A STUDY OF THE AURORAL ARCS AND DRAPERIES

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Summary. The result of height determinations of the lower border of 355 arcs and 293 draperies have been given. The material has been separated in groups according to weak, medium, strong and very strong auroral displays, and it is shown that the height frequency curves show a displacement towards lower heights with increasing intensities. The influence of the moon's hourangle on the heights is investigated and it shown that there is a positive evidence for a tidal effect, the mean values of the heights are displaced 3—5 km towards greater heights from ebb- to floodtide. The direction of 215 auroral arcs have been measured and the mean diurnal variation in the period 16^h—24^h MET for Tromsø is demonstrated.

A. The Heights and Directions of Auroral Arcs.

1. Introduction.

Among the varieties of auroral forms the auroral arc is the type which exhibits the simplest and most constant appearance, and which perhaps has been the most extensively studied by the observers. The directions of the arcs have been measured with greater or less accuracy already centuries ago[1]. The heights of several hundred individual arcs have been measured by means of parallactic photos by a number of observers since the photographic method was introduced by Størmer[2 3 4 5] in 1909. The spectral composition of the luminosity for various heights within an arc has been studied by spectral[6] and filter[7] methods. Concerning the heights of the lower border the normal green-yellow arc is the type which exhibits the greatest constancy of the auroral forms with a definitive maximum in the height curve between 100 and 110 km. This is the case for arcs measured in the northern part of Norway near the auroral zone as well as for arcs measured over southern Norway from Oslo[8].

Arcs of unusual appearance may lie in other high intervals. Størmer[9] has observed a faint grey arc over southern Norway lying in a height of 200 km. In northern Norway a strong arc with a strong red-coloured lower edge was observed to go down to 70 km above the surface of the earth[10].

In the following a summary of the results of *height* determination of the lower border of the *normal yellow-green* arcs over Tromsø will be given. In the last part of the paper the results of the determinations of the *directions* of the arcs will be given.

2. The Material.

The material used was selected from the stock of parallactic photos taken in the period 1929—1938. The parallactic photos were taken from the observatory as the main station and from Tenness in Balsfjord as the second station, the latter lying at a distance of

[1] Fritz, Das Polarlicht (Leipzig 1881) p. 36—43.

[2] Størmer, Bericht über eine Expedition nach Bossekop etc. Vid. Selsk. Skr. I. Math.-Nat. Kl. No. 17 (1911).

[3] Størmer, Rapport sur une éxpédition d'aurores boréales a Bossekop et Store Korsnes pendant le printemps de l'année 1913, Geofys. Publ. *1*, No. 5 (1921).

[4] Vegard and Krogness, The Position in Space of the Aurora Polaris, Geofys. Publ. *1*, No. 1 (1920).

[5] Harang and Tønsberg, Geofys. Publ. *9*, No. 5 (1932).

[6] Vegard, Zeitschr. f. Geophys. *6*, 42 (1932).

[7] Harang, Geofys. Publ. *10*, No. 8, (1934), Zeitschr. f. Geophys. 7, 324 (1931).

[8] Størmer, Geofys. Publ. *4*, No. 7 (1926), curve II.

[9] Størmer, Geofys. Publ. *11*, No. 5 (1935).

[10] Harang and Bauer, Gerl. Beitr. Geophys. *37*, 109 (1932).

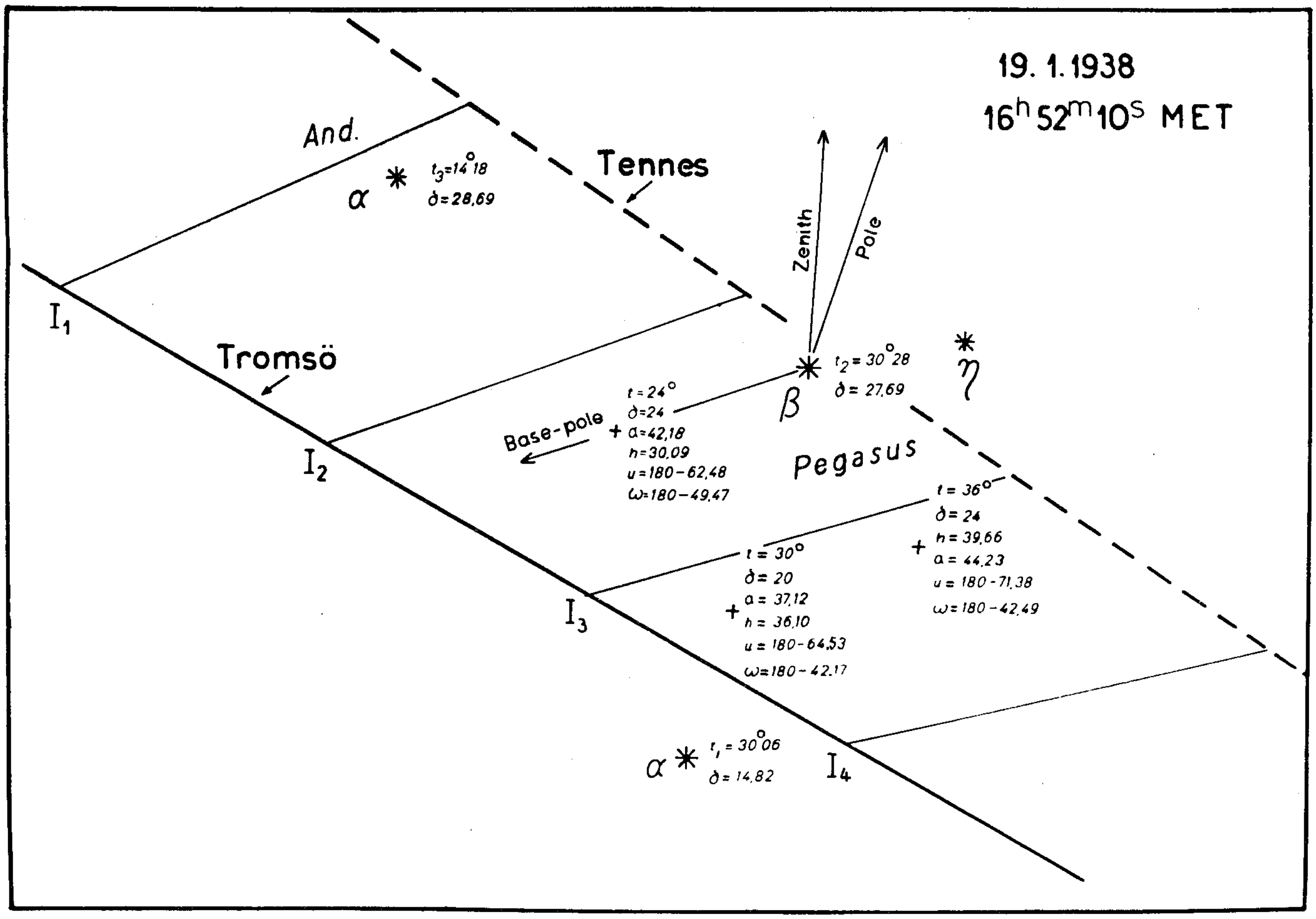

Fig. 1.

43.4 km to the south of Tromsø. Almost all photos were taken in the time interval 16^h—24^h MET. Usually several pictures were taken in succession when quiet arcs appeared. In table 1 are given the dates on which auroral arcs were photographed. N gives the number of parallactic photos used.

Table 1.

Date	Time, MET	N	Date	Time, MET	N
17/10 1929	21. 8—21.21	4	7/1 1933	19.41—23. 5	16
21/10	20 39—21.44	2	21/1	22.18—22.20	4
13/11	21. 6—21.43	9	23/2	19. 2—23. 1	36
21/11	21.20—21.22	3	24/2	19.25—21.25	41
30/11	20.37—21.11	5	26/2	20.42—20.44	6
5/12	20.52—20.53	2	3/4	21.13—23.24	26
7/12	20.55—20.57	5	24/10 1935	21.30—21.35	4
23/1 1930	22. 8—22.51	11	21/1 1936	20.28—20.29	2
27/3	20.44—22.20	8	26/1	17.18—22.30	26
28/3	20.48—20.49	1	16/2	17.28—21. 9	42
23/10	20.46—20.52	3	17/2	17.58—20.40	20
14/9 1931	20.59—21.45	7	19/2	17.44—20.37	5
1/11	19.27—19.31	2	21/2	19.12—20.00	29
16/11	19.58—19.59	2	19/1 1938	16.51—16.52	2
9/1 1932	20.51—21.36	7	27/1	16.35—16.46	14
4/2	21.13—21.18	2			
27/10	20.16—21.10	9		$\Sigma N = 335$	

The total number of photos used amounts to 355 pairs. The method of calculating the height from a pair of parallactic photos has been described in earlier papers[3 4 5]. The method used for the material here treated is described in details in the paper last mentioned and will not be repeated here. As an illustration of the method the following calculation of a pair of photos will be given in table 2.

Table 2.

January 19th, 1938. 16.52.10 MET.

P	u_1	u_2	p	h	a	r	H	D
	°	°	°	°	°	km	km	km
I_1	48.3	62.0	13.7	41.1	6.6	162	108	119
I_2	53.8	68.0	14.2	39.8	18.4	164	107	123
I_3	60.1	74.0	13.9	36.8	30.0	172	105	135
I_4	66.9	80.0	13.1	33.1	40.4	189	106	155

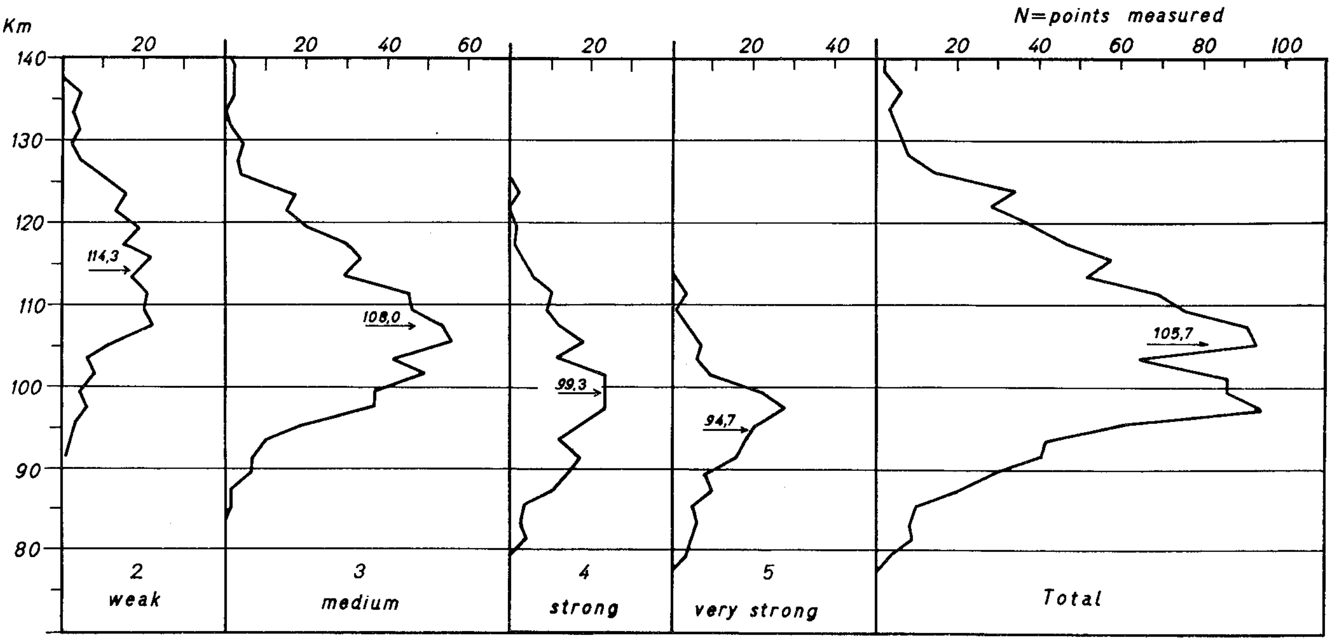

Fig. 2. Distribution of heights of lower border of arcs.

Here are, referred to the main station, Tromsø:

p: the parallax,
h: the height
a: the azimuth
r: the distance
H: the height above the earth's surface
D: the distance of the horizontal projection of the point from Tromsø
u_1 and u_2: the base-distances.

The projection of the photos is shown i fig. 1.

3. Height Statistics.

The mean distribution of heights of the arcs is well known from earlier measurements. A closer study of the heights of different forms of arcs and draperies has been made exspecially by Størmer. From his photos taken at the Bossekop-expedition in 1913 Størmer shows clearly that very intense, varicoloured draperies, mostly red underneath, show a remarkable lower height of the lower border than the faint and tranquil auroral curtains[11].

From the material from Tromsø[12] it has previously been shown that the heights of arcs and bands decreased when the aurorae showed traces of reddish or pink colour. It would be of interest to carry further the analysis of the influence of the intensity of the heights. The material was divided into four classes, according to the following scale of intensity:

weak: *2*,
medium: *3*,
strong: *4*,
very strong: *5*.

Table 3.

h	n				h	n			
	2	*3*	*4*	*5*		*2*	*3*	*4*	*5*
79— 80				4	111—112	21	45	10	4
81— 82			4	5	113—114	17	29	5	
83— 84			3	6	115—116	22	23	3	
85— 86		1	4	5	117—118	15	30	1	
87— 88		1	9	10	119—120	19	20	1	
89— 90		6	14	8	121—122	13	15		
91— 92	1	7	17	16	123—124	16	17	2	
93— 94	2	10	12	18	125—126	10	4		
95— 96	3	19	18	21	127—128	5	3		
97— 98	6	37	23	28	129—130	2	4		
99—100	4	37	23	22	131—132	4	1		
101—102	8	45	23	10	133—134	3			
103—104	6	41	11	6	135—136	4	2		
105—106	12	56	18	7	137—138		2		
107—108	22	53	12	4	139—140		2		
109—110	20	46	9	1	141—142	1			

For photos showing intensity *5* it was often noted in the diary that the arc showed faint pink colour or showed a faint crimson lower border.

Although the photos are not furnished with any intensity scale, a fairly reliable classification of the intensity of the arcs can be made by comparing the

[11] Størmer, Terr. Mag. *21*, 157 (1916).
[12] Geofys. Publ. *12*, No. 1, p. 26 (1937).

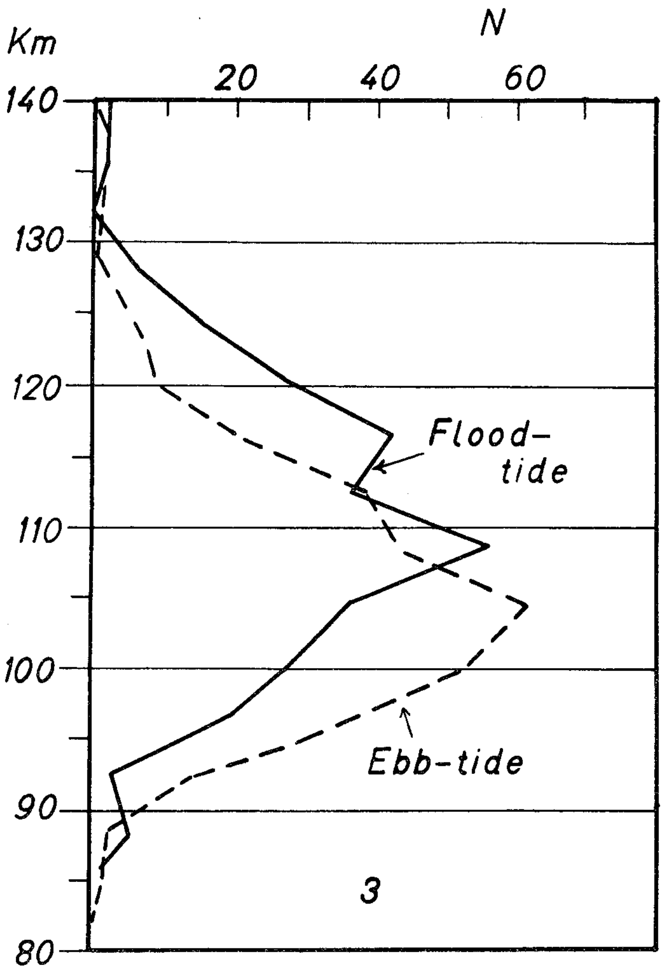

Fig. 3. Heights of lower border of arcs of medium strenght, *3*, during flood- and ebb-tide conditions.

Table 4.

Intensity	Mean height	n
2	114.3 km	236
3	108.0 »	566
4	99.3 »	222
5	94,7 »	175
H_c =	104.1 km	1199

density of the arc with the visibility of the stars in the background. A strong arc with few and faint stars in the background is thus easily distinguished from a faint or medium arc with long exposure.

In table 3 are given the results of the height statistics. The results are shown graphically in fig. 2. In the figure and the table the number of points, n, have been summed up for each 2 km.

Table 3 and fig. 2 show that the interval of heights display a continuous decrease with increasing intensities. The mean heights for each class are given in table 4.

If we instead of the mean value of the classes H_c calculate the mean value of all points measured out, we get the following value $H_p = 105.7$ km. The mean value of the lower border of all points H_p, falls near to the values previously observed. Vegard and Krogness[4], give a value of 107.9 km for all forms.

An interesting feature in the frequency curves previously observed are the two maxima at 100 and 106 km. The maxima are especially pronounced in the curves given by Vegard and Krogness[4], but they are also distinctly seen in the curve given by Størmer[3].

From our analysis of the frequency curves we see that no double maxima occur in the curves for each of the four intensities. In the sum curve, however, double maxima occur at the heights of 100 and 105 km. The lower maximum we see, is in this case formed by the presence of the strong and very strong classes.

In an interesting paper Egedal[13] has traced the influence of the moon on the height curve given by Vegard and Krogness. He was able to show that there was a preponderance of the maximum at 106 km at flood-tide and a similar preponderance of the maximum at 100 km during ebb-tide.

Although the hight curves for each of the classes here given exhibit only one single maximum, it would be of interest to see whether an influence of the moon could be traced. The usual method for in-

Table 5.

h	Flood-tide	Ebb-tide	h	Flood-tide	Ebb-tide
79— 80			111—112	20	25
81— 82			113—114	16	13
83— 84			115—116	22	13
85— 86		1	117—118	14	8
87— 88	1		119—120	12	6
89— 90	4	2	121—122	11	3
91— 92	1	6	123—124	4	6
93— 94	1	9	125—126	3	
95— 96	5	14	127—128	3	
97— 98	14	23	129—130		1
99—100	13	24	131—132		1
101—102	15	30	133—134		
103—104	13	28	135—136		2
105—106	23	33	137—138	2	
107—108	32	21	139—140	2	
109—110	24	22			

[13] Egedal, Publikationer fra Det Danske Meteorologiske Institut (Communications Magnétique Nr. 10, 1930). Nature *124*, 913 (1929).

vestigating the moon's influence is to arrange the material according to the moon's hour-angle and make a Fourier analysis. This would give the phase-angles and the amplitudes of the different harmonic components. The material, however, is not sufficient for such a detailed analysis, and we must restrict ourselves to an attempt to trace the effect qualitatively. Flood-tide was assumed at the moon's hour-angle in the intervals $t_{\langle} = 9^h—15^h$ and $21^h—3^h$, and ebb-tide for the moon's hour-angle at $t_{\langle} = 3^h—9^h$ and $15^h—21^h$ In table 5 the frequencies of the auroral points during flood- and ebb-tide for arcs of medium strenght, *3*, are given.

In fig. 3 the number of height determinations within each interval of 4 km has been summed up. From table 5 and fig. 3 it is evident that there is a preponderance of greater heights during flood-tide. The frequency curves show an almost paralell displacement from ebb-tide to flood-tide conditions, thus giving a strong support to Egedal's hypotheses.

A similar analysis has been made of the heights of the classes *2*, *4*, and *5*. The results are illustrated in fig. 4.

For these classes there is no definite evidence for a displacement of the height curves from flood- to ebb-tide conditions. The mean values of the heights are also the same during flood- and ebb-tide. Now

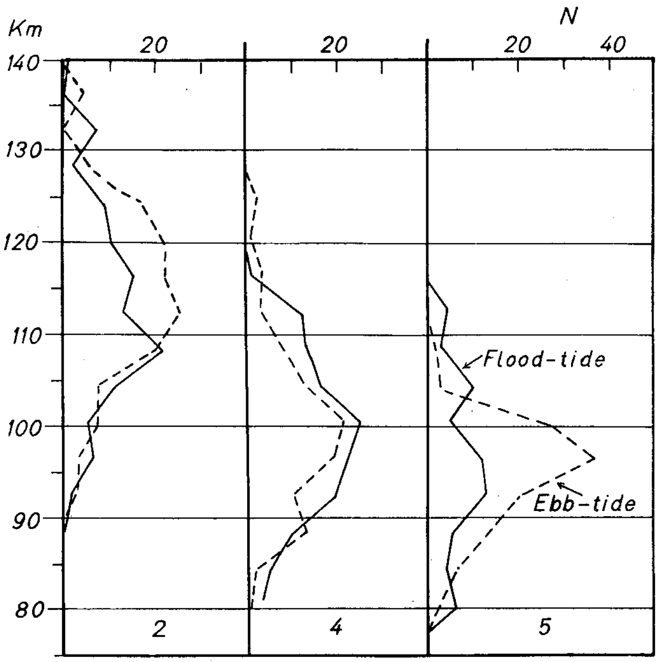

Fig. 4. Heights of lower border of arcs of intensities *2*, *4* and *5* during flood- and ebb-tide conditions.

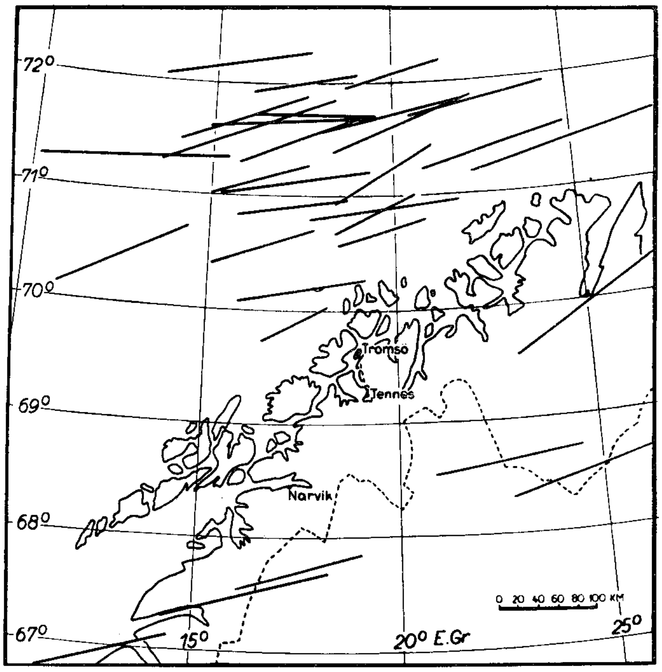

Fig. 5. Position of the arcs during the period 1929—31.

the material for these classes is considerably more limited than for the arcs of medium strenght, and we may regard this negative result as a not decisive argument against the hypothesis of a tidal influence.

4. The Direction of the Arcs.

A discussion of the older observations of the direction of the auroral arcs is given in the classial work of Fritz[1], in which it was clearly shown that the direction of the arcs over Scandinavia is apparantly perpendicular to the direction of the declination. This point has been studied more closely by Vegard[4] in his discussion of the observations from the Polar Year 1882—83 and from the observations in Bossekop in 1839—40 and 1912—13. In his discussion of the direction of the auroral arcs Vegard has referred the direction to the position of the magnetic meridian, the latter defined as a great circle going through the earth's magnetic axis point and the place of observation. Referred to the magnetic meridian the mean values of azimuth of the western part of the auroral arcs is of the magnitude 100—105°. For places along or near the auroral zone Vegard gives the mean value of 102.1°. The maps showing the position of the arcs of Scandinavia published by Størmer[8] show the same feature.

[1] loc. cit. p. 40—44.
[4] loc. cit. p. 117—136, see also Phil. Mag. *42*, 47 (1921).
[8] loc. cit. Pl. 48.

Table 6.

Date	MET	φ	λ	a	L	Date	MET	φ	λ	a	L
					km						km
17/10 1929	21h 15m	71.1°	17.0°	— 8° ± 4°	150	26/2 1933	20h 43m	71.7°	10.8°	— 5° ± 3°	210
21/10	20 42	71.7	19.8	—12 5	145	3/4	21 13	71.1	24.3	— 3 4	160
13/11	21 7	70.8	18.6	—25 4	90		21 18	71.0	20.5	— 3 4	160
	21 8	70.6	16.9	—19 5	110		21 20	71.0	24.2	+ 3 5	100
	21 20	71.4	22.6	—15 8	150		23 6	71.5	14.8	—14 10	120
	21 35	72.0	17.5	—10 8	100		23 9	71.1	12.7	—11 5	170
	21 43	70.7	19.5	—17 4	90		23 12	71.8	14.8	— 6 5	100
21/11	21 21	68.6	23.0	— 9 4	150		23 24	68.7	20.5	—28 4	60
30/11	20 38	70.9	19.6	— 7 3	150	24/10 1935	21 31	68.3	25.0	— 6 3	180
	21 11	71.7	20.2	—22 10	150		21 35	67.9	18.2	— 7 3	185
7/12	20 55	71.4	25.0	—13 6	210	21/1 1936	20 29	68.4	19.0	— 6 3	110
23/1 1930	22 08	69.8	17.2	—27 7	75	26/1	17 20	68.2	19.0	— 8 4	125
	22 32	71.7	16.5	—20 10	135		17 23	71.7	19.0	—11 4	140
	22 43	71.5	17.5	—21 8	135		17 44	71.6	20.0	—14 4	150
	22 47	71.6	16.5	—20 9	180		18 07	71.5	20.0	—11 3	170
	22 51	71.7	17.0	— 4 8	160		22 30	71.5	17.0	—32 5	175
27/3	20 44	67.5	16.7	—16 8	170	16/2	17 40	70.5	20.2	— 0 3	110
	21 19	68.5	24.0	—16 8	100		17 41	70.4	15.0	— 1 2	155
	22 16	72.2	16.2	—10 8	145		17 51	70.1	16.0	+ 3 2	125
	22 17	70.9	17 0	— 8 5	110		17 52	70.2	13.0	— 5 2	250
28/3	20 49	71.8	22.4	—12 6	140		18 4	70.3	20.3	+ 9 8	90
23/10	20 47	71.0	16.5	—17 5	100		18 29	70.3	20.2	+11 6	190
	20 52	72.1	20.0	—16 8	95		18 30	70.4	14.5	+ 4 4	190
14/9 1931	21 00	66.9	12.5	—19 4	185		18 32	70.6	14.5	— 1 2	190
	21 43	67.7	17.5	—15 10	130		18 33	70.6	21.0	+ 6 8	175
1/11	19 28	71.7	17.8	— 1 3	125		18 34	70.8	21.8	— 1 4	110
	19 31	71.3	12.5	— 3 4	190		18 35	71.3	21.8	— 2 5	110
16/11	19 58	70.2	17.5	—10 6	130		18 37	71.3	16.2	—14 6	125
9/1 1932	20 51	69.3	16 0	— 3 3	130		18 40	71.5	22.5	— 5 5	145
	21 16	71.0	14.5	—15 5	165		18 41	71.4	17.0	—16 10	135
	21 35	69.9	14.5	—13 5	145		21 7	68.7	22.4	—14 4	140
27/10	20 17	70.6	18.3	— 6 4	85		21 9	71.2	20.5	— 7 3	110
	20 20	70.2	15.0	—13 5	125	17/2	18 11	68.1	19.7	— 5 3	110
	21 10	70.8	19.2	—19 5	115		18 12	67.9	19.5	—11 6	120
7/1 1933	19 47	72.4	20.7	— 7 5	190		18 14	67.6	22.0	— 6 4	135
	20 8	71.5	13.8	— 9 8	200		18 16	67.4	22.0	— 9 3	125
	20 14	71.0	15.4	—15 6	110		18 18	67.0	21.5	— 6 4	190
	23 4	70.5	12.6	—15 3	175		18 21	72.0	14.9	+ 3 8	220
21/1	22 18	72.2	19.0	— 0 5	120	19/2	17 44	70.1	21.5	—11 3	95
23/2	19 36	71.8	13.5	—12 5	120		20 37	67.7	19.5	— 1 5	130
	19 42	67.7	19.8	—12 5	90	21/2	19 12	70.5	16.8	—18 3	80
	19 43	67.7	19.0	— 2 10	90		19 47	71.8	16.8	—10 3	220
	19 52	67.8	20.9	—20 7	80		19 48	71.8	14.5	— 8 5	120
	19 55	67.5	18.3	—15 5	110		19 49	71.7	18.5	— 5 4	120
	20 12	70.3	23.3	— 2 2	150		19 49	71.6	19.5	— 3 4	120
	20 14	70.1	21.9	+ 4 5	65		19 50	71.5	16.0	— 3 3	185
	20 20	69.9	21.3	— 9 3	70		19 51	71.5	16.0	+ 2 5	185
	20 23	71.5	20.0	—13 10	105		19 51	71.4	16.0	+ 1 5	185
	20 25	71.1	17.3	—13 6	75		19 56	70.9	23.8	— 0 3	150
24/2	19 28	68.2	19.0	— 9 10	30		19 58	71.0	16.0	+ 1 5	150
	19 30	68.3	20.1	— 8 5	60		19 59	71.2	19.9	+ 0 5	65
	19 32	68.0	18.5	—15 5	80		19 59	71.1	18.7	+ 3 5	100
	19 34	68.0	19.0	— 8 4	80	19/1 1938	16 52	68.6	18.0	— 1 3	90
	20 17	71 6	15.2	— 3 4	140	27/1	16 40	70.9	18.5	— 1 3	95
	21 17	71.1	21.0	— 6 4	90		16 41	70.8	16.0	— 4 4	130
	21 18	71.0	21.0	— 5 3	85		16 42	70.6	12.5	—13 5	200
	21 20	70.5	16.0	— 8 4	80		16 45	71.3	24.0	— 2 6	180
	21 21	70.5	16.0	—10 5	60		16 46	71.1	18.1	— 9 8	80

The direction of the arcs for Tromsø were determined by plotting the footpoints of the lower border of the arcs on a map and measuring the angle between the mean direction of the arc and a meridian circle which cuts the arc approxemately in the middle. The mean position of the arc was usually determined by means of several parallactic photos, and from the scattering of the points the accuracy of the determination could be estimated.

To express the direction of the arc we have used the azimuth of the *normal* to the arc, the direction of which is pointing to the south. In table 5 are

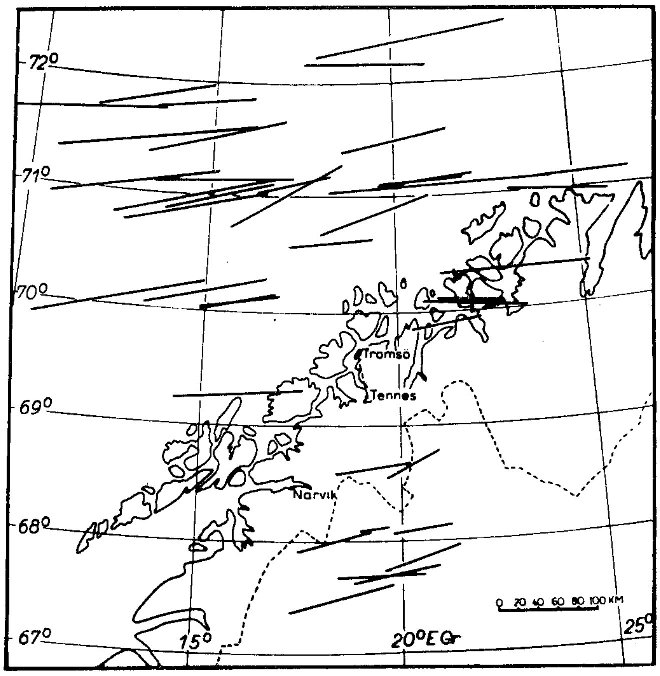

Fig. 6. Position of the arcs during the period 1932—33.

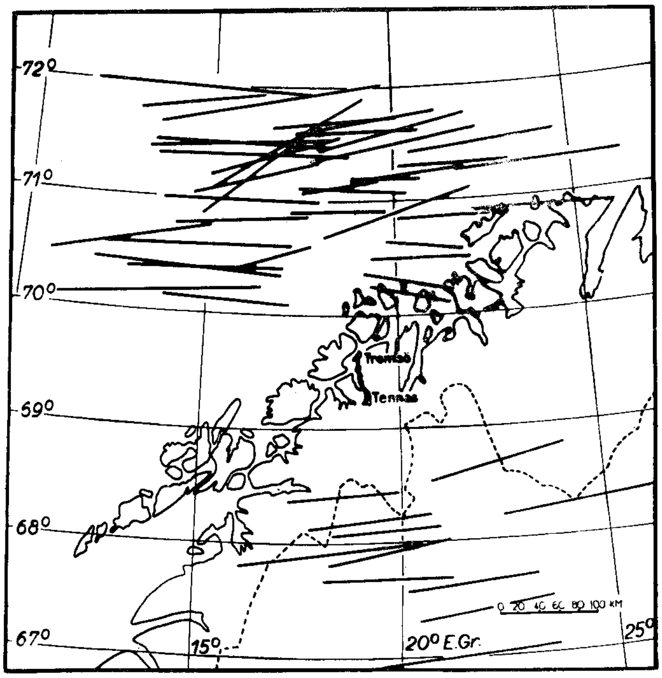

Fig. 7. Position of the arcs during the period 1934—38.

Table 7.

Date	MET	a	Date	MET	a	Date	MET	a	Date	MET	a
9/11 1929	17.17	— 2.0		19.53	+ 2.7	2/12 1929	19. 5	— 1.6		21.11	— 10.5
	17.18	— 3.4		16.55	— 4.2		19.13	— 3.4		21.12	—15.5
	17.23	— 5.6		16.56	+ 0.8		19.15	— 5.5		21.15	—14.0
	17.26	+ 2.5		16.57	+ 0.0		19.17	— 3.3	23/1 1930	22. 5	—15.2
	17.29	+ 3.8		16.59	+ 2.3		19.20	— 6.8		22.38	—29.0
	17.34	— 1.6		17. 0	— 4.4		19.22	—10.0		22.40	—31.3
	17.37	— 3.3	30/11 1929	16.52	— 2.7		19.24	—10.4		17.19	— 3.0
	17.44	— 4.1		16.54	— 2.5		19.44	+ 0.2		17.22	— 5.0
	17.45	— 5.1		16.56	— 6.0	5/12	18.24	— 5.9		17.25	— 5.4
	17.50	—12.8		16.58	— 6.9		18.29	— 4.3		17.28	— 6.3
	18. 1	—16.6		16.59	— 6.8		18.32	— 8.7		17.31	— 9.5
	18. 7	—13.8		17. 3	— 3.9		18.36	—13.1		17.39	—11.7
	18. 9	— 6.7		17. 4	— 8.4		18.43	—16.1		17.41	— 5.1
	18.9	— 5.4		17. 6	— 4.3		18.46	—15.1		18.17	— 0.9
	18.16	— 7.4		17. 7	— 4.3		18.48	—13.8		18.22	+ 0.1
19/11	21.22	—16.6		17.19	— 0.7		18.49	— 0.5		18.24	— 2.9
	21.23	—15.4		17.13	— 4.5		20.26	—12.2		18.35	— 6.4
	21.24	—13.6		17.15	— 6.7		20.26	—11.7		18.47	— 3.0
	21.26	—17.1		17.17	— 7.7		20.53	—20.1		18.51	— 3.0
	21.27	—17.5		17.18	— 5.9		20.54	—19.6		18.54	— 2.9
27/11	16.44	+ 0.5		17.20	— 5.8		20.57	—16.9		18.57	— 3.0
	16.46	+ 0.4		17.22	— 4.8		21. 2	—15.1	24/1	18.59	—11.1
	16.47	+ 0.2		18. 0	—15.3		21. 4	—12.5		19.21	— 6 2
	16.48	— 2.4		18. 3	—14.5		21. 8	—16.5		19.23	— 4.8
	16.49	— 3.1		18. 4	—14.6		21. 9	—15.0			

given the values of each determination in the period 1929—1938. a is the azimuth of the normal, φ and λ are the geographical coordinates of the middle of the arc and L is the length of the arc within the field of picture which has been used.

In fig. 5, 6 and 7 the position of the arcs during the period 1929—31, 1932—33 and 1934—38 are illustrated.

Table 6 and the figures indicate that the mean direction of the arcs determined in the period 1929—31,

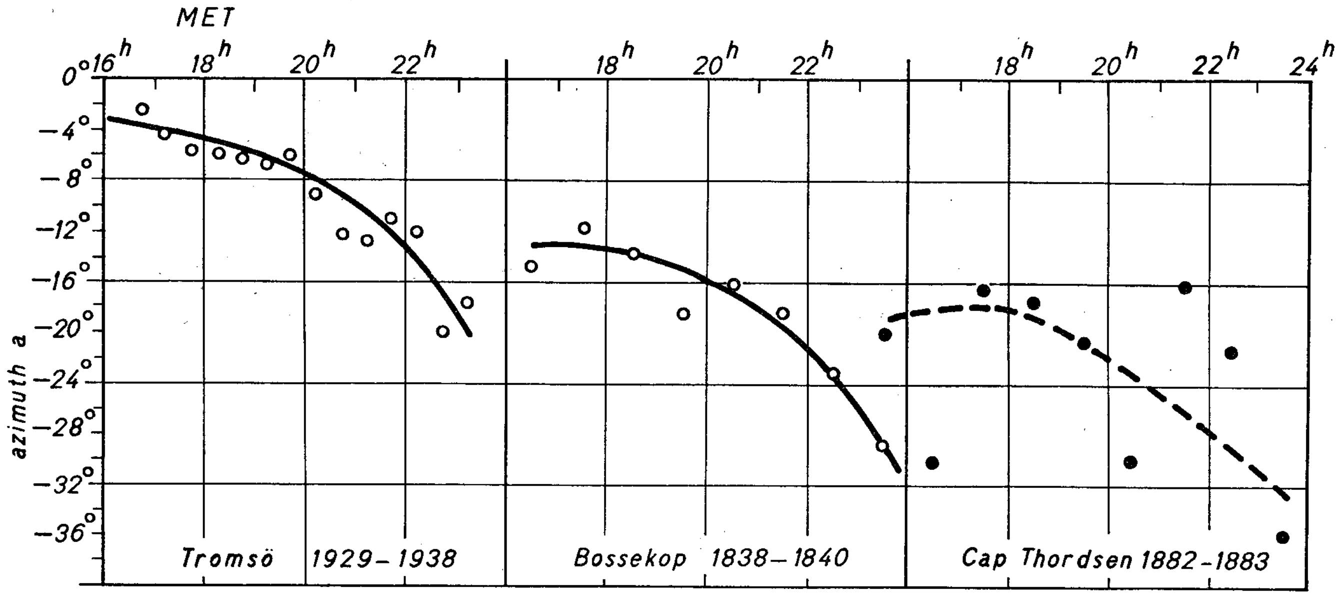

Fig. 8. Variation of the direction of the arcs during the afternoon and evening hours. *a* is the azimuth of the normal of the arcs, referred to the geographical meridian.

is somewhat different from the values measured during the two later periods. A closer inspection shows that this is not due to a secular variation of the direction of the arcs. In the years 1929—31 we could not start the parallactic photography till 20^h MET, and the greater part of the photos are taken in the period 21^h—24^h. Later we have had the opportunity of photographing from two stations the splended auroral arcs appearing in the afternoon from 16^h—17^h MET.

Besides the determinations given in table 6 we have from the period 1929—30 a considerable number of photos of arcs taken from Tromsø *alone* during the afternoon at 16^h—17^h MET. The western and eastern part of the arcs were photographed simultaneously by means of two cameras from Tromsø alone. The determination of the direction of the arcs from a pair of such photos will be described in an appendix. In our opinion this method is the most accurate method we have used for *direction* determinations. In table 7 the determinations of the azimuth, *a*, of the normal of the arcs from such pair of photos are given.

The mean variation of the direction of the arcs is seen from table 8. *a* is the mean value of the azimuth of the normal during each half hour, *n* is the number of determinations.

From the observations of Bravais[4] in Bossekop in 1838—40 it was evident that the direction of the

Table 8.

MET	*a*	*n*	MET	*a*	*n*
	°			°	
16.30—17.00	— 2.7	21	20.00—20.30	— 9.4	12
17.00—17.30	— 4 5	23	20.30—21.00	—12.2	13
17.30—18.00	— 5.8	14	21.00—21.30	—12.9	31
18.00—18.30	— 6.0	22	21.30—22 00	—11.0	6
18.30—19.00	— 6.3	20	22.00—22.30	—12.0	5
19.00—19.30	— 6.7	13	22.30—23.00	—20.1	5
19.30—20.00	— 6.0	21	23.00—23.30	—17.8	6

arcs showed a diurnal variation. In the material from Cap Thordsen (Svalbard) in 1882—83[4] a diurnal variation could also be staded. In fig. 8 the variation of the direction of the arcs during the afternoon and evening hours is demonstrated for the three places of observation.

From the parallactic photos taken in 1913—14 at the Haldde observatory[4] the mean value of the azimuths of the normal to the diffuse arcs and drapery-shaped arcs were determined to 16.8° respectively 8.8°. Now these arcs were almost all photographed in the interval 21^h—23^h MET. From the mean curve in fig. 8 the corresponding value at 22^h for Tromsø is 15°, — a value which falls very near to the values determined by Vegard and Krogness for Bossekop.

Fig. 8 shows that for Tromsø and Bossekop the diurnal variation goes paralell. For Cap Thordsen the single points lie more scattered.

Referring the direction of the arcs, according to Vegard, to the magnetic azimuth, we get the following values for the most constant period, 16^h—19^h MET:

[4] loc. cit. p. 124—127.

Table 9.

	a	A^{m}	a_m
	°	°	°
Tromsø 1929—1938	— 4.8	—28.55	—23.75
Bossekop 1838—1840	—14.0	—30.53	—16.53

Here A_m is the azimuth of the magnetic meridian computed for the years of observations, and a_m is the azimuth of the normal to the arcs referred to the magnetic meridian.

The differences between Tromsø and Bossekop in the values of a and a_m are so great that they can hardly be caused by any systematic error. In the values of a_m the effect of the secular variation of the earth's magnetic field has been eliminated. In the computation of the magnetic azimuth A_m we have used the formula of Carlheim-Gyllenskiöld mentioned in the paper of Vegard and Krogness[4], giving the position and secular variation of the earth's magnetic axis' point. To what degree of accuracy this formula represents the secular variation of the magnetic azimuth at various places along the auroral zone, is not clear. According to this formula the magnetic meridian at Bossekop should have changed from —30°53′ in 1839 to —27°84′ in 1934. This secular change is astonishingly small compared with the secular change in the declination, which, according to Tønsberg[14], has changed in Bossekop from 10°40′ W in 1838—39 to 1°35′ E in 1932—33. If the secular change of the magnetic azimuth is greater than expressed by Carlheim-Gyllenskiöld's formula the values for a_m for Tromsø and Bossekop will be brought nearer each other.

B. The Heights of Draperies.

1. The Material.

It is to be expected that the decrease of heights with increasing intensities which has been demonstrated by the arcs, also should appear for other auroral forms. Further it would be of interest to investigate if the supposed tidal effect could be traced in the heights of other forms. For this purpose 293 pairs of photos of draperies were calculated. The material was selected from the stock of photos taken at the observatory in the period 1931—1939. The material was collected on the nights given in table 10.

Table 10.

Date	Time, MET	N	Date	Time, MET	N
8/9 1931	21.29—21.48	4	19/3 1933	21.38—24.15	9
14/9	21. 5—22.13	25	3/4	21.42—21.44	2
26/10	20.32—20.45	13	24/10 1935	20. 7—21.27	9
15/11	18.44—19.14	8	27/10	17.50—21.56	6
27/10 1932	20.21—24.37	29	5/11	21.23—23.48	5
7/1 1933	19.52—20.56	12	21/1 1936	20.43—20.56	13
20/1	23.16—24.23	6	26/1	17.47—23. 7	10
21/1	21.48—21.53	6	16/2	18.43—20.58	9
20/2	21.43—23.19	14	17/2	18. 9—18.10	2
23/2	19.32—20.42	8	19/2	18.38—20.35	8
24/2	19.37—20.58	29	21/2	18.25—19.33	37
25/2	23. 6—23. 8	4	19/1 1938	16.35—16.38	16
18/3	24.32—24.34	9			$\Sigma N = 293$

For the intensity characterization the steps *weak* (2) *medium* (3) and *strong* (4) were used. Now a classification according to intensities by the draperies is more difficult than by the arcs. A drapery usual has areas of intense and faint luminosities, which often make a decisive classification difficult. The greater part of the draperies has therefore been classified as medium. Only in cases where the uniform intensity of the whole form must be characterized as weak or strong these two classes have been used.

2. Height Statistics.

In table 11 are given the results of the height statistics of the lower border of the draperies for the three classes of intensities. The number n of auroral points in intervals of 2 km has been summed up.

Table 11.

km	n			km	n		
	2	3	4		2	3	4
79— 80				111—112	5	58	14
81— 82		1	1	113—114	6	71	17
83— 84		3	4	115—116	6	54	8
85— 86		1	4	117—118	10	46	7
87— 88		4	13	119—120	4	38	8
89— 90	1	6	9	121—122	3	28	4
91— 92	1	10	16	123—124	9	25	2
93— 94		8	16	125—126	5	25	2
95— 96	4	18	12	127—128	3	10	4
97— 98	4	31	25	129—130		8	
99—100	3	39	14	131—132	3	5	
101—102	3	52	9	133—134	1	5	
103—104	5	40	18	135—136		1	
105—106	7	65	13	137—138		1	
107—108	11	73	13	139—140			
109—110	15	62	5				

[4] Loc. cit. p. 130.

[14] Norwegian Publications from the Polar Year 1932—1933, No. 2. Publ. fra Det Norske inst. for Kosmisk Fysikk nr. 6, p. 13.

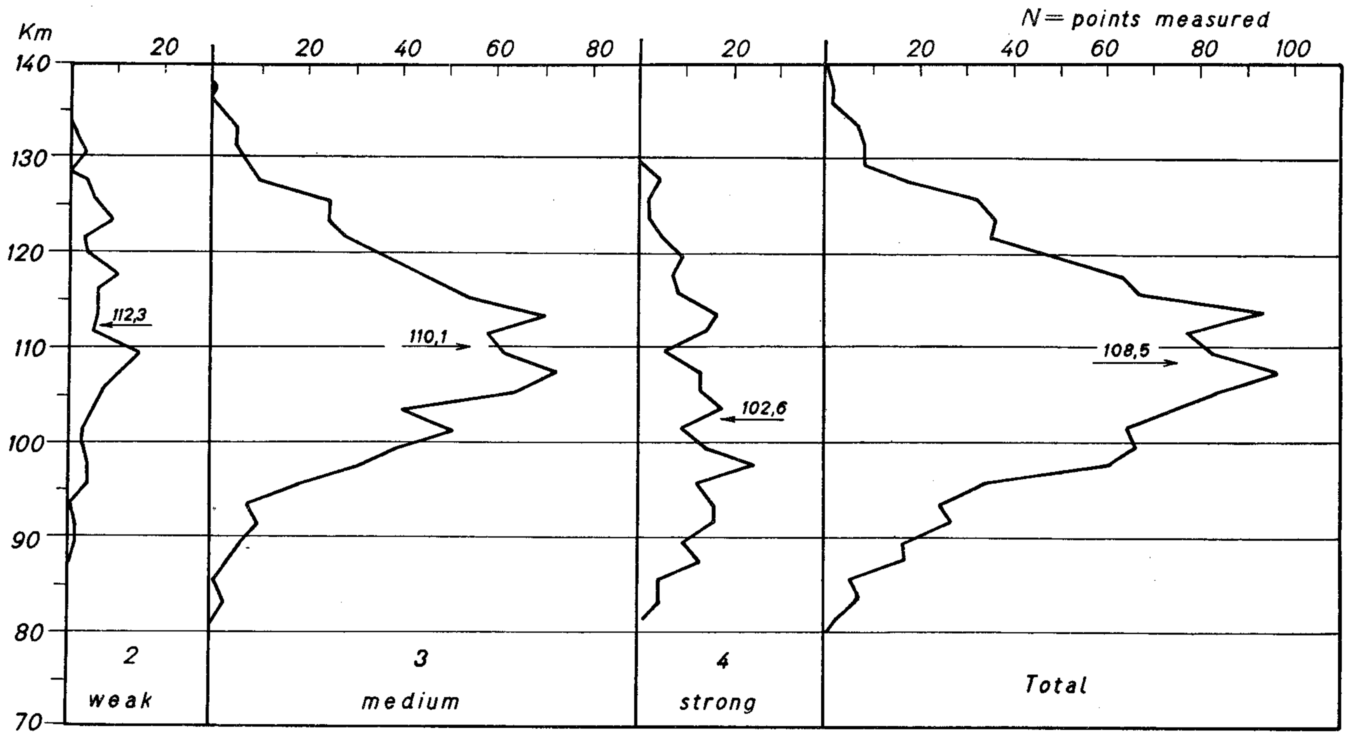

Fig. 9. Distribution of heights of lower border of the draperies.

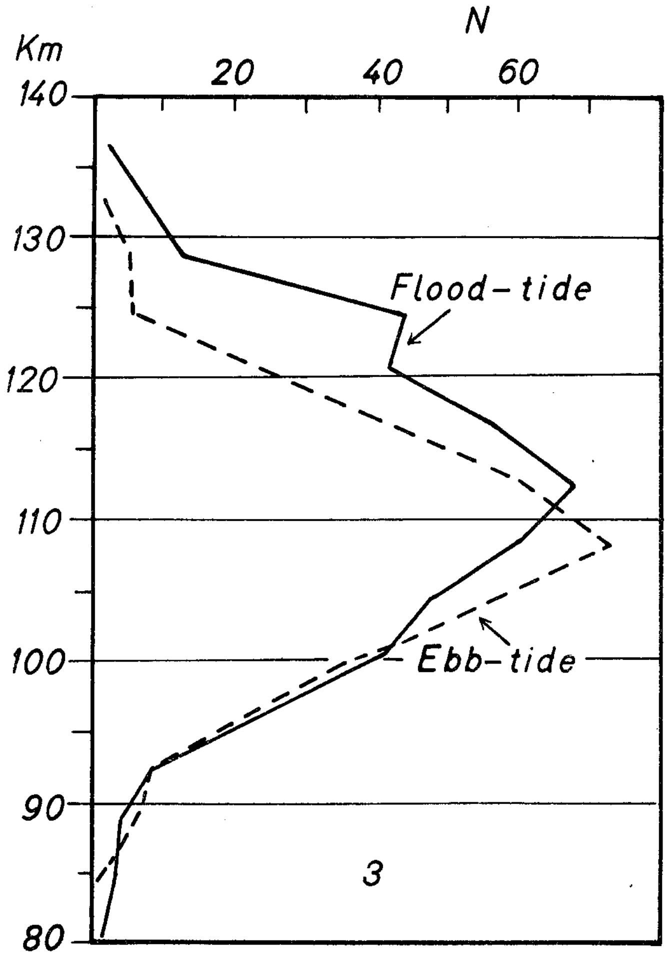

Fig. 10.

Table 12 gives the mean height for each of the three classes of intensities:

Table 12.

Intensity	Mean height	n
2	112.3 km	109
3	110.1 »	788
4	102.6 »	238
	H_c = 108.3 km	1135

Table 13.

h	Flood-tide	Ebb-tide	h	Flood-tide	Ebb-tide
81—82	1		111—112	34	24
83—84	2	1	113—114	34	37
85—86	1		115—116	25	29
87—88	1	3	117—118	32	14
89—90	3	3	119—120	23	15
91—92	7	3	121—122	19	9
93—94	2	6	123—124	22	3
95—96	9	9	125—126	22	3
97—98	17	14	127—128	7	3
99—100	20	19	129—130	6	2
101—102	21	31	131—132	4	1
103—104	18	22	133—134	4	1
105—106	30	35	135—136	1	
107—108	31	42	137—138	1	
109—110	29	33			

The mean value of the three classes is $H_c = 108.3$ km. If we calculate the mean height of *all* points measured out, we get the value $H_p = 108.5$ km.

The heights of the lower border of the draperies show the same continous decrease with increasing intensities which was demonstrated by the arcs. We also see that the mean heights of the draperies on an average lie som km higher than those of the arcs.

As for the arcs the influence of the moon's hour-angle on the heights of the draperies was investigated. In this analysis only draperies of medium intensity were used.

In table 13 the frequencies of the auroral points during flood- and ebb-tide are given. The effect is demonstrated in fig. 10 where the number of auroral points is summed up for each interval of 4 km.

As for the arcs of medium intensity we find a similar displacement of the mean values of the heights from flood- to ebb-tide. The displacement of the height-frequency curve is not so uniform by the draperies, however, as by the arcs.

Appendix.

Methods of Determining the Auroral Arc Directions from a Single Station.

Observations have shown that the mean direction of the arcs and the diurnal variation of this are quantities which can be accurately determined and which further are characteristic for the place of observation. It should therefore be of special significance to secure reliable series of observations from places on both hemispheres, as well for geographical as for secular studies of the mean directions of the arcs. Principally the most complete solution of determining the direction of the arcs is to measure the heights by means of parallactic photos and plot the foot-points of the lower border on a map. Unfortunately the possibilities for parallactic photography are limited, chiefly because the telephone lines seldom are free to one's disposal in the afternoon hours when often the most splended and quiet arcs appear.

In the following we shall give a brief discussion of the methods for direction determinations from a *single* station, and in more details describe a method used in Tromsø which in our opinion gives reliable results and is easy to carry out.

Several methods have been used by various observers for determining the direction of the arcs from a single station. Common for all methods is the assumption that the height above the earth's surface of the lower border is *constant*. The discussion of the heights of the western and eastern part of the arcs by Vegard and Krogness[4] shows that this assumption is correct.

A method used by several observers (Hansteen, Bravais) is to observe the azimuth of the highest point of the arc, the direction to which should give the normal to the arc. Another method is to draw the position of the arc on a celestial map. In the reduction of the single photos taken on the "Maud" expedition[15] along the Sibirian coast the following method was adopted. A constant height of the lower border was assumed and the horizontal projection on the earth's surface of the lower border was determined by the graphical methods used in the reduction of parallactic photos.

The method used in Tromsø for direction determination from a single station was a further development of the first method of determining the azimuth of the highest point of the arc. The following procedure was adopted. By means of *two* cameras the western and eastern halves of the arc were photographed simultaneously, W- and E-photos. The photos were enlarged and the lower border drawn off on a white paper using the same process as with the parallactic photos.* The heights and azimuth for a number of stairs (usually three) were computed on each picture. By means of a suitable "net" the azimuths of a point on the lower border of the arc on the W- and E-projections were read off for the same values of the heights (h). A number of values of h were used, usually in steps of 2° increase. Table 14 shows the result of a determination by means of a W- and E-photo.

Table 14.

September 11th, 1929. $18^h\,9^m\,42^s$ MET.

h	a_W	a_E	a
°	°	°	°
42	180 — 35.0	180 + 25.9	— 4.5
40	— 40.9	+ 32.0	— 4.4
38	— 45.9	+ 36.1	— 4.9
36	— 51.5	+ 39.4	— 6.1
34	— 56.5	+ 42.2	— 7.1

Mean: —5.4

[4] loc. cit. p. 102.

[15] Wesøe, Aurora Photographs, The Norwegian North Polar Expedition with the "Maud" 1918—1925, Scientific Results, Vol. I No. 6 (1928) Oslo.

* The explanation of the method presupposes knowledge of the methods of reduction of parallactic photos by means of "nets". A description of the methods are given in the papers of Størmer[2], Vegard and Krogness[4], and Harang and Tønsberg[5]. Details of the methods used in Tromsø are given in the last paper.

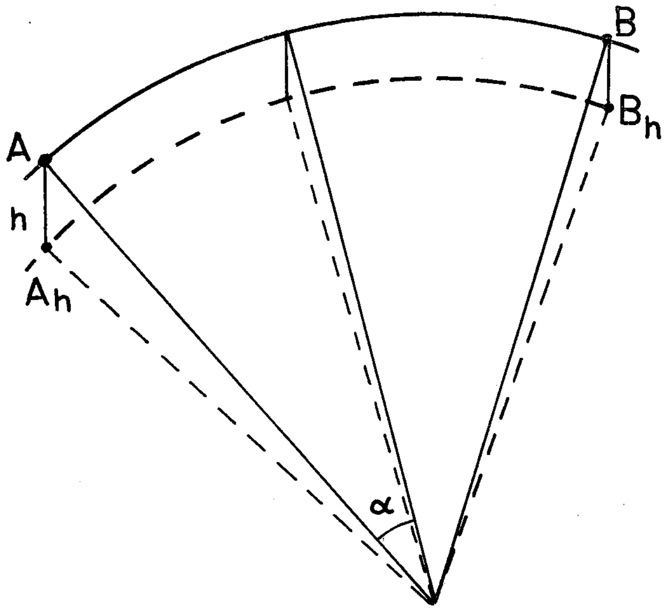

Fig. 11.

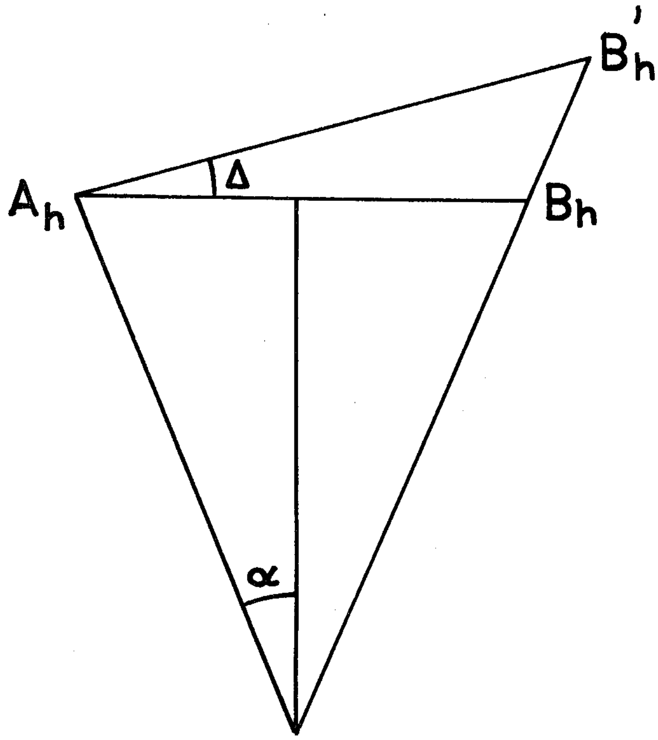

Fig. 12.

Here a_W and a_E are the azimuths of a point on the lower border of the arc on the W- and E-photos corresponding to the height h. a is then the azimuth of the normal to the arc.

From table 14 it is evident that there is a systematic increase in the (numerical) values of a with decreasing heights. This is due to the fact that the western and eastern halves of the arc have not been symmetrical with respect to the middle of the arc. We may add that it is not usual that a determination shows such a great systematic change in a with the heights as demonstrated in table 14. The systematic variation in a do not usually exceed 1°—1.5° in a single determination. This circumstance should indicate that the uncertainty in the determination of a for a single set of W- and E-photos should not exceed 1°. It is easy to show that the systematic change in the values of a for decreasing values of h is due to the fact that the western half of the arc has a stronger curvature than the eastern half, *i. e.*, the arc is not a circle segment but a spiral. There seems to be no systematic change in the direction of this asymmetry of the arcs. Of 86 arcs measured, 23 showed for decreasing heights no systematic change in a greater than 0.3°, 32 arcs showed a slight increase and 31 a slight decrease in a for decreasing values for h.

Computation of the maximum error in the arc direction determination when the lower border of the arc has not uniform height above the earth's surface.

In the cases when arc direction determinations are made by photographing the eastern and western part of the arc from a single station, it would be of interest to compute the maximum error occurring in the direction determination if it may assumed that the height of the arc is not uniform.

We assume that the eastern part B of the arc, see fig. 11, increases its height to B', which is an amount of Δh greater than the height at A. Viewed from the observing station this will appear as if the horizontal projection of the corresponding point B_h was displaced to B'_h, and one would get an error in the direction determination of an angle of Δ.

After some computation, we get the following expression for the error:

$$\operatorname{tg} \Delta = \frac{\Delta h}{h} \operatorname{cotg} \alpha \cdot \frac{1}{2 + \Delta h/h}$$

In table 15 are given the values of Δ for a series of values of $\Delta h/h$ and α, the variation is illustrated in fig. 13.

Table 15.

	$\Delta h/h=0.05$	$\Delta h/h=0.1$	$\Delta h/h=0.15$
$\alpha=10^\circ$	$\Delta=8.0^\circ$	$\Delta=15.1^\circ$	$\Delta=21.4^\circ$
20	3.8	7.5	10.9
30	2.4	4.7	7.1
40	1.6	3.1	4.7

When observing, the values of α have been between 30° and 40°. If now the eastern part of the arc lies in an height of 105 km, and the western part in 100 km, this would imply an error in the direction determination by this method of about 2°.

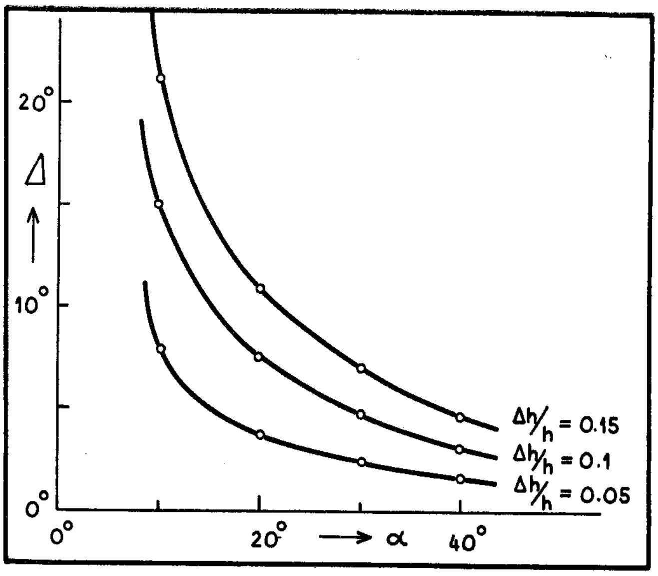

Fig. 13.

Aknowledgements.

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