RESULTS OF REGISTRATIONS OF THE ATMOSPHERIC ELECTRIC POTENTIAL GRADIENT AT THE AURORAL OBSERVATORY, TROMSÖ, DURING THE PERIOD MARCH 1932—JULY 1933

BY

EINAR BARLINDHAUG

(Manuscript received 27. october 1934.)

1. Introduction.

It is a well-known fact dating back from the pioneer work of Thomson, Exner, Elster and Geitel and others, that an electrostatic potential of a magnitude of about 100 volts per meter is maintained in the free atmosphere. Registrations from different observatories show that this potential gradient exhibits more or less periodic variations. Registrations from days with no meteorological disturbances, *i.e.* days with clear sky and faint wind or none at all, give curves which show the normal and undisturbed diurnal and annual variation characteristic for the place. Meteorological disturbances effect the potential gradient strongly.

Registrations of the potential gradient have in Norway been conducted for a considerable period at Aas Meteorological Observatory near Oslo by Mr. Russeltvedt, meteorologist at the Norwegian Meteorological Institute, Oslo.[1] In the northern part of Norway registrations have only been conducted over somewhat short periods. The most valuable series of observations were made by G. C. Simpson in Karasjok, 1906.[2] Observations have occasionally been made by Birkeland and Krogness at the Haldde Observatory, and by Harang at the Auroral Observatory, Tromsö, — specially with a view to the investigation of a possible connection between aurorae and variations of the potential gradient.

2. Location and Site of the Station.

The Auroral Observatory is located on the Tromsö Island, an island about 50 kms from the open sea with a coast climate. The geographical coordinates are: $\varphi = 69°39'8$ N., $\lambda = 18°56'9$ E. Gr. The observatory is situated 112 meters above the sea level at a distance of about 2 kms from the centre of Tromsö, a town with about 11 000 inhabitants and a few minor industries. Disturbances of the observations by smoke pollution from the town are negligible. Fig. 1 shows the Tromsø Island and the site of the observatory. Fig. 2 shows the observatory grounds and the position of the buildings.

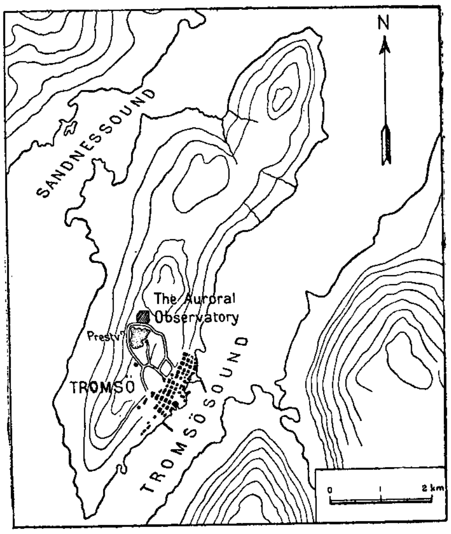

Fig. 1. The Tromsö Island.

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[1] Hourly values during each year from 1916 are given in «Norsk Meteorologisk Årbok», Oslo.

[2] Trans. Roy. Soc. 205,61 (1906).

The difference in potential between a point in the air and the earth's surface was measured by means of a collector connected to an electrometer. If the field is undisturbed *i.e.* if the potential levels are horizontal, the potential gradient is $\frac{V}{h}$ where V is the potential measured and h the height of the collector over the earth. The collector was erected close to the observatory building, where the field was disturbed by the building and the birch trees which sourrounded it and covered the sourroundings of the observatory. If we now assume that variations in an undisturbed field close by are followed by simultaneous and proportional variations of the disturbed field in the neighbourhood of the collector, we may use the records from the electrometer connected with the collector as a measure of the variations of the potential gradient in the undisturbed field. The registrations were standardized by absolute measurements of the potential gradient at an undisturbed place on the plain surface of the ice on a small lake, «Prestvannet», which lies about 300 meters from the collector.

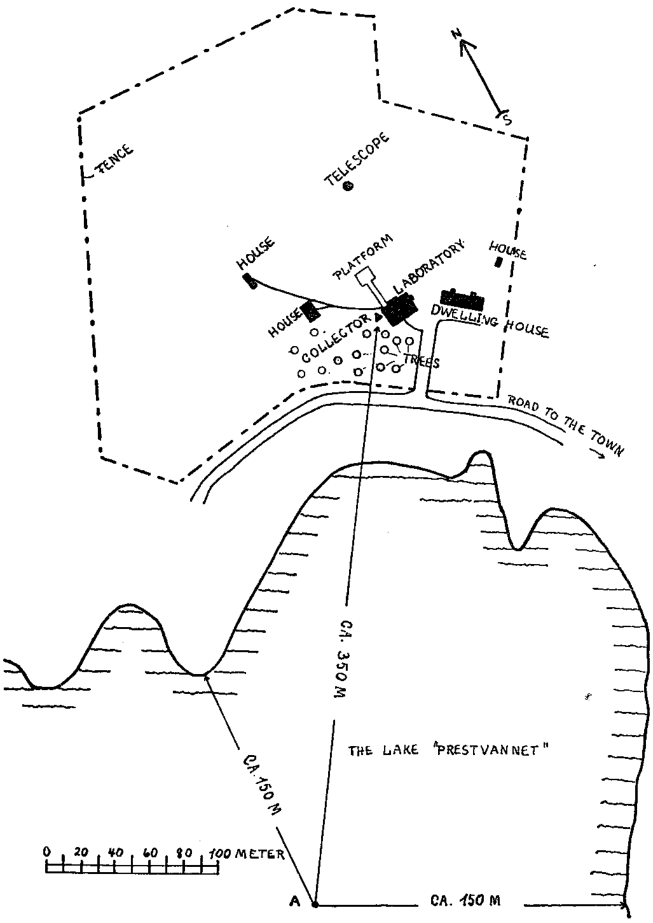

Fig. 2. The Observatory Grounds showing the Position of the Buildings.

Instrumental equipment. As collector in the absolute measurements there was used a flame collector. The height of the point of reference over the flame was calculated in the same manner as that employed by Benndorf[1] for the waterdrop collector, and was found to be 7 cms. The collector was placed on an ebonite rod and connected with a Wulf bifilar electrometer.

As recording collector for the registrations we used Russeltvedt's mechanical collector, a description of which is given by Russeltvedt in «Instrumente und Apparate für die luftelektrischen Untersuchungen an dem meteorologischen Observatorium in Ås. Beiheft zum Jahrbuch des Norwegischen Meteorologischen Instituts für 1925», and a short description of the collector is also given in «Handbuch der Exp.-phys. Geophys. 1 Teil, S. 356». As this type of collector is comparatively little known we will give a short description of it. Fig. 3 shows the collector. *A* is the conductor which is insulated and mounted on the axis of a motor. B is a cylindric box. When rotating the conductor when it is in the position indicated in the figure, will be negatively charged through influence by the electric field, and the lower part of the collector and the electrometer system which in this position is connected with the conductor through the brush (a), will consequently be positively charged. When the conductor has been turned 180° it will be connected to earth through the brush (b). When the conductor again moves in the free air it will again be negatively charged through influence and thus increase the positive

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[1] Handb. d. Exp.-phys. XXV, 1 Teil, P. 360.

charge of the electrometer system. Thus it will proceed until the positive charge of the conductor and the electrometer system has reached the value which compensates the effect of influence of the electric field. Variations in the electric field will thus be followed by variations in the influenced charge of the electrometer system. The chief advantage of this collector is that it requires a very short time for charging the recording system up to the value corresponding to the electric potential. Usually the motor was adjusted for 1000 turns in a minute. By this collector we avoid to a great extent the usual difficulties connected with the insulation.

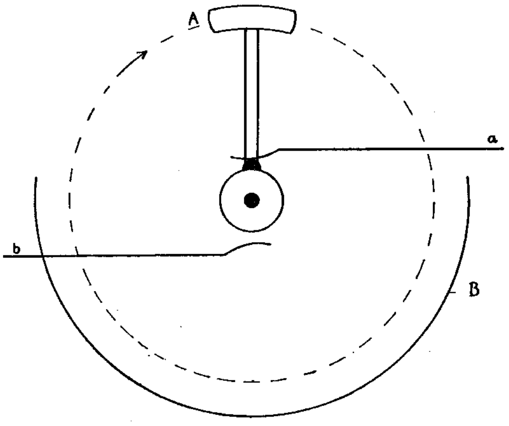

Fig. 3. The Russeltvedt Collector, in outline.

The collector was placed on a frame at a height of 5 ½ meters above the earth surface just outside the observatory building.

The conducting wire from collector to electrometer was placed inside a waterpipe of 7 cms diameter and fastened partially by means of paraffin and ebonite. On account of the great capacity of the wire and the electrometer system, the time for charging was long — about one minute — but at the same time the whole system was very stable. The recording electrometer was placed inside the observatory building. It was a quadrant electrometer of the Benndorf type which had been modified so that one could use photographic registration. During the registrations, two electrometers of the same type with some difference in the sensitivity were used. The potential to be recorded was put on the needle of the electrometer and the two pairs of quadrants were usually kept at a potential of + and — 45 volts.

During the registrations the needle of the electrometer was earthed by a slide attached to a clockwork for a short time every hour. We thus obtain on the curve every hour a point which indicates the zero position of the electrometer and in this way we have an effective control of any possible leakage. The temperature in the room in which the registrations were made was usually constant at 14°—15° C. In connection with the registrations a diary was kept of the weather conditions.

Standardizing Tests. The reduction factor was as previously mentioned, determined by absolute measurements of the potential gradient on the plain surface of the ice on the lake «Prestvannet». The reduction factor could therefore only be determined in the period November—May, when the lake was covered with ice. The following table 1 gives the results of the determinations: —

Table 1.

Date.	Reduction factor.
19 Apr. 1932	10.9 and 9.0
5 May 1932	9.9
25 Nov. 1932	11.3, 10.8 and 10.4
3 Dec. 1932	8.6, 9.0 and 10.2
14 Jan. 1933	11.2
13 Feb. 1933	9.8 and 10.7
20 Nov. 1933	10.4
25 Jan. 1934	8.4 and 10.0

Table 2.

Month. 1932	Number of quiet Days.	Month. 1933	Number of quiet Days.
April	10	January	6
May	13	February	11
June	7	March	6
July	8	April	3
August	6	May	8
September	4	June	6
October	7		
November	9		
December	4		

As mean value of the reduction factor we have used the value 10 *i.e.* the potentials recorded from the collector through the electrometer have to be multiplied by 10 to give the potential gradient in volts per meter of the undisturbed field in the free atmosphere. The reduction factor was determined only on days with clear sky and calm conditions. The probable error of a single determination is assumed to be less than 20 per cent.

3. Discussion of the Registrations.

As previously mentioned the potential gradient is strongly effected by meteorological disturbances. In order to obtain the diurnal and annual variation on quiet days, we will select days and part of days which are meteorologically undisturbed. Days with precipitation, cloudy weather, wind and fog were excluded. This selection of undisturbed time intervals was made by consulting the diary, and also the meteorological registrations from the meteorological observatory Tromsö which is situated 900 meters from the Auroral Observatory.

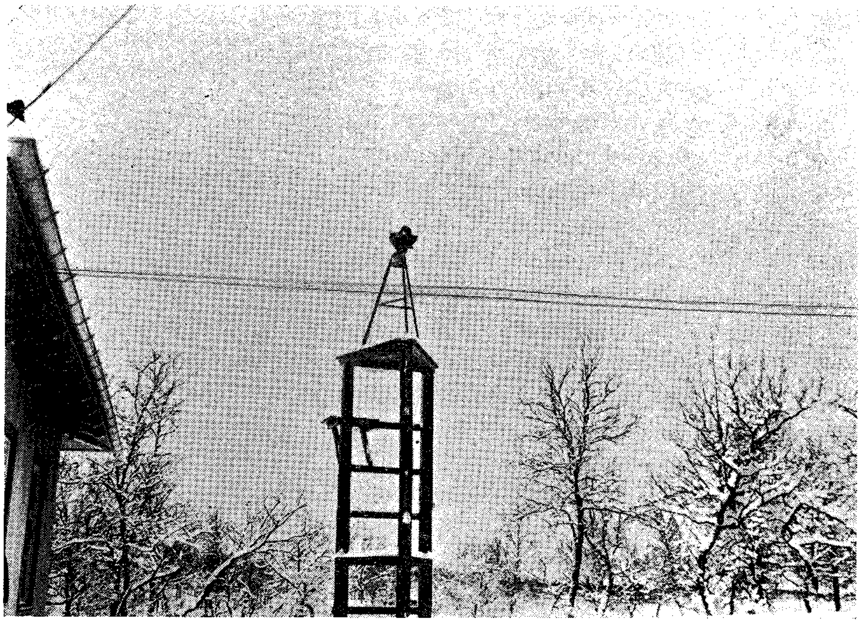

Fig. 4. The Russeltvedt Collector in Position.

On account of the weather conditions at Tromsö only a small number of days proved to be quiet, but we believe that by merely limiting the material in such a way, we shall obtain the variations characteristic of the place. The following table 2 gives the number of days in each month which we have characterised as meteorologically undisturbed.

In table 3 is given the quiet hourly mean of the potential gradient in volts per meter during the period of registration. The maximum and minimum values are especially indicated out in the table. For the months of April, May and June we have records as well for the year 1932 as 1933. In table 3 the mean values for 1932 and 1933 for these three months have been tabulated.

Fig. 5 shows the **annual variation** of the potential gradient during the period of registrations, the mean values for each month have been used. In the same figure Simpsons curve for Karasjok, 1906 — the mean curve from Aas for the periods 1919—28[1] — and the mean curve for Europe[2] — are given.

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[1] The values have been taken from a table in the introduction to «Norsk Meteorologisk Årbok», Oslo, 1928.

[2] Mache und Schweidler: Die Atmosphärische Elektrizität, P. 25, 1906.

Table 3.

M.E.T.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	.	Mean
Jan	110	102	86	**75**	**75**	82	90	98	108	114	112	116	124	130	134	**136**	135	134	133	134	134	134	122	118	113
Feb	111	101	88	86	**84**	86	93	102	115	118	114	125	129	131	130	129	127	130	135	138	**139**	137	132	118	**125**
Mar	100	94	85	**83**	**78**	82	82	85	105	122	130	130	127	133	140	**142**	138	133	127	128	123	118	113	106	113
Apr	80	75	69	**62**	**62**	71	86	98	110	113	112	112	121	125	**129**	**129**	**129**	120	118	115	111	102	96	81	101
May	88	83	**77**	80	88	90	100	103	**108**	105	102	98	96	95	97	105	111	**113**	**113**	112	108	104	100	93	99
Jun	80	87	**83**	84	**83**	89	91	96	98	99	**101**	100	96	99	105	112	113	120	**121**	115	110	106	105	100	100
Jul	90	78	73	**69**	71	84	93	101	101	103	103	105	**107**	101	97	106	109	110	110	112	**113**	111	103	91	98
Aug	93	78	70	**65**	70	73	86	96	100	105	105	107	118	120	122	**123**	**123**	113	108	102	102	100	100	97	99
Sep........	70	**63**	65	65	67	65	78	95	110	128	**130**	128	122	**132**	128	**132**	118	113	108	115	105	98	92	85	100
Oct........	86	79	**71**	**63**	67	70	73	80	90	109	114	116	120	**123**	121	117	116	123	126	130	**131**	122	117	110	103
Nov	73	70	69	**67**	70	77	80	86	87	96	95	100	103	108	110	111	117	118	126	**131**	127	116	114	89	**97**
Dec	80	75	73	67	**63**	65	68	80	83	83	88	105	108	118	118	120	127	**130**	125	120	118	115	108	105	**97**
Winter.....	92	86	78	73	**72**	77	83	92	101	108	109	115	119	124	127	128	**129**	128	127	128	125	120	114	103	108
Summer ...	86	78	73	**71**	74	79	87	95	102	101	109	109	110	112	112	**118**	115	115	114	114	112	107	103	96	100
Year	89	82	76	**72**	73	78	85	93	102	104	109	112	114	118	120	**122**	**122**	**122**	121	121	118	114	109	99	104

Table 4.

M.E.T.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23		Mean Value.	Number of quiet Days.
Winter, Volts/m	—16	—22	—30	—35	—36	—29	—25	—16	— 7	0	1	7	11	16	19	20	21	20	19	20	17	12	6	— 5	108 Volts/m	49
Summer, »	—14	—22	—27	—29	—26	—21	—13	— 5	— 2	1	9	9	10	12	12	18	15	15	14	14	12	7	3	— 4	100 »	59
Year, »	—15	—22	—28	—32	—31	—26	—19	—11	— 2	0	5	8	10	14	16	18	18	18	17	17	14	10	5	— 5	104 »	108

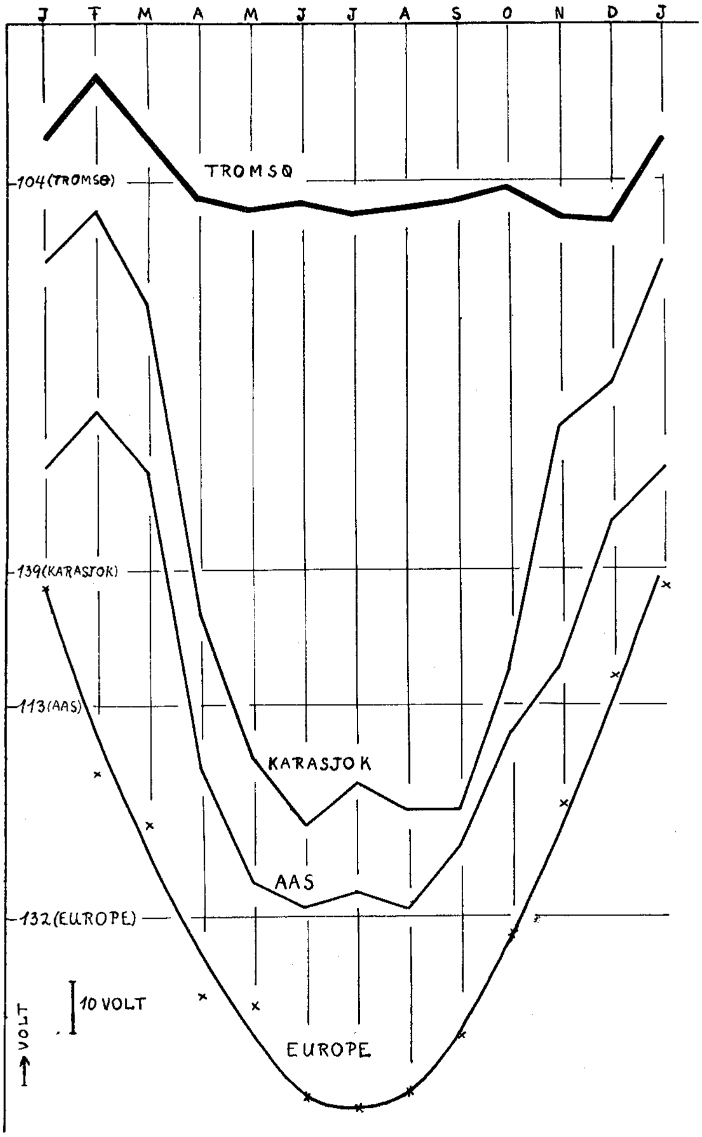

Fig. 5. Annual Curves.

From fig. 5 it is evident that the annual curve for Tromsö shows a period with a distinct maximum in February and a level minimum during the summer and autumn. Regarding the weather conditions during the period of registration, the cold winter set in during the last days of January and lasted until the middle of April. Here we also have the maximum value on the curve. October 1932 was also comparatively cold and the annual curve also here shows a small maximum. The minimum value on the curve extends from May to December. During the months of September and December we had especially much rain.

The annual curve from Tromsö exhibits a similarity compared with the other curves on the figure. The comparatively great difference in amplitudes between Tromsö and the two stations Aas and Karasjok, may be explained by the more predominant coast climate of Tromsö as compared with that of the other stations. It may also be added that during the year 1932 there was more rain in Tromsö than usual.

The average value of the potential gradient during the period of registration in Tromsö is 104 volts per meter.

Fig. 6. shows the **diurnal variation** of the potential gradient for each month, for summer and winter time and for the whole year. For comparision we have also drawn the mean diurnal curves during the year for Karasjok 1906 and for Aas during the period 1919—28. The division of the year into summer and winter season has been made by consulting the records of temperature, the summer season May—October having a mean normal temperature above 0° C. and the winter season November—April having a temperature below 0° C.

The diurnal curves for the summer and winter season and the whole year have been harmonically analized using 5 terms. In Table 4 (page 7) are given the differences from the mean value used in the calculation of the series.

The following series were developed:

Winter:
$$PG = 108 + 26.8 \sin(195.6 + t) + 6.2 \sin(148.2 + 2\,t)$$
$$+ 1.18 \sin(81.7 + 3\,t) + 1.25 \sin(306.9 + 4\,t) \ldots\ldots$$

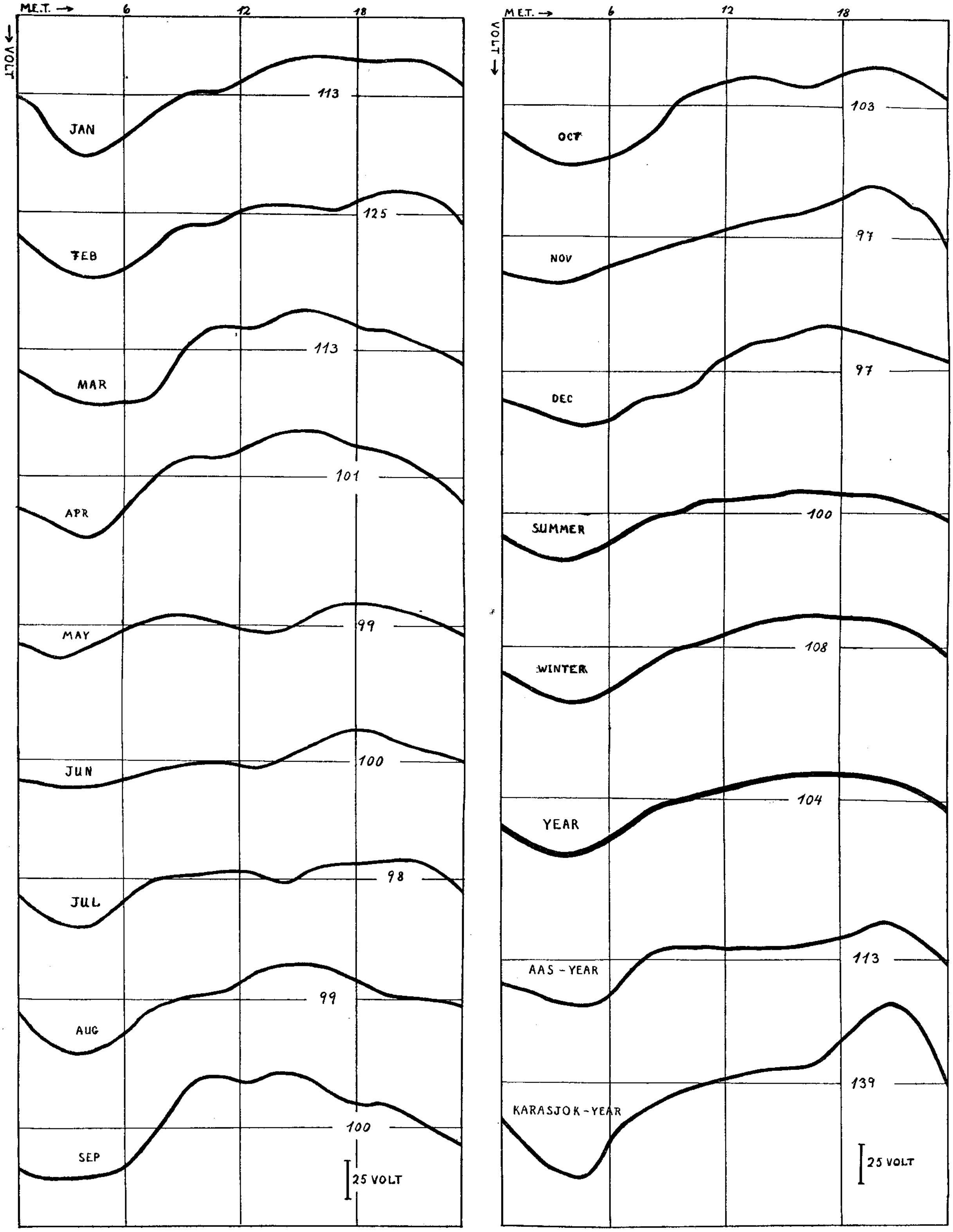

Fig. 6. Quiet Diurnal Variations.

Summer:
$$PG = 100 + 19.5 \sin (207.5 + t) + 7.8 \sin (159.2 + 2t) + 2.6 \sin (105 + 3t) + 0.25 \sin (0 + 4t) \ldots\ldots$$

Year:
$$PG = 104 + 23.1 \sin (200.2 + t) + 6.6 \sin (155 + 2t) + 1.5 \sin (101.3 + 3t) + 0.5 \sin (281.3 + 4t) \ldots\ldots$$

It is evident from the series that only the first three terms are of importance. Further, we see that the 24 hours wave is predominant. The proportion between the amplitudes of the 24 hours wave and the 12 hours wave are in the three cases: winter 1 : 4.3 — summer 1 : 2.5 — and year 1 : 3.5. Further, we see that there is no noticeable variation in the phase during the year.

The diurnal curves show a distinct minimum at 4^h M. E. T. and a broad maximum at 16^h M. E. T. Comparing the diurnal curves from Tromsö with Karasjok and Aas, there is a resemblance in the general character of the curves, but there is also some difference. The 12 hours wave is more predominant at Karasjok and Aas. As a comparison of the results of earlier registrations of the potential gradient in the northern part of Norway we will give the series developed by Simpson[1] from his registrations at Karasjok 1906, of the diurnal variation during the year:

$$PG = 139 + 39 \sin (177 + t) + 23 \sin (158 + 2t) + 5 \sin (178 + 3t) \ldots\ldots$$

Mauchly[2] and Hoffmann[3] have pointed out that the diurnal variation of the potential gradient shows the same character over all oceans, with a minimum value at 3—4^h G. M. T. and a maximum value at 18^h G. M. T. We see that this coincides with the time for the extreme values at Tromsö.

In discussing the results from the records from all observatories, it has been stated that the character of the diurnal curve from land stations may oscillate between two types, one single wave curve with a minimum at 4^h and a maximum at 18^h, and another type consisting of a double wave with a minimum and a maximum value at about the same hours, but with a secondary maximum at about 8^h. At Aas and Potsdam[4] the single wave predominates in winter and the double wave in summer. At Kew[5] the double wave predominates strongly the whole year. At Karasjok and Tromsö the single wave is predominant the whole year.

Investigation of other Factors which effect the Potential Gradient. As previously mentioned, we only used meteorologically undisturbed days for determining the annual and diurnal curves, — the greater part of the year the curves were disturbed by meteorological disturbances. In the following a short dicussion of the type of influence of the different kinds of meteorological disturbances on the potential gradient will be given.

Effect of rain. During quiet rain *i.e.* rain falling vertically, the curves always show a negative potential. This is in accordance with observations from other observatories. Fig. 7 a and b show two records taken during periods of rain, the first during quiet rain, the other during more intense rain. From the records it is evident that the potential rises to values of about 1000 volts. Faint and quiet rain only diminish the normal positive potential but are not able to turn the direction of the field. *Dew* shows the same effect as faint, quiet rain.

Showers of rain i. e. rain falling during rapid changes in pressure connected with wind, produce great and rapid changes in the potential. Values of + or — several thou-

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[1] Loc cit. page 65.

[2] Phys. Rev. Vol. 18, 1921, 161.

[3] Beitr. z. Phys. d. fr. Atm. 11, 1—19, 1924.

[4] Handb. d. Exp. Phys. XXV, 1, p. 288.

[5] Mache und Schweidler: Die Atmosphärische Elektrizität. p. 30, 1906.

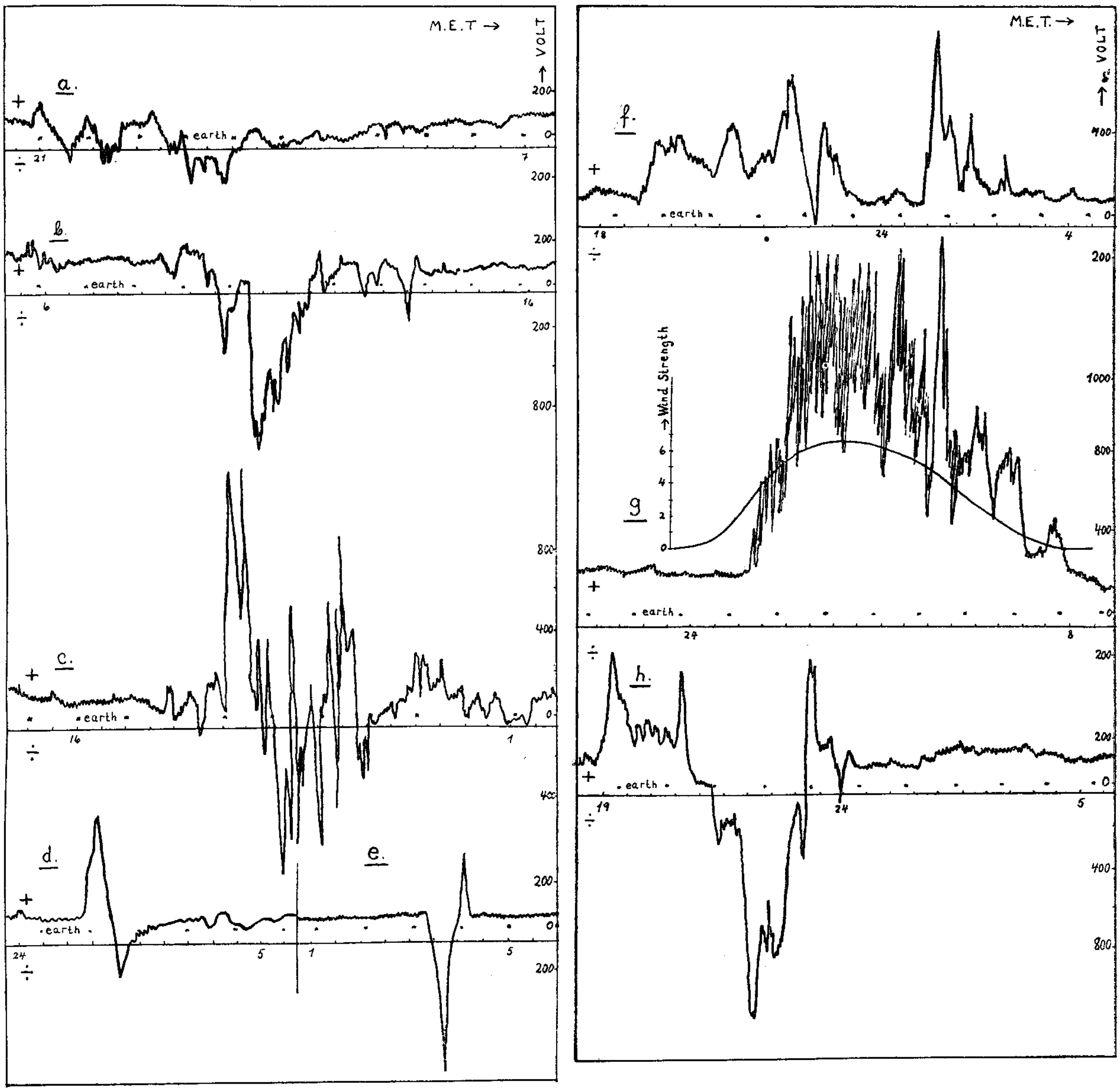

Fig. 7. Records during (a) quiet rain, (b) more intense rain, (c), (d) and (e) showers of rain, (f) quiet snow-fall, (g) wind and snow-fall and (h) a transition of dry snow to rain through sleet.

sand volts occur in the course of a short time. Fig. 7, c, d and e show types of records during showers. From the records it is evident that the disturbance may start as a sudden increase of the field as well as a sudden decrease. The number of positive disturbances and negative disturbances of the field at Tromsö seems to be of the same magnitude. The deflections in positive and negative direction of the potential are also of the same magnitude. Thunderstorms have not appeared at Tromsö during the time of registration.

During a *quiet snow-fall i.e.* snow falling vertically, the curves always show an increase of positive potential. The snow falling at low temperature thus seems to give the earth an excess of negative charge. Fig. 7, f shows an usual type of record during a quiet snow-fall. During *wind and snow-fall* the records show a great excess of positive potential, which depends on the wind velocity and the quantity of snow which falls. Fig. 7, g shows a record of this type. The snow-fall began at 1^h M. E. T., the wind velocity was 0. From 1^h to 3^h the strength of velocity of the wind increased to 6, at 5^h the wind decreased again. The snow-fall continued to 7^h. The wind velocity curve is given in the same figure. H. U. Sverdrup[1] has observed the same effect on the «Maud Expedition». *Showers of snow* show the same effect as showers of rain, there is always an excess of positive potential.

The transitions of *dry snow to rain through sleet* are demonstrated by the record in fig. 7, h. At 19^h M. E. T. the snow-fall began. There is at this time an excess of positive potential. Just before 21^h the falling snow turned into sleet, and the excess of positive potential was diminished. From 21^h to 23^h there was rain and an excess of negative potential appeared. At about 24^h the rain had turned into sleet again and there appeared an excess of positive potential.

Precipitation in the form of *hail* is rare, and the records show during hail an excess of positive potential.

Mist and *fog* which here at Tromsö appear just over the surface of the earth, increase the positive potential. They appear to have the same effect as dust in the air.

Wind on clear days seems to have no predominant effect on the records. The effects of wind during precipitation have been mentioned before. Some examples of wind carrying dust from the town have been noted during the time of registration. The records then show an excess of positive potential. An increase of the *absolute humidity* showed a decrease in the potential. No direct effect of *temperature* has been found.

High quiet cover of *clouds* seems to have no influence on the potential. Thick cover of clouds lying at lower altitudes and drifts of clouds produce irregular variations of the potential. We may frequently observe deflections in positive and negative directions as clouds pass over the observatory.

Earth magnetic disturbances. The magnetic records from the observatory and the records of the potential gradient were compared in order to see if there was any connection between earth magnetic storms and aurorae on the one hand, and the variations of the potential gradient on the other. It could at once be stated that the great magnetic storms which usually occur at midnight had no noticeable effect on the potential gradient. This is in accordance with the observations of Simpson, Birkeland, Krogness and others. We may regard it as a well established point of view that the magnetic storms and aurorae have no noticeable effect on the potential gradient at the level of the earth's surface.

4. Summary.

The atmospheric electric potential gradient was recorded at the Auroral Observatory, Tromsö during the period April 1932—June 1933. The reduction factor was determined by absolute measurements carried out on the lake «Prestvannet» in the neighbourhood of the observatory. The diurnal curve for each month and the annual curve for the variation of the potential gradient for meteorologically undisturbed days have been given. A detailed discussion of the influence of different types of meteorological disturbances on the potential gradient is given in the last part of the paper.

Acknowledgment is made to Mr. L. Harang, director of the Auroral Observatory, Tromsö, for many valuable suggestions concerning the experimental work and preparation of the results.

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[1] Zeits. f. Geophys. 1927, Heft 2/3, Page 96.

Printed February 18th, 1935.