
67 »	$\varDelta$	—0.93	—0.84	—0.85	—0.88	—0.69	—0.81	—0.88	—1.02	0.32	—0.49	—0.12
	σ_c	0.52	0.38	0.37	0.54	0.52	0.46	0.36	0.42	0.55	0.50	0.28
135 »	$\varDelta$	—1.32	—1.06	—1.32	—1.38	—0.92	—0.91	—1.22	—1.57	0.61	0.49	1.02
	σ_c	0.56	0.65	0.57	0.49	0.57	0.57	0.36	0.36	0.61	0.40	0.45

other calibrations for the pressure at + 20° C under a pressure of 1 000 mb, and for the temperature curve the value obtained at a temperature of + 20° C. On the basis of the thus obtained basic corrections the calibrations curves were transformed into new ones and these were then compared with the curves obtained in the calibrations. On the basis of the observed differences the mean difference values (Δ') and the standard deviation σ'_e were computed. The results are presented in Table 2.

PRESSURE. Examination of the mean difference values will show that the algebraic sign changes for the greater part and that the numerical values of the differences are quite small. Hence, it is possible in this way to ascertain that upon the average a quite correct calibration curve of pressure is obtained by application of the basic correction.

The pressure curve amended by application of the basic correction gives, upon the average, an equally great standard deviation over the whole observation range. This means that the standard deviation for real pressure observation increases with decrease of pressure because the standard deviation for observation method decreases upon shifting towards low pressure, i.e., towards the larger constant condenser. Thus we can ascertain that the necessary basic correction in pressure measurement somewhat lowers pressure measurement accuracy under low pressure or in stratosphere.

TEMPERATURE. A basic correction due to continuous changes occuring in the thermometer is not absolutely necessary. Because discontinuity will, if basic corrections are not applied, appear in temperature measurements near the earth's surface it has been considered advantageous to apply a basic correction to temperature also. If the time interval between calibrations is long, upon the average slightly more accurate temperature values will be obtained by application of the basic correction as evident from intercomparison of corresponding mean difference values Δ an Δ' given in the Tables 1 and 2.

Intercomparison of the standard deviation values of the temperature observations in Table 1 and those in Table 2 will show that the basic correction somewhat raises the standard deviation value. This means that due to the effect of the basic corrections the accidental temperature measurement errors grow.

CALIBRATION ACCURACY. Basic corrections are used in soundings wherefore the data in Table 2 serve to give a picture of the accuracy of the real calibration curves. When we take into consideration the mean values of pressure and temperature calibrations we obtain, according to the standard

Table 2. Mean difference (Δ') between calibration curves amended by application af basic corrections and real calibration curves and standard deviation (σ'_c) (hyperbolic scale).

Time interval between calibrations		Pressure							Temperature	
		+20° C			—60° C					
		500	200	50	100	500	200	50	—20°	—60°
7 days	Δ'	0.04	0.06	—0.04	0.05	—0.07	—0.16	—0.24	—0.04	0.13
	σ'	0.43	0.55	0.49	0.42	0.57	0.60	0.57	0.42	0.55
23 »	Δ'	0.06	—0.04	—0.12	0.02	—0.23	—0.25	—0.31	—0.27	0.07
	σ'	0.42	0.54	0.56	0.67	0.52	0.52	0.55	0.74	0.59
67 »	Δ'	0.08	0.08	0.04	0.24	0.12	0.05	—0.09	—0.81	—0.44
	σ'	0.31	0.32	0.34	0.50	0.45	0.40	0.38	0.53	0.57
135 »	Δ'	0.28	—0.01	—0.07	0.42	0.41	0.09	—0.25	—0.12	0.41
	σ'	0.45	0.39	0.38	0.60	0.45	0.35	0.44	0.56	0.55

deviation data in Table 2, for pressure measurement accuracy 8 mb, 6 mb, 4 mb and 4 mb under the pressures 1 000 mb, 500 mb, 200 mb and 50 mb, respectively. The accuracy of the temperature calibration is 0.6 C° throughout the whole measurement area.

Accuracy of soundings

For studying the accuracy of pressure and temperature measurements in sounding, observations were made at Ilmala so that two radiosondes were suspended to one and the same balloon. The upper radiosonde was at a distance of 10 meters from the balloon while the lower radiosonde hung in day-time observations at a distance of 40 meters and in night observations at a distance of 20 meters from the said balloon. Because the upper sonde only was provided with a hygrometer, only the thermometer data and the barometer data could be intercompared on the basis of the observations taken.

From the observations the concurrent pressure and temperature values of the two sondes were measured every even minute. The pressure differrence (Δ P) and the temperature difference (Δ T) were computed by subtracting the values given by the lower sonde from those given by the upper sonde. For each observation pair was computed both the pressure difference mean values and the temperature difference mean values over each 10 minutes period. The thus obtained pressure differences are presented in Table 3 with notations on observation day and observation time. At the foot of the Table 3 is computed separately the mean values of the differences obtained from day and night observations. Table 3 also shows the number (n) of day and night observations. Because in day observations the sondes were 30 meters apart this height difference caused so much difference in pressures and temperatures that the mean values were, when the average pressure and temperature conditions were taken into consideration, reduced to one and the same level. The reduction was not carried on in night observations.

The pressure difference at day time is reversed to that at night. The differences, however, are so small as to be quite possible when the accuracy to be attained is taken into consideration. (Cf. Table 5).

The corresponding temperature differences and the mean values computed therefrom as also the number of observations are presented in Table 4. The mean value of day observations is reduced to one and the same level, but the reduction is not carried on to night observations.

Table 3. Differences of pressure (mb) twin soundings.

Ascending time min.			2—10	12—20	22—30	32—40	42—50	52—60	62—70	72—80
Mean pressure mb			790	490	275	162	96	58	49	30
	Date	GG								
Day soundings	15. 6. 50	11.58	0.6	—2.0	—6.0	—3.6	—4.6	—6.2	—3.3	
	22. 6. 50	02.33	—4.2	—5.6	—7.0	—4.8	—5.6	—5.8		
	22. 6. 50	06.06	—2.0	—1.6	—0.8	—1.0	—1.8	—1.8		
	22. 6. 50	09.52	—6.6	—6.6	—5.0	—4.0	—5.6	—3.4	—5.2	
	8. 5. 51	06.16	4.2	2.2	6.0	4.6	3.8	1.2	2.2	3.0
	17. 5. 51	04.47	—4.6	—2.0	0.6	2.4	3.6	5.0	4.0	2.8
	17. 5. 51	06.43	2.0	0.0	2.0	—0.8	—1.0	—0.2	0.6	
	16. 10. 51	12.47	5.0	10.6	11.0	7.4	8.4	10.0		
	17. 10. 51	12.29	0.6	—2.6	0.2	0.0	—2.0			
	18. 10. 51	13.03	—6.8	—6.4	—6.4	—8.6	—7.2	—6.4	—5.0	
	19. 10. 51	12.42	—10.0	—13.2	—8.6	—8.6	—8.6	—3.6		
	23. 10. 51	12.39	—9.2	—14.8	—12.6	—9.2	—9.4	—9.2		
	24. 10. 51	12.36	1.0	—3.4	—5.6	—3.0	—1.4	—0.2		
	25. 10. 51	12.36	—3.6	0.8	—4.6	—5.4	—3.8	—6.2		
	26. 10. 51	12.43	—14.2	—14.6						
	ΔP		—0.1	—1.7	—0.9	—1.2	—1.6	—1.6	—0.8	
	n		15	15	14	14	14	13	6	2
Night soundings	16. 10. 51	15.11	—1.2	8.0	8.5	11.0	9.2	10.0		
	18. 10. 51	15.09	0.0	—1.0	3.0	5.2	3.0	—1.8		
	19. 10. 51	15.12	0.5	0.4	—1.0	5.2	7.6	8.8		
	23. 10. 51	14.52	—5.8	—10.6	—7.8	—1.2	—1.8	0.0		
	24. 10. 51	14.47	—4.8	—0.5	4.0	5.2	6.2	4.0		
	25. 10. 51	14.54	0.0	—	—	—5.5	—4.0			
	26. 10. 51	14.41	3.8	1.0	0.2	6.0	6.2	6.4	6.0	
	24. 1. 52	14.31	—	—1.4	—1.4					
	28. 1. 52	14.34	—3.8	—2.8	—2.6	—1.2	—2.4	1.0		
	5. 2. 52	02.35	—2.6	3.8	3.5	6.0				
	12. 2. 52	03.09	0.0	2.2	4.0	1.4	1.4			
	14. 2. 52	02.32	—0.4	9.0						
	29. 10. 52	14.32	—4.2	0.6	—0.2	—1.0	3.0	—2.0		
	30. 10. 52	14.37	3.0	—1.0	—0.8	0.0	0.8	1.1		
	31. 10. 52	14.34	2.4	4.0	7.4	8.4	10.0			
	1. 11. 52	14.30	12.0	12.8	11.8	10.0	7.8	7.0		
	ΔP		—0.1	1.6	2.0	3.5	3.6	2.4	—	
	n		15	15	14	14	13	10	1	

Table. 4. Differences of temperature (°C) twin soundings.

Ascending time min.			2—10	12—20	22—30	32—40	42—50	52—60	62—70	72—80
Mean pressure mb			790	490	275	162	96	58	49	30
	Date	GG								
Day soundings	15. 6. 50	11.58	—0.6	—0.8	—0.9	0.7	0.4	0.1	0.2	
	22. 6. 50	02.33	0.2	0.2	—0.1	0.4	—0.1	—0.6		
	22. 6. 50	06.06	0.3	—0.1	—0.3	0.7	0.2	—0.2		
	22. 6. 50	09.52	1.4	2.0	1.5	—0.4	—0.2	—0.4	—0.8	
	8. 5. 51	06.16	—0.8	—1.0	—0.5	—0.9	—0.7	—0.7	—0.7	0.2
	17. 5. 51	04.47	0.1	0.0	0.0	0.4	0.3	0.7	0.8	2.1
	17. 5. 51	06.43	1.0	1.5	1.6	1.7	1.9	1.7	2.0	
	16. 10. 51	12.47	0.8	1.0	1.1	1.6	1.3	1.3		
	17. 10. 51	12.29	0.1	—0.6	—1.2	—1.1	—0.8			
	18. 10. 51	13.03	0.0	—1.2	—1.7	—1.7	—1.7	—2.5	—2.8	
	19. 10. 51	12.42	—0.4	—0.7	—0.5	0.0	—0.3	—0.5		
	23. 10. 51	12.39	—0.2	0.3	0.9	1.6	1.1	1.0		
	24. 10. 51	12.36	0.4	—0.5	—0.4	0.0	0.0	0.2		
	25. 10. 51	12.36	—0.5	—0.6	—0.8	—0.6	—0.7	—0.4		
	26. 10. 51	12.43	—0.8	—0.9						
		ΔT	—0.1	—0.3	—0.3	—0.3	—0.0	0.0	—0.2	—
		n	15	15	14	14	14	13	6	2
Night soundings.	16. 10. 51	15.11	0.1	0.5	0.0	0.3	0.4	0.7		
	18. 10. 51	15.09	—0.5	—1.3	—1.4	—1.0	—1.1	—1.0		
	19. 10. 51	15.12	0.3	—0.3	—2.2	—2.8	—2.9	—3.0		
	23. 10. 51	14.52	0.7	—0.5	—0.5	—0.7	—0.7	—0.7		
	24. 10. 51	14.47	0.0	0.5	0.4	0.2	0.2	0.3		
	25. 10. 51	14.54	0.9	1.5	—	—	1.2	1.3		
	26. 10. 51	14.41	0.4	0.3	—0.7	0.2	—0.2	0.4	0.0	
	24. 1.52	14.31	—	—2.3	—1.5					
	28. 1. 52	14.34	—0.6	—0.8	—0.2	—0.2	0.0	0.2		
	5. 2. 52	02.35	—0.7	—1.1	—1.2	—1.4				
	12. 2. 52	03.09	—0.1	—0.4	—0.2	—0.6	—0.7			
	14. 2. 52	02.32	—0.3	—0.4						
	29. 10. 52	14.32	—0.4	—0.3	0.0	0.0	0.0	0.0		
	30. 10. 52	14.37	1.1	0.9	1.4	1.6	1.3	1.2		
	31. 10. 52	14.34	—0.3	—1.1	—0.9	—0.8	—0.6			
	1. 11. 52	14.30	—0.2	—0.3	—0.4	—0.9	—1.0	—0.7		
		ΔT	0.0	—0.3	—0.5	—0.4	—0.3	—0.1	—	
		n	15	16	14	13	13	11	1	

Both at day and night the temperature difference is negligibly small. Taking into consideration the fact that in day observations the Sun's height angle varied from 14° to 42° it seems probable that the distance between the sonde and the balloon has no noteworthy effect on temperature measurements, which result deviates from the results presented by RAAB and RODSKJER (2). Insofar as the balloon warms the air and this is observed with the sonde, the effect described will still appear at a distance of 40 meters from the balloon or then the effect is so small as to be unaccountable for with the accuracy attained.

The standard deviation was computed from both the pressure and the temperature differences. When observation is taken with one sonde and the standard deviation is σ_l, then the standard deviation of the observed difference is $\sigma_\Delta = \sqrt{2}\,\sigma_l$ wherefore $\sigma_l = \frac{1}{\sqrt{2}}\sigma_\Delta$. From the observations taken were computed separately standard deviation for pressure and for temperature of the day observations and separately those of the night observations. Table 5 shows the data obtained.

Table 5. Standard deviation of pressure (σ_p) and temperature (σ_T) computed with twin soundings.

Ascending time min		2—10	12—20	22—30	32—40	42—50	52—60	62—70
Day	σ_p mb	4.8	5.2	4.4	3.6	3.6	3.5	3.1
	σ_T °C	0.52	0.68	0.76	0.77	0.69	0.78	0.82
Night	σ_p mb	4.4	4.0	4.1	3.0	3.2	3.3	—
	σ_T °C	0.46	0.66	0.68	0.72	0.78	0.82	—

Examination of Table 5 will show that the standard deviation for *pressure measurement* is fairly the same both at night and day. At lower levels pressure measurement is more inaccurate than higher up. The standard deviation of *temperature measurement* is at its minimum, 0.5° C, near the earth's surface and increases slightly to 0.8° C on moving upwards.

Upon intercomparing the standard deviation data obtained from twin soundings and successive calibrations it will be observed that the standard deviation of pressure is in soundings slightly smaller than that in successive calibrations. Again, standard deviation of temperature is in soundings near the earth's surface smaller and in soundings higher up slightly greater than that by calibrations. The differences, however, are so minute as not to justify the drawing of definite conclusions in one way or the other. However, it seems probable that *in sounding the pressure and temperature observations are obtained with as great accuracy as those in calibrations.* This means that no disturbances whatever due to ascent or flight occur in the measuring elements of the Finnish radiosondes.

The height of standard levels

The heights of standard levels were computed from each observation. The data obtained were then used in computing, from twin soundings, the height differences at levels of 850, 700, 500, 300, 200 and 100 mb.

The results obtained are presented in Table 6. This Table shows that the difference upon the average is quite small and that the maximum difference at a level of 850 and 700 mb is about 0.5 % of the height and at higher levels about from 0.5 % to 0.9 % of the height. The standard deviation of height of the isobar level as computed by means of the differences is from 0.1 % to 0.3 % of the height.

Observations with three theodolites and accuracy of pressure measurement

To determine the accuracy of pressure observations the radiosonde balloons were followed with three theodolites placed at the corners of a triangle having sides measuring about 8, 10 and 12 kilometers, respectively. Radiotelephony interconnected the theodolites personel and gave the time signals, which were also entered in the recording charts. Thus, all the observation points received the time signals at precisely the same moment. Some balloons carried two radiosondes arranged respectively at 10 meters and 40 meters distance from the balloon.

The observations were made during daytime. For this reason radiation errors occur in the measurements. The temperatures measured were corrected by means of a radiation correction error computed for the Finnish radiosonde [(3) and (5)].

From the observations made with the theodolites the heights of three different observation pairs were computed. The mean value of these was considered as real height. The standard deviation σ_{Th} between separate observation pairs and this mean value can be regarded as representing

Table 6. Height differences (gpm) of standard levels according to results of twin soundings (upper-lower) and standard deviation σ_H (gpm) of one height value.

	Date	GG	850	700	500	300	200	100
Day soundings	15. 6. 50	11.58	—2	—11	—8	—4	4	5
	22. 6. 50	02.33	1	1	5	9	4	—13
	22. 6. 50	06.06	2	6	5	1	6	21
	22. 6. 50	09.52	5	16	40	77	83	75
	8. 5. 51	08.16	—6	—11	—29	—45	—45	—62
	17. 5. 51	04.47	1	0	3	—3	—1	6
	17. 5. 51	06.43	3	9	23	43	65	103
	16. 10. 51	12.43	—1	5	—2	—1	—6	21
	17. 10. 51	12.29	0	1	—2	—18	—27	—34
	18. 10. 51	13.03	2	5	6	0	—11	—46
	19. 10. 51	12.42	6	12	25	34	35	36
	23. 10. 51	12.39	1	1	14	53	88	5
	24. 10. 51	12.31	2	2	3	6	9	14
	25. 10. 51	12.31	—1	—2	—8	—21	—27	—40
	26. 10. 51	12.43	0	2	0			
	⊿H		1	2	5	10	13	6
	σ_H		2	5	11	22	28	31
Night soundings	16. 10. 51	15.11	5	9	9	—7	—34	—27
	18. 10. 51	15.09	1	—2	—8	—33	—51	—73
	19. 10. 51	14.12	0	2	5	—2	—32	—87
	23. 10. 51	14.52	3	9	21	34	41	28
	24. 10. 51	14.47	1	4	11	12	9	14
	25. 10. 51	14.54	6	14	30			
	26. 10. 51	14.41	1	3	6	16	15	19
	24. 1. 52	14.34	0	0	—12	—43	—59	
	28. 1. 52	14.34	0	—2	—9	—13	—18	—27
	5. 2. 52	02.35	—3	—4	—11	—39	—50	—74
	12. 2. 52	03.09	—1	—3	—6	—15	—28	—47
	14. 2. 52	02.32	—2	—3				
	29. 10. 52	14.32	0	—1	—5	—6	—3	2
	30. 10. 52	14.37	4	11	11	38	54	86
	31. 10. 52	14.34	—1	—2	—12	—39	—45	—65
	1. 11. 52	14.30	—2	—9	—24	—49	—64	—82
	⊿H		1	2	1	—10	—19	—24
	σ_H		2	4	10	19	25	35

the accuracy of the observations taken with three theodolites. The standard deviation is computed for heights reached during different ascending times. The results obtained are presented in Table 7 which shows that the standard deviation in observations taken with theodolites up to a height of 7 kilometers is about 15 meters and grows with further ascension. At a height of 20 kilometers the standard deviation is about 100 meters wherefore the balloon height obtained with the three theodolites i squite accurate.

The difference ($\Delta_{Th\text{-}RS}$) between the mean height computed from the theodolite observations and the height computed from soundings provides a basis for studying the accuracy of pressure measurement. In computing this difference naturally the height difference between the balloon and the sondes must be taken into consideration. As evident from Table 7 the theodolite observation gives, upon the average, a somewhat higher height than that computed by means of sounding. Near the earth's surface the difference is the smallest and increases on moving upwards to a height of about 23 kilometers and then decreases again on further ascension. The standard deviation of this difference ($\sigma_{Th\text{-}RS}$) (cf. Table 6) shows that the standard deviation of height computed from a certain sounding point is 56 meters near the earth's surface but increases fairly rapidly with increasing height. Thus we can ascertain that the height accuracy of a certain sounding point is 2—5 % of the height. The computed height deviation of a certain sounding point is, again, dependent upon both the pressure measurement standard deviation σ_p at said point and the standard deviation σ_Φ due to the temperature and the pressure standard deviations brought about in the height between the said point and the earth's surface. Hence $\sigma^2_{Th\text{-}RS} = \sigma^2_p + \sigma^2{}_\Phi$. According to Nyberg (1) $\sigma_\Phi = a\sqrt{\sigma^2_T + b\sigma^2_p}$, wherein the factor a is dependent upon Φ and the factor b upon the lapse rate. In computing the values of σ_Φ, let us assume that $\sigma_T = 0.7$ and $\sigma_p = 5$ mb which correspond to the standard deviation values obtained from twin soundings. By using the thus computed σ_Φ values we obtain the values for σ_p in gpm and mb presented in Table 7. This indicates that the standard deviation of pressure observations is now slightly greater than that in twin soundings. This may partly be due to the smaller number of observations.

Because the height derived from the observations made with theodolites is slightly greater than that obtained from observations made with soundings there is cause to touch a little upon this matter. Obvious ly the sounding height computed from pressure, temperature and humidity observations is systematically too great because the thermometer lag has

Table 7. The results of soundings and observations with three theodolites. Number of theodolite observations is 4 and that of soundings 7.

Ascending time	2—10	12—20	22—30	32—40	42—50	52—60	62—70	72—80	82—90	min.
Approximate height.	0—3	3—6	6—9	9—12	12—15	15—19	19—23	23—27	27—30	gpkm
Δ_{Th-RS}	—6	22	24	66	106	162	323	173	41	gpm
σ_{Th}	12	16	15	44	98	103	98	255	359	—»—
σ_{Th-RS}	56	80	103	189	275	470	827	1276	1222	—»—
σ_p	54	79	102	184	258	458	820	1252	1213	—»—
σ_p	5.4	6.2	5.6	6.8	5.8	6.4	5.9	5.0	3.4	mb

not been taken into consideration. When the accuracy of the pressure measurement forms the basis of the investigation it is probable that the radiosonde barometer is free of systematic errors.

Conclusions

The observation method of the Finnish radiosonde gives an accuracy which varies to some extent, in the different parts of the temperature and pressure scale. This is a defect which should be corrected although the results already as such are quite satisfactory.

The accuracy of the pressure and temperature measurements is practically of the same order when determined either by successive calibrations or twin soundings This indicates that to reach greater accuracy the constructional details of the devices employed must be developed.

The observations of the radiosonde balloons made with the three theodolites indicate that the barometer of the Finnish radiosonde is free of systematic errors.

When using the *double value of standard deviation* as measure for accuracy we obtain, on the basis of the foregoing comparison results, an accuracy of *10 mb for pressure* measurement and an accuracy of *1.5° C for temperature* measurement and an accuracy of *0.5 % for height of standard levels.*

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