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ON THE ACCURACY OF WIND MEASUREMENTS MADE WITH THE RADIOTHEODOLITE USED DURING THE SWEDISH—FINNISH—SWISS IGY EXPEDITION TO SPITZBERGEN

by

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Abstract

The accuracy of the Finnish radiotheodolite observations is discussed in the light of the data collected by the Swedish-Finnish-Swiss IGY Expedition to Spitzbergen.

Introduction

Finland took part in the Swedish-Finnish-Swiss IGY Expedition to Murchison Bay in North-East Land, close to the north coast of Spitzbergen. The geographical coordinates of the Station are lat. 80°03.5′ N, long. 18°15′ E and the altitude 7 m. The leader of the expedition was Prof. GÖSTA H. LILJEQUIST, of the University of Uppsala, and altogether 13 men wintered at this station.

The aerological (PTUW) observations were sponsored by the Finnish National Committee for the International Geophysical Year. The Finnish members of the expedition were: Mr. MATTI J. T. ARO, physician, Mr. ERKKI GRÖNDAHL, radiosonde technician, and the writer, acting as leader of the aerological group. In addition, Mr. MATTI WILSKA, an engineer from the company Vaisala Oy/Ltd., took part in the establishment of the aerological station. Besides the Finnish participants most of the other members of the expedition also took part in the aerological work.

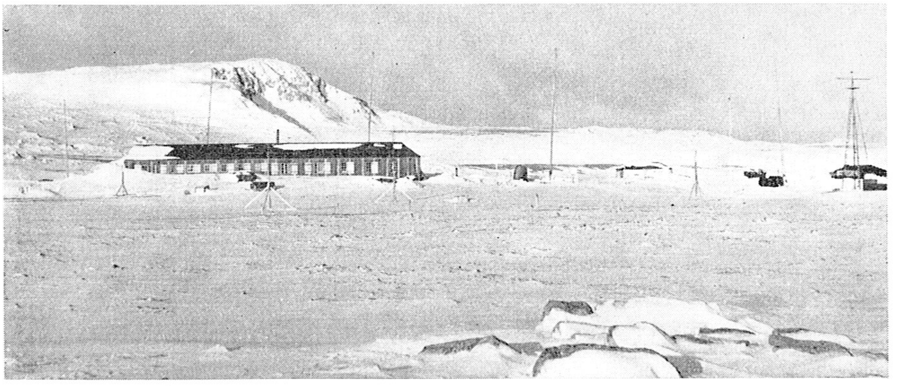

Fig. 1. A general view of the base of the expedition.

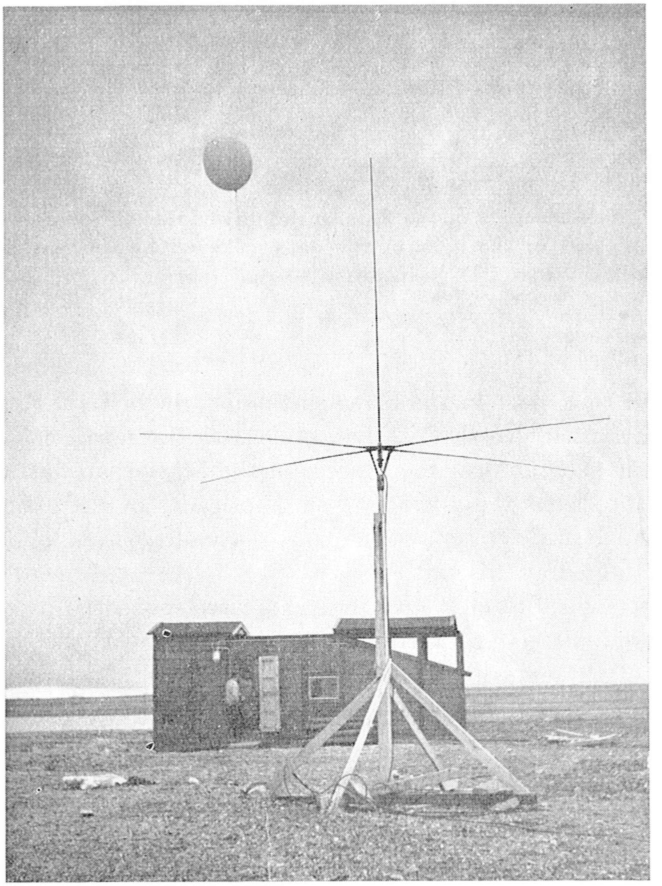

Fig. 2. Launching the radiosonde from the balloon hut. A radiotheodolite antenna on the foreground.

The sounding equipment (PTU and RT receivers with accessories) was loaned to the expedition by the firm Vaisala Oy/Ltd. The radiosondes were obtained from the same firm.

Observations

A total of 874 PTU soundings was performed; for 851 of these a wind sounding was obtained with the radiotheodolite. Thus, 23 soundings are totally without wind data. Wind data are lacking 25 times between the 300 mb level and the bursting height of the balloon and 3 times between 500 and 300 mb. In most of these cases the balloon was actually tracked by means of the RT up to the bursting height but owing to the very small elevation angle (11—9 degrees) the wind velocities obtained were too uncertain to be accepted.

Whenever the weather permitted, the balloon was also tracked by means of an optical theodolite. In all, 134 wind soundings were made both with the radiotheodolite (RT) and with the optical theodolite (OT). These soundings are tabulated according to the different months in the table below:

Table 1. Distribution of the soundings according to the different months.

Month	VIII	IX	X	XI	XII	I	II	III	IV	V	VI	VII	VIII	Total
Number of soundings	1	14	5	8	11	6	5	20	24	16	11	6	7	134

The OT observations were used for examining the accuracy of the RT wind soundings. In this investigation the OT observations are regarded as free from errors. This assumption, of course, is not strictly valid, but since it is a well known fact that the accuracy of OT observations is essentially better than that of RT observations, the combined error RT + OT renders a good idea of the accuracy of the radiotheodolite.

In this investigation the following notations have been used:

A = azimuth angle,
A_0 and A_R = azimuth angle with OT and RT, respectively,
a = the mutual distance of the RT antennas,
dd = wind direction (degrees),
ff = wind velocity (knots),
h = elevation angle,
h_0 and h_R = elevation angle with OT and RT, respectively,

M = mean,
MD = mean deviation,
N_x and N_y = the phase differences of RT [2],
n = number of observations,
OT = optical theodolite,
RT = radiotheodolite,
ΔA = $A_R - A_0$, $\Delta h = h_R - h_0$, $\Delta dd = dd_R - dd_0$ and $\Delta ff = ff_R - ff_0$,
σ = standard deviation,
λ = wave length.

The wind was computed at 2-minute intervals around the levels 850, 700, 500, 400, 300, 200, 150, 100, 70, and 50 mb. From these data the differences RT — OT were computed for the following quantities: A (degrees), h (degrees), dd (degrees) and ff (knots). The differences ΔA and Δh were corrected according to the wave front curvature of the incoming radio signal as well as for the eccentric position of the OT [3]. These corrections are of minimal significance for the wind data (dd, ff) which therefore have not been corrected.

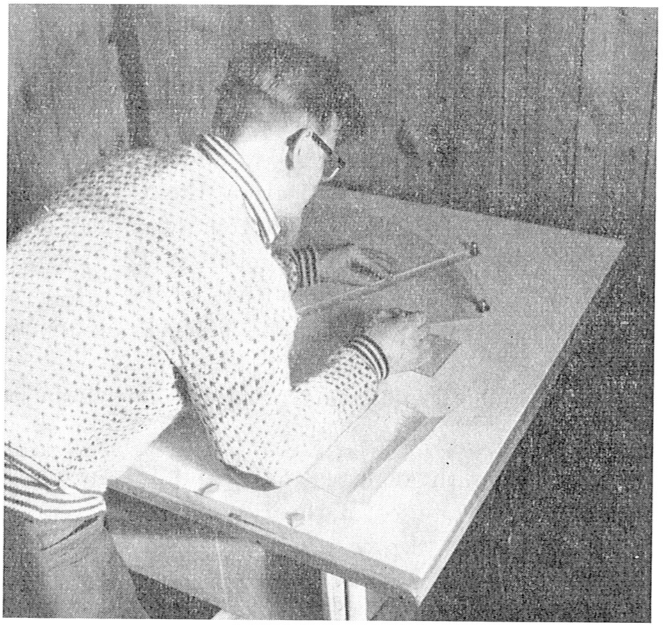

Fig. 3. Evaluation of an upper-wind measurement.

In most cases, about 82% of all, the 24 Mc/s frequency of the radiosonde was used for tracking the balloon. Only these observations will be treated in this investigation.

Dependence of the elevation angle error on the elevation

Generally, the mean value of each error, representing the systematic error, and the mean deviation from it or the random error, were examined. The whole material was grouped according to suitable principles and the M and MD of these groups were calculated.

Table 2. Elevation angle error Δh.

$h°$	$\leqq 17$	17—20	20—24	24—30	30—40	40—55	55—75	>75	M
M	−0.18	−0.18	−0.02	0.24	0.22	0.03	−0.05	−0.41	0.04
MD	±0.60	±0.55	±0.51	±0.42	±0.37	±0.52	±0.38	±0.43	±0.44
n	16	30	34	101	204	218	152	12	767

All elevation angles of less than 17 degrees are included in the same group. The notations 17—20, 20—24, etc., actually mean a difference from 17.1° to 20.0°, 20.1°—24.0° and so on. On examination of the mean of the groups, it is seen that the mean is less than 0.24° except in the last group, in which the elevation angle >75°. High values of MD are a consequence of the fact that Table 2 contains all soundings while MD of the individual soundings, as we can see from Table 8, is only about a half or a third of the above values.

Dependence of the systematic errors ΔA and Δh on the balloon azimuth

When examining the dependence of azimuth and elevation angle errors on the balloon azimuth the material was grouped in 8 groups of 45 degrees each (see Table 3).

In each of these eight groups the mean value of the errors ΔA and Δh as well as the MD of observations and the standard deviation σ of each mean value, is calculated. In this case n denotes the number of observations in each group.

In figures 4 and 5, M and σ have been plotted in accordance with Table 3. The balloon azimuth is the abscissa and the error is the ordinate

Table 3. Dependence of ΔA and Δh on the balloon azimuth.

$A°$	0—45	45—90	90—135	135—180	180—225	225—270	270—315	315—360
n	82	57	101	125	94	99	109	103
				Azimuth angle error ΔA				
M	−0.25	0.04	0.28	0.40	0.21	−0.03	−0.39	−0.21
MD	±0.34	±0.61	±0.53	±0.36	±0.51	±0.40	±0.37	±0.40
σ	±0.04	±0.07	±0.05	±0.04	±0.05	±0.04	±0.04	±0.04
				Elevation angle error Δh				
M	0.29	0.27	0.13	0.04	−0.21	−0.19	−0.14	0.40
MD	±0.45	±0.29	±0.47	±0.38	±0.39	±0.39	±0.38	±0.30
σ	±0.05	±0.04	±0.05	±0.03	±0.04	±0.04	±0.04	±0.03

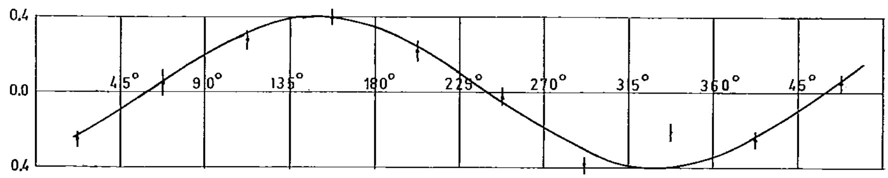

Fig. 4. Dependence of the systematic error ΔA on the balloon azimuth.

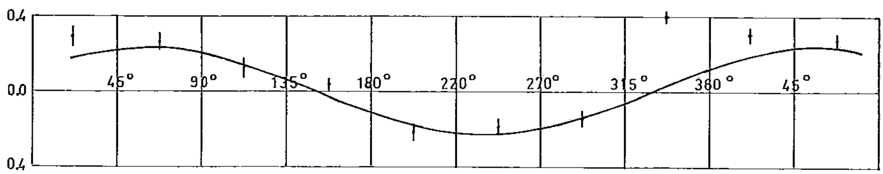

Fig. 5. Dependence of the systematic error Δh on the balloon azimuth.

of the plots. The plots were approximated by the following empirical sine-curves

$$\begin{cases} \Delta A = 0.40 \sin (A - 60°) \ °C \\ \Delta h = 0.23 \sin (A + 30°) \ °C \, . \end{cases} \tag{1}$$

The former curve has been drawn in figure 4 and the latter one in figure 5. It will be seen that these curves run through the M points at the limits of the standard deviations (σ), except in the group 315°—360° where both ΔA and Δh deviate remarkably from the sine-curves. The ΔA point in group 270°—315° and the Δh point in 0°—45° also fall a little outside the curves.

The regularly running systematic error can be explained as the zero

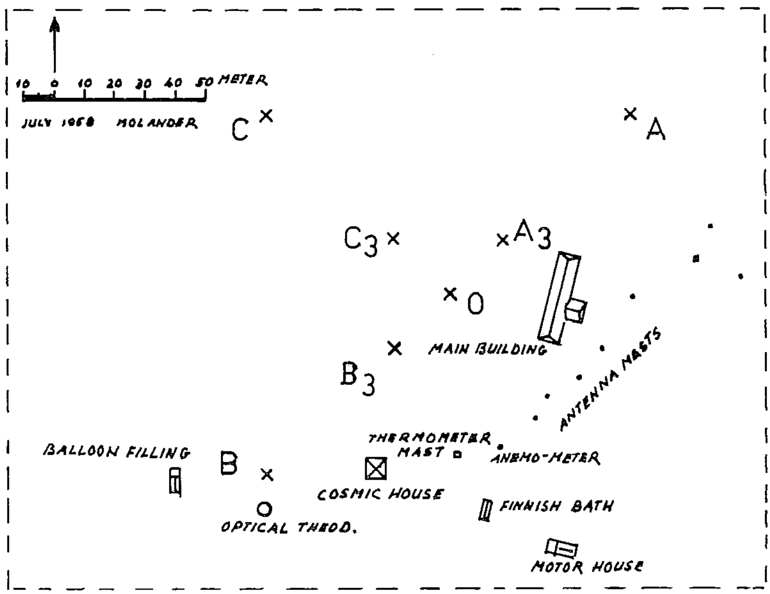

Fig. 6. The position of the RT antenna field.

errors of RT readings N_x and N_y and the exceptional deviations the influence of some outer disturbing reflectors (masts etc.).

Figure 6 shows the position of the RT antenna field. The antennas are erected at the points A, B, C, A_3, B_3, C_3, and 0. The azimuth angles used are calculated from the south or CB direction ($= 0°$) westwards. Then the system of radiomasts and antennas for the radio communications of the base and not belonging to the RT are situated in the sector between 290°—340°. Therefore the assumption that the deviations from the sine-curves are caused by the reflections in these extra reflectors seems quite acceptable.

To explain the influence of zero errors in N_x and N_y we have to take into account that the coordinate systems of RT and OT do not coincide but that of the latter is turned 90° clockwise from the former. In this way we get the following equations for the RT when using the azimuths according to the OT coordinate system [2]:

$$\begin{cases} \dfrac{\lambda}{a} N_x = -\cos h \sin A \\ \dfrac{\lambda}{a} N_y = \cos h \cos A \end{cases} \tag{2}$$

Here N_x and N_y are the observed direction readings. We assume that there exist zero errors, ξ in N_x and η in N_y, and consequently $N_x - \xi$ and $N_y - \eta$ are the correct readings. If the corresponding elevation and azimuth angles are denoted with h' and A' we obtain instead of (2) the following:

$$\begin{cases} \frac{\lambda}{a}(N_x - \xi) = -\cos h' \sin A' \\ \frac{\lambda}{a}(N_y - \eta) = \cos h' \cos A' \end{cases} \tag{3}$$

Subtracting (2)—(3) and replacing the differences by differentials we get:

$$\begin{cases} \frac{\lambda}{a}(-\xi \sin A + \eta \cos A) = -\sin h \cdot \Delta h \\ \frac{\lambda}{a}(\xi \cos A + \eta \sin A) = -\cos h \cdot \Delta A \end{cases} \tag{4}$$

where

$$\begin{cases} \Delta h = h - h' \\ \Delta A = A - A' \end{cases}$$

Denoting:

$$\begin{cases} \xi = r \sin \varphi \\ \eta = -r \cos \varphi \end{cases} \tag{5}$$

we obtain:

$$\begin{cases} \Delta A = \frac{\lambda r}{a \cos h} \sin (A - \varphi) \\ \Delta h = \frac{\lambda r}{a \sin h} \cos (A - \varphi) = \frac{\lambda r}{a \sin h} \sin (A - \varphi + 90^\circ) \end{cases} \tag{6}$$

Comparing these equations with (1), in which 0.40° and 0.23° are expressed in radians, we get:

$$\frac{\lambda r}{a \cos h} = \frac{0.40}{57.3}, \frac{\lambda r}{a \sin h} = \frac{0.23}{57.3}, \varphi = 60^\circ . \tag{7}$$

From these equations it follows further that:

$$\cot h = \frac{0.23}{0.40} = 0.575 \text{ or } h = 60.1^\circ$$

$$\begin{cases} \cos h = 0.498 \\ \sin h = 0.866 \end{cases}$$

Table 5. Dependence of ΔA, Δh, Δdd and Δff on the wind velocities at different pressure levels.

		≤ 5 knots				6−20 knots				21−40 knots				41−60 knots				≥ 61 knots			
		ΔA	Δh	Δdd	Δff	ΔA	Δh	Δdd	Δff	ΔA	Δh	Δdd	Δff	ΔA	Δh	Δdd	Δff	ΔA	Δh	Δdd	Δff
850 700	M	0.71	−0.27	−3.5	0.6	0.03	−0.02	−0.2	−0.1	−0.08	0.14	0.1	0.0								
	MD	±0.67	±0.40	±15.1	±0.6	±0.58	±0.51	±4.1	±1.0	±0.23	±0.39	±1.9	±1.7								
	n	20				162				35											
500 400 300	M	0.56	−0.23	3.2	0.0	0.18	0.08	0.2	0.2	−0.07	0.21	−0.2	0.1	−0.03	0.19	0.6	1.1	0.06	−0.56	−0.1	8.5
	MD	±0.50	±0.28	±15.7	±0.1	±0.59	±0.37	±3.6	±1.0	±0.39	±0.46	±1.9	±2.4	±0.23	±0.42	±1.1	±2.5	±0.14	±0.79	±1.1	±10.0
	n	11				128				136				29				7			
200 150	M	0.19	0.08	12.0	1.2	−0.04	0.06	−0.3	0.2	0.00	0.25	−0.8	0.8	0.00	0.00	−1.0	4.0				
	MD	±0.40	±0.24	±23.1	±1.4	±0.47	±0.39	±5.0	±1.6	±0.22	±0.42	±3.8	±4.4	±0.20	±0.20	±1.0	±0.0				
	n	20				86				26				2							
100 70 50	M	−0.15	0.12	−5.0	1.4	−0.13	0.12	−1.1	−0.4	−0.04	0.02	1.2	0.2								
	MD	±0.54	±0.44	±26.3	±2.1	±0.36	±0.38	±10.3	±2.4	±0.15	±0.49	±3.2	±3.4								
	n	25				76				9											

and

$$\frac{\lambda r}{a} = \frac{0.40}{57.3} \times 0.498 = \frac{0.23}{57.3} \times 0.866 = 0.00348.$$

Since $\lambda = 12.5$ m, $a = 120$ m, we get the value of r:

$$r = \frac{120}{12.5} \times 0.00348 = 0.0334 \tag{8}$$

Finally ξ and η are computed from (5):

$$\begin{cases} \xi = 0.0334 \times 0.866 = 0.029 \approx 0.03 \\ \eta = -\ 0.0334 \times 0.498 = -\ 0.017 \approx -0.02 \end{cases} \tag{9}$$

Thus, the constant zero errors 0.03 and $-$ 0.02 in the theodolite readings N_x and N_y respectively, cause the smoothed systematic errors in azimuth and elevation angles as shown by the sine-curves in figures 4 and 5. It has to be noticed that the reading accuracy of RT direction components N_x and N_y is of the order of magnitude of 0.01.

Dependence of ΔA, Δh, Δdd and Δff on the wind velocity at different pressure levels

Table 5 contains the mean values (M) and the mean deviations (MD) of different RT errors at certain constant pressure levels at different wind speeds and grouped as follows: 850—700, 500—300, 200—150 and 100—50 mb. The mean values M, i.e. the systematic errors, are so small that they have no practical significance.

The mean deviations MD show that the wind velocity is obtained more accurately for lighter winds while the wind direction is naturally more accurate for higher wind speeds. The wind errors, both in direction and velocity, increase at all wind speeds from 200 mb upwards, i.e. in the lower stratosphere. As to the direction errors ΔA and Δh it is seen that their MD is only slightly dependent on the altitude, probably diminishing a little with increasing altitude. We can obtain a better idea of the situation by combining all the data of Table 5, first as regards the dependence on wind speed, then on altitude.

It will be seen from these tables that random error (mean deviation) of the elevation angle h may increase slightly with wind speed (Table 6) but is more or less independent of the altitude (Table 7). The azimuth error diminishes with increasing wind velocity and slightly also with increasing altitude. Concerning the random wind errors, the direction

Table 6. Mean deviation of RT errors in dependence on wind velocity.

Windspeed	ΔA	Δh	Δdd	Δdd	Δff
knots	degrees			knots	
≤ 5	±0.53	±0.35	±21.0	±1.3	±0.6
6—20	.52	.42	5.2	1.4	1.3
21—40	.33	.44	2.2	1.2	2.6
41 ≤	.18	.47	1.1	1.0	3.7

Table 7. Mean deviation of RT errors in dependence on altitude.

Altitude	ΔA	Δh	Δdd	Δdd	Δff
mb	degrees			knots	
850—700	±0.53	±0.48	± 4.7	±1.1	±1.1
500—300	.65	.41	3.0	1.0	1.9
200—150	.40	.37	7.4	1.4	2.1
100— 50	.37	.40	13.3	2.4	2.0

error decreases, as stated earlier, with increasing wind speed but increases with altitude. As a given error in wind direction has smaller significance in a light wind than in a strong wind, it is advisable also to calculate the error component (in knots) perpendicular to the wind direction. This is obtained by multiplying the direction error (in radians) by the wind velocity. These values are also given in Tables 6 and 7 (Δdd knots). This error is of about the same magnitude as the wind speed error, but as the latter increases with increasing wind velocity the former seems to decrease slightly.

Some examples of individual soundings

In Table 8 we have reproduced the results concerning four individual soundings with different flying directions and wind speeds, namely on 18. 9. 57, 4. 3. 58, 5. 4. 58 and 23. 6. 58. The values are given for even minutes, also used for calculating the wind. For each observed direction the azimuth and elevation angles and their errors are given. The wind is computed for every two-minute interval. The errors of each wind direction and speed are given, the direction error also as a component error perpendicular to the wind direction (Δdd knots). The arithmetic mean M of each error, i.e. the systematic part of the error, as well as the mean

Table 8. Four samples of individual wind soundings.

18. 9. 57 at 05.17 o'clock

min	A_0	ΔA	h_0	Δh	dd_0	Δdd	ff_0	Δff	Δdd
					degrees		knots		
10	228.9	0.3	65.0	−0.5	258	2	12	0	0
12	237.9	0.4	61.7	−0.3	247	−4	13	−1	−1
14	239.9	−0.3	58.2	−0.2	259	0	13	0	0
16	243.6	−0.3	56.2	−0.6	288	−4	14	1	−1
18	251.7	−0.6	54.3	−0.2	284	1	19	−1	0
20	258.1	−0.4	51.7	−0.1	289	−1	19	0	−0
22	263.3	−0.2	49.2	−0.2	288	4	19	2	1
24	267.9	−0.3	47.2	−0.2	306	−4	24	−2	−2
26	272.9	−0.3	45.3	−0.4	306	0	25	1	0
28	277.7	−0.5	43.3	−0.3	315	−5	25	−4	−2
30	282.2	−0.8	41.7	−0.2	320	6	26	1	3
32	286.6	−0.7	40.2	0.3	312	−4	18	4	−2
34	288.6	−0.6	39.5	0.0	312	−2	18	2	−1
36	290.1	−0.4	38.9	−0.3	318	10	13	−1	2
38	291.8	−0.4	38.6	0.1	312	−2	15	0	−1
40	292.7	−0.3	38.2	0.0	314	0	11	2	0
42	293.7	−0.2	38.4	−0.2	322	−4	17	−1	−1
44	295.0	−0.2	38.2	−0.1	312	−2	13	2	−1
46	295.9	−0.4	38.3	−0.3	325	−5	15	0	−1
48	297.1	−0.5	38.4	−0.5	300	0	16	−2	0
50	297.2	−0.3	38.2	0.0	300	0	14	−2	0
52	297.4	−0.4	38.0	0.2	300	2	15	1	1
54	297.6	−0.3	38.0	−0.1	317	−5	14	3	−1
56	298.0	−0.4	37.9	−0.3	312	−2	16	5	−1
58	298.7	−0.2	37.7	−0.5	314	−1	14	−1	−0
60	299.1	−0.3	37.8	−0.6					
M		−0.33		−0.21		−0.8		0.4	0.0
MD		±0.16		±0.17		±2.6		±1.6	±0.9

4. 3. 58 at 10.54 o'clock

min	A_0	ΔA	h_0	Δh	dd_0	Δdd	ff_0	Δff	Δdd
					degrees		knots		
4	108.6	0.0	27.9	−0.3	98	0	38	3	0
6	103.8	0.2	23.6	−0.5	95	1	48	1	1
8	100.8	0.2	20.9	−0.4	92	−1	47	0	−1
10	98.1	0.1	19.8	−0.1	80	3	49	−1	3
12	94.9	0.1	18.9	0.1	82	0	48	2	0
14	92.7	0.1	18.5	0.1	88	0	48	6	0
16	91.9	0.1	18.1	0.0	84	0	48	−2	0
18	90.9	−0.1	17.7	0.0	83	−1	54	−1	−1
20	90.0	−0.1	17.4	0.1	78	4	52	0	4
22	88.7	0.3	16.9	0.2	78	0	41	0	0
24	87.8	0.4	16.7	0.2	80	0	42	6	0
26	87.2	0.3	16.5	0.1	74	2	32	4	1
28	86.5	0.3	16.6	0.2	70	−13	30	−8	−7
30	85.7	0.2	16.7	0.4	70	0	20	8	0
32	85.2	0.1	17.1	0.2	60	4	23	6	2
34	84.3	0.1	17.4	0.1	56	6	25	5	3
36	83.3	0.1	17.7	0.0	60	−3	28	−5	−1
38	82.4	0.2	17.9	0.1	59	4	24	5	2
40	81.6	0.3	18.1	0.0	60	3	15	3	1
42	81.2	0.3	18.5	−0.1	61	−33	20	−11	−12
44	80.7	0.3	18.8	0.2	50	2	15	3	1
46	80.1	0.3	19.1	0.2	52	−5	15	−4	−1
48	79.6	0.3	19.5	0.3	54	6	20	2	2
50	79.0	0.3	19.8	0.3	50	5	17	2	2
52	78.5	0.3	20.1	0.2	80	0	16	−4	0
54	78.6	0.2	20.4	0.2					
M		0.19		0.07		−0.7		0.8	0.0
MD		±0.10		±0.15		±4.3		±3.4	±1.8

min	A_0	ΔA	h_0	Δh	dd_0	Δdd	ff_0	Δff	Δdd
5. 4. 58 at 11.00 o'clock									
					degrees			knots	
4	106.7	0.2	60.2	−0.4	102	0	7	0	0
6	105.0	0.0	59.8	−0.1	60	2	5	0	0
8	96.4	0.3	62.7	0.0	320	20	4	−1	1
10	90.4	−1.0	70.2	−1.5	8	−14	7	0	−2
12	71.9	0.6	71.7	0.1	330	5	8	1	1
14	49.5	0.3	74.4	0.0	346	−3	11	0	−1
16	29.1	0.5	72.7	1.4	334	0	18	1	0
18	7.4	0.8	68.1	0.1	330	−1	17	0	−0
20	357.2	−1.5	64.0	0.9	328	2	13	1	0
22	351.6	0.4	61.9	0.3	318	−1	12	1	−0
24	346.5	0.2	60.7	0.1	320	−6	7	−1	−1
26	344.6	−0.2	61.0	0.1	290	10	3	−1	0
28	343.1	0.5	62.3	0.3	280	8	5	0	1
30	339.9	0.8	63.2	0.2	290	0	7	0	0
32	336.6	1.0	63.5	0.0	300	−10	5	0	−1
34	334 8	0.6	63.8	0.4	269	5	6	1	1
36	331.5	0.3	64.3	0.1	290	−10	7	0	−1
38	328.9	−0.2	64.1	0.5	250	28	6	−1	2
40	326.1	0.4	64.5	0.1	290	−7	7	0	−1
42	324.1	0.1	64.5	0.2	310	−4	11	−1	−1
44	322.6	−0.1	63.7	0.3	270	4	11	3	1
46	318.8	−0.6	63.8	−0.1	295	5	12	−2	1
48	317.0	−0.2	62.9	0.0	320	−2	10	−1	0
50	317.0	−0.1	62.3	0.2					
M		0.13		0.13		1.3		0.0	0.0
MD		±0.43		±0.28		±6.6		±0.7	±0.7

min	A_0	ΔA	h_0	Δh	dd_0	Δdd	ff_0	Δff	Δdd
23. 6. 58 at 10.53 o'clock									
					degrees			knots	
4	152.6	0.4	38.5	−0.2	153	0	7	−1	0
6	152.4	0.2	43.9	0.3	200	0	4	0	0
8	156.6	0.6	49.6	0.1	200	3	8	1	0
10	164.6	0.4	51.8	−0.2	198	−2	11	0	−0
12	170.5	0.1	52.0	0.0	216	4	13	1	1
14	178.9	1.2	51.4	−0.2	216	0	21	1	0
16	187.7	0.9	48.4	−0.4	218	2	24	−1	1
18	194.1	0.6	44.8	−0.4	219	2	28	−2	1
20	199.5	0.2	41.2	0.1	213	5	33	4	2
22	202.7	0.5	37.3	−0.1	220	−2	41	−2	−1
24	205.8	−0.1	33.9	0.2	219	1	45	3	1
26	208.1	0.4	30.9	−0.1	223	1	52	1	1
28	210.6	0.5	28 2	−0.1	228	0	53	4	0
30	213.2	0.5	25.7	0.1	224	−2	38	4	−1
32	214.2	0.3	24.6	−0.3	218	2	22	−3	1
34	214.4	0.4	24.4	0.0	206	4	17	2	1
36	214.1	0.4	24.6	−0.1	210	0	16	1	0
38	214.0	0.4	24.8	0.0	202	−7	12	−3	−1
40	213.7	0.4	25.1	0.2	200	0	12	−3	0
42	213.3	0.6	25.4	0.3	220	−5	12	−2	−1
44	213.5	0.3	25.8	0.4	180	−30	9	−3	−3
46	212.9	0.3	26.5	0.5	190	5	10	0	1
48	212.4	0.4	26.9	0.6	180	10	8	2	2
50	211.9	0.4	27.4	0.5	220	0	10	−4	0
52	212.0	0.4	27.8	0.7	210	−4	7	8	−1
54	211.9	0.4	28.4	0.3					
M		0.43		0.08		−0.5		0.3	0.2
MD		±0.14		±0.24		±3.6		±2.2	±0.8

deviation *MD* of the individual errors, i.e. the random errors of observations, have been calculated and inserted below the Table 8. It will be seen that the wind error in individual soundings is of the same order of magnitude as in Tables 6 and 7. Further, it is established that in these soundings the random errors of azimuth and elevation angles are only a half or one-third of the corresponding errors in the earlier tables, which concern the sounding data as a whole.

Conclusions

The wind direction and velocity are usually obtained from radiotheodolite observations more accurately than is necessary for plotting on the weather chart. The random error of the azimuth angle in individual soundings is usually less than 0.2° except at very light wind speeds. The *MD* of the elevation angle, again, is smaller than 0.25° at all elevation angles. These figures can be regarded as representing the accuracy of the radiotheodolite observations on the Swedish-Finnish-Swiss IGY Expedition to Spitzbergen.

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REFERENCES

1. Liljequist, G. H., 1959: Murchison Bay. Den svensk-finsk-schweiziska expeditionen till Nordostlandet 1957—58. *Ymär* Nr. 2, 81—139. Stockholm.
2. Väisälä, Vilho, 1953: A new radiotheodolite. *Proceedings of the Indian Academy of Sciences*, 37, 223—228.
3. —»— 1959: Correction to be used when comparing radiotheodolite with an optical theodolite. *Vaisala News*, Nr. 4, 10—14.