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On the Measurement and Nature of Atmospherics Produced by Electric Discharges in Snow Squalls and from Other Sources

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Abstract

This article deals with a special type of atmospherics produced within snow squalls. It discusses the possibilities of the genesis of such atmospherics. There is also a discussion of the theoretical principles and methods of measuring atmospherics by means of open-air antenna circuits and suitable cathode ray oscillographs. The article contains examples of typical meteorological situations with atmospherics of the type discussed. Special attention has been given to a case where a bank of cumulo-nimbus clouds was located near the east coast of the Baltic and visible from Uppsala. Exemples are given of the typical variation forms of atmospherics produced in squalls within a limited range inside this cloud-bank.

Introduction

It is a generally accepted fact that terrestrial atmospherics are produced by lightning discharges from thunderstorm clouds. In such northern countries as Sweden this applies mainly to the warm season. Thunderstorms occur seldom during the cold seasons and they produce atmospherics of a variation feature typical of lightning discharges. On the other hand, we have observed atmospherics of such a number and intensity during the cold season in Sweden and when the sources of atmospherics within the range of measurement sensitivity could not have been influenced by thunderstorms that we are obliged to assume the existence of sources capable of producing atmospherics in other ways than by lightning discharges in the accepted sense of the word. This applies especially to those occasions when the general meteorological situation is characterized by the occurrence of snow squalls. Hence during the past winter we have undertaken some special investigations to ascertain whether or not electrical discharges within snow clouds, of other variation types than common lightning discharges, might serve as prominent sources of atmospherics.

Electric Field Conditions in Squalls of Snow Clouds.

It is a well known fact that areas of dry-snow clouds, or ice crystals, may serve as sources of considerable static-charges. This is proved by experience when airplanes pass through areas that produce heavy precipitation—static interferences (GUNN, HALL, KINZER 1946 and GUNN 1948). According to GUNN, the highest intensities of the electrostatic field observed when aircraft pass through a thunderstorm-cloud were found at altitudes somewhat comparable to the freezing level. Mean field intensities of 1,300 volts/cm were observed from nine different thunder-clouds. The free charge was characterized mainly by bipolar distributions; hence the field lines were distributed mainly within the cloud.

Sometimes the intensively charged precipitation particles from a snow cloud squall must be distributed, e. g. in a volume extending from the cloud and down to the earth. If, as a first approximation, we assume this volume to be a cylinder and the volume charge distribution to be homogeneous, it is easy, by means of the potential theory, to calculate the field force intensity along the axis of the charged cylindric volume. This field intensity may be considerable if the cylinder is high enough, as for instance in a high snow squall cloud. On the other hand, in ordinary thin snow clouds the electric field intensity will not be very great.

I have personally observed such a case during a trip to U.S.A. in November 1928 with the Swedish liner *Gripsholm*. On a dark afternoon the ship was passing through a heavy snow squall, and on the masts and other pointed high parts of the ship I observed very pronounced Saint Elmo's-fire phenomena. This was a typical evidence of the strong electrical field through which the liner was passing. There are many other indications of heavily charged particles in snow squalls.

One evident and necessary condition for the production of electric discharges of a disruptive character, e. g. in the form of sparks, corona discharges, or streamers inside a snow cloud must be a field force of sufficient intensity. There is no evidence that the discharge resistance would be significantly diminished within an atmosphere filled with snow particles. On the other hand, the well known values between spheres—30,000 volts/cm in ordinary laboratory air—might not be necessary, the more so if one considers the diminishing of the discharge resistance with decreasing atmospheric pressure. Values down to 3,000 volts/cm have, according to GUNN (1948), been measured directly just before a flying bomber was struck by lightning. The height of the bomber was about 4 km above ground.

In this connection one particular comment appears appropriate. A cumulo-nimbus cloud as well as a snow squall cloud of about the same dimensions can be the site of considerable charges and hence of a strong electric field force between different regions of the cloud. If, in a cumulo-nimbus cloud, disruptive electric discharges in the form of lightning are observed, the cloud and the process will be classified as a thunderstorm from the meteorological point of view. In other words, there exists a limiting stage of the intensity of the field force which is the necessary condition for the development of an electric discharge and hence for classifying the cloud as a thunderstorm. An ordinary flash of lightning between the cloud and the earth has spark lengths of between 1 and 2.5 kilometres; spark lengths between clouds reach much greater values. From an electrophysical point of view there must exist discharge phenomena of much shorter discharge lengths before such long discharges occur. In this connection we should keep in mind the existence of the typical predischarges connected with ordinary lightning discharges. Such shorter discharges between limited regions of the charged clouds must be assumed to have a low intensity of luminosity. They are, in general, hidden by the accumulation of particles. Thus they are not visible unless the observer is quite close to the discharge channel. An observer on the ground will not be able to notice these discharges. Our experience of the low visibility within snow squalls is sufficient to acknowledge this opinion.

It is the author's opinion that electric discharge of smaller range must occur within thunderstorm clouds and especially within snow squall clouds of a sufficient extension. Both spark lengths, current variation values, and hence transported charges are smaller than the values we have to accept in the case of ordinary lightning discharges, but the theoretical considerations presented below show that atmospherics generated by the former type of discharge do not differ in the general characteristics of their variation from what applies to a lightning discharge. The dimensions of field force and current variations of the case in question must evidently be much more limited.

The only way to demonstrate the existence of the type of discharges mentioned is to use experimental electromagnetic methods. The intention is here to prove the existence of atmospherics caused by squalls of snow clouds. Here it is first necessary to present some theoretical considerations.

Theoretical Considerations

a) *Effects of electric discharges in electric field above ground.*

It is quite easy to calculate the electromagnetic variations resulting from an electric discharge of a cloud. To simplify the case we assume the discharge path towards the ground to be vertical and the transported charge to be concentrated to a point. As is well known, such an estimation applies to a homogeneous charge within a spherical volume—an approximation which is acceptable in many cases.

We assume a charged volume of the cloud to be concentrated to a point A at a distance d from o and at a height h above the ground (see Fig. 1). Further we assume that the transported charge has values $+ Q$, and the current value I at time $t - \frac{d}{c}$ where c represents the velocity of light.

From the well known theory of electric images by Lord KELVIN we are able to consider the action of a discharge between point A and the ground as follows. Besides charge

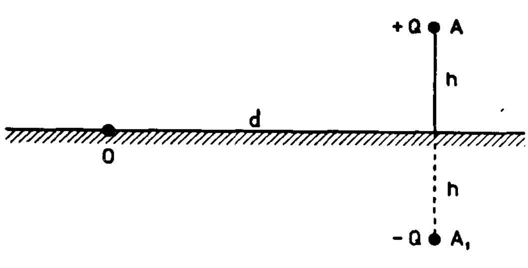


Fig. 1. Circuit for calculating variation of electromagnetic field from vertical lightning paths.

$+ Q$ in point A we have the same charge but with the opposite sign $(- Q)$ in point A_1 symmetrically situated towards A with respect to the ground. In the discharge circuit two currents must be considered, both having the same intensity I, one passing from A to the ground and the other in the same direction from the ground towards A_1.

From an analysis by LEJAY (1926) it is possible to apply the general equations of MAXWELL to the discharge circuit. He has also given general solutions in the case of discharges towards the ground in other directions than the vertical. It is possible to carry out similar calculations also with respect to discharges between two regions inside the cloud.

The electrical action in a point o on the earth, situated at distance d, can be represented by a vector F at right angles to the ground, and with a downward direction in the actual case. The expression for the vector in electromagnetic units C.G.S. is given by equation (1) under the supposition that d is great in comparison with h.

$$F = c^2 \cdot \frac{2h}{d^3} Q + c \frac{2h}{d^2} I + \frac{2h}{d} \frac{dI}{dt} \qquad (1)$$

Here, as before, c represents the velocity of light, or $3 \cdot 10^{10}$ cm/sec. By introducing $I = \frac{dQ}{dt}$ we obtain

$$F = c^2 \cdot \frac{2h}{d^3} Q + c \frac{2h}{d^2} \frac{dQ}{dt} + \frac{2h}{d} \frac{d^2Q}{dt^2} \qquad (2)$$

If the first term in (1) is neglected, we obtain the magnetic field vector H, which is at right angles to the direction from o towards the path of lightning. The expression for H is

$$H = \frac{2h}{d^2} I + \frac{1}{c} \frac{2h}{d} \frac{dI}{dt} \qquad (3)$$

The three terms that enter the field force as given by (2) represent, in sequence, the electrostatic field, the induction field and the radiation field. In equation (2) the distance enters with a factor $\frac{1}{d^3}$ in the first, with $\frac{1}{d^2}$ in the second, and with $\frac{1}{d}$ in the third term. Hence the relative values of the terms vary considerably with the distance from the channel of lightning. This will be shown through some values of I, Q, and dI/dt which have been taken from some of our own researches (NORINDER 1944). These values are given in table 1:

There is also another reservation to be made. In equation (1) we have considered the discharge path to be vertical and to pass between the ground and a point A within the cloud. In the special case that we have to deal with here we must consider a discharge between two points within a cloud. Also in this case it is possible to use the theory of electric images, as has been done earlier by WILSON (1916) and applied by MAURAIN (1948). One finds from such calculations that either the higher or the lower charge will dominate the sign and magnitude of the electric force near the ground, depending upon the relation between heights of the charges above the ground and upon the distance to the point of observation. In the case of two equal charges of negative and positive signs respectively, one situated above the other, a change of the sign in the field force will occur at a certain distance from the discharge channel. If we assume a negative charge to be situated at a height of 2 km, and another, positive one, at a height of 5 km vertically above the other, the field force will change sign at a distance of 5.5 km.

Table 1

Distance	Electrostatic term $c^2 \frac{2h}{d^3} Q$		Induction term $c \frac{2h}{d^2} I$		Radiation term $\frac{2h}{d} \frac{dI}{dt}$		
	Q		I		$\frac{dI}{dt}$		
	5 coul	10 coul	10 000 A	50 000 A	500 A/μsec	1 000 A/μsec	2 000 A/μsec
5 km	14.4 V/cm	28.8 V/cm	0.48 V/cm	2.4 V/cm	0.4 V/cm	0.8 V/cm	1.6 V/cm
10 »	1.8 »	3.6 »	$1.2 \cdot 10^{-1}$ »	0.6 »	0.2 »	0.4 »	0.8 »
100 »	$1.8 \cdot 10^{-3}$ »	$3.6 \cdot 10^{-3}$ »	$1.2 \cdot 10^{-3}$ »	$6 \cdot 10^{-3}$ »	0.02 »	0.04 »	0.08 »
1000 »	$1.8 \cdot 10^{-6}$ »	$3.6 \cdot 10^{-6}$ »	$1.2 \cdot 10^{-5}$ »	$6 \cdot 10^{-5}$ »	0.002 »	0.004 »	0.008 »

Table 1 contains such values of I, Q, and dI/dt as we have been able to measure in actual cases of lightning discharges.

When dealing with discharges within snow clouds we must assume much smaller magnitudes of the corresponding values. In table 2 the result is given of such a calculation.

Table 2

Distance	Electrostatic term $c^2 \frac{2h}{d^3} Q$	Induction term $c \frac{2h}{d^2} I$	Radiation term $\frac{2h}{d} \frac{dI}{dt}$
	Q	I	$\frac{dI}{dt}$
	0.5 coul	1000 A	100 A/μsec
5 km	1.44 V/cm	$4.8 \cdot 10^{-2}$V/cm	$8 \cdot 10^{-2}$V/cm
10 »	0.18 »	$1.2 \cdot 10^{-2}$ »	$4 \cdot 10^{-2}$ »
100 »	$1.8 \cdot 10^{-4}$ »	$1.2 \cdot 10^{-4}$ »	$4 \cdot 10^{-3}$ »
1 000 »	$1.8 \cdot 10^{-7}$ »	$1.2 \cdot 10^{-6}$ »	$4 \cdot 10^{-4}$ »

There are several reasons why one must be cautious in applying calculations based on (2). The main objection against a too far-reaching calculation is the rapid variations with time of the current that in most cases govern the electric discharges of the atmosphere. This fact will cause a complex variation feature of dQ/dt and d^2Q/dt^2 the result of which will be very complex forms of the calculated curves. This has been demonstrated by the present writer (NORINDER 1936).

There are other considerations to be inlucded in the calculations. The discharge impulses pass through regions of the atmosphere where the ionization sometimes changes considerably from one locality to another. The discharges are characterized by very shifting variation features, which must be considered to be equivalent to frequencies of different group velocity values. Hence the change of the ionization in the atmosphere will cause additional modifications of the curve forms—results that are not possible to calculate. A further complication arises from the effect of the reflection of the impulses at the upper layers of the ionosphere.

The calculations presented above will be considered as a help in understanding the transformation that an electric discharge impulse undergoes with regard to distance. At the source within the cloud the impulse current variation may have a typical and unipolar exponential variation form with rapid superimposed shorter variations. When the impulse has passed a distance of some kilometres it has very often undergone a transformation into variation type of double polarity. During their subsequent passage the transformations will be much more complicated.

The way to carry out research into the interesting transformation of the impulses with regard to distance must primarily be a problem reserved for systematic experimental measurements. For research of this kind it is necessary to analyze the transformations of the atmospherics in individual cases by using recording stations at known distances from the sources of the discharges. One condition is that measuring methods are available which allow results reducible to an equivalent measure.

b) *Methods of measuring electric field variations at distances from discharges.*

The method of measuring the variations of the electric field components as emitted by a discharge at various distances from a current path is based on the application of a suitable open antenna circuit. This arrangement was used by the present writer (NORINDER 1924, 1925, 1934) when the aperiodic variation forms of lightning discharges were first discovered. The same method was applied by APPLETON and WATT (1923) in the first study of the variation forms of atmospherics.

The antenna circuit must be placed parallel with the horizontal level of the ground in an open and undisturbed region (see Fig. 2). Hence we are able to consider the antenna wire to be exposed mainly in an equipotential surface. Let us consider the field force to be E in volts/metre; thus the potential above the ground at the height h is hE. In this case we suppose the field force lines to be directed down to the ground. In order to eliminate the oscillations proper of the antenna circuit provoked by some rapid variations of the lightning discharge, a damping resistance R_1 is introduced as well as a measuring resistance R_2. Above this latter resistance voltage variation V is connected to the deviation plates of an oscillograph. Parallel with the deviation plates a variable capacity can, if necessary, be introduced in order to regulate the voltage deviation. If this capacity is introduced it must be considered in the following calculations.

The relation between V and E is given by equation (4)

$$\frac{dE}{dt} = \frac{R_1 + R_2}{hR_2}\left\{\frac{dV}{dt} + \frac{1}{(R_1 + R_2)}\,\frac{V}{C}\right\} \quad (4)$$

We have in a special case $R_1 \ll R_2$ (e. g) $R_1 = 250\,\Omega$, $R_2 = 20\,000\,\Omega$), and R_1 can thus be omitted in comparison with R_2. Taking this into consideration, and with $R_2 = R$, we obtain:

$$\frac{dE}{dt} = \frac{1}{h}\left\{\frac{dV}{dt} + \frac{1\,V}{RC}\right\} \quad (5)$$

The sign of the right hand member depends on how the sign of the oscillographic voltage is determined. By using the sign of E, so that the lines of force go towards the ground and by supposing an increase of the field force with time, the result will be a positive sign of the right member of (5). Which of the two terms dV/dt or V/RC is in preponderance depends on the sloping ratio of the recorded curve and on the value of RC. With a small value of R, we have approximately:

$$\frac{dE}{dt} = \frac{1}{hRC}\,V \text{ or } E = \frac{1}{hRC}\int Vdt \quad (6)$$

In this case the second term is the preponderant one. In order to obtain the variation of

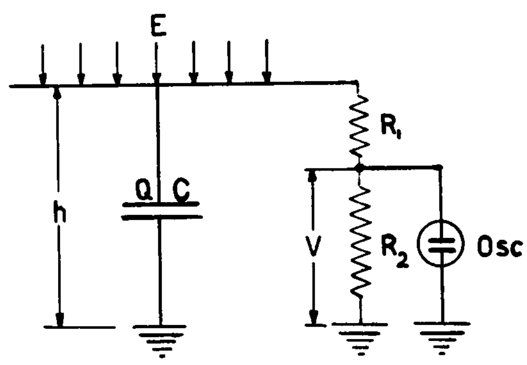


Fig. 2. Schematic diagram of antenna circuit for calculation of field variations of lightning discharges and atmospherics.

field force E, we must in such a case integrate the oscillographic curves. This is called the dE/dt method. With a high value of R, (5) will be transformed to:

$$\frac{dE}{dt} = \frac{1}{h}\frac{dV}{dt} \text{ or } E = \frac{1}{h} V \qquad (7)$$

In this case the first term is the more important one and we receive the variation of the field force without an integration procedure and thus directly. This is called the E method.

The more elaborate dE/dt method is used in those cases when the field measurements are taken at a place where local disturbances, e. g. from high tension line systems, disturb the results. It is always preferable to select a locality for field measurements where no local disturbances can influence the measurements. In such a case one has ample opportunity of using, if necessary, both measuring methods. With the exception of measurements made quite near to the discharge channel it is necessary to introduce into the measuring circuit an amplifier of such a construction that the atmospherics can be recorded without distortion. Such a circuit with an amplifier included is reproduced in Fig. 3.

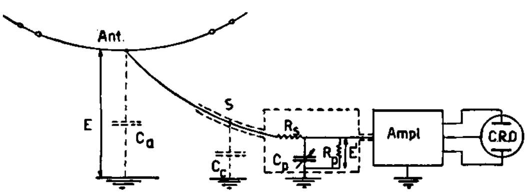


Fig. 3. Antenna circuit connected above amplifier to cathode ray oscillograph. Constants used: $C_a = 300\,\mu\mu$F: $C_c = 0.001\,\mu$F; $C_p = 0.001 - 0.1\,\mu$F; $R_p = 5$ meg Ω; $R_s = 50\,\Omega$.

It is necessary to operate the field station at places where local disturbances are eliminated. An important condition must be that the field of the antenna circuits are undisturbed and commensurable. Such a field station, Funbo-Lövsta, one of the stations belonging to the Institute, is illustrated in Fig. 4.

As a suitable instrument for the measurements a special type of cathode ray oscillograph was developed. The cathode ray tube was of the sealed-off pattern. The cathode ray oscillo-

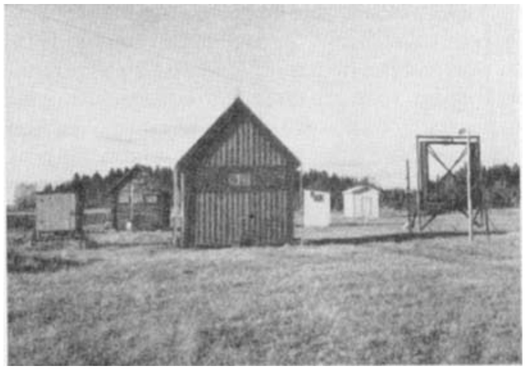


Fig. 4. External view of a field station at Funbo-Lövsta for measuring lightning discharges and atmospherics.

graphs constructed at the Institute were specially adapted for use in the study of atmospherics. The instruments were provided with a film camera arrangement in combination with a sensitive lens system. This resulted in very good photographing properties also in the case of rapid phenomena down to a duration of a microsecond. A view of such an instrument is reproduced in Fig. 5—6.

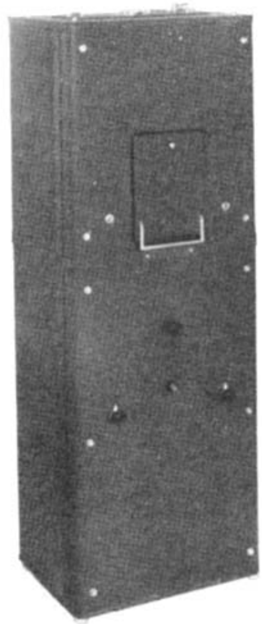


Fig. 5. External view of a cathode ray oscillograph with a tube of the sealed-off pattern.

Fig. 6. Internal view of cathode ray oscillograph in Fig. 5.

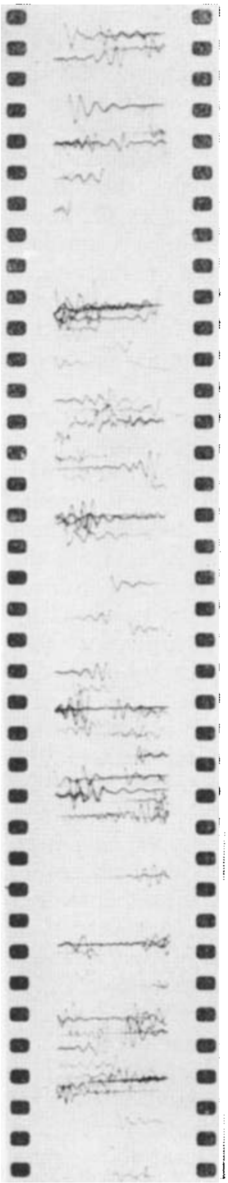


Fig. 7. Original photograph of oscillograms of atmospherics.

The sealed-off type of cathode ray oscillograph has been used especially in simultaneous recordings of atmospherics at two stations located at considerable distances from each other. In such cases the oscillographs were provided with a simultaneous time marking system, controlled by syncronisation from the Swedish syncronised electric power system. An original photograph of oscillograms of atmospherics is reproduced in Fig. 7.

In order to localize the sources of the atmospherics it was necessary to operate with direction finders. A view of such a direction finder constructed by Stoffregen (1947) and described elsewhere is given in Fig. 8.

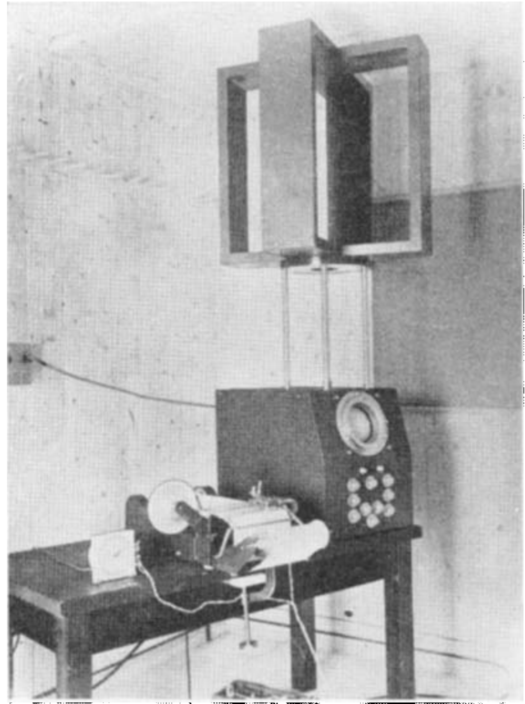


Fig. 8. Direction finder specially constructed for locating sources of atmospherics.

Measurements of Atmospherics with Special Reference to Snow Squalls

The most significant variation feature of the atmospherics emitted during the winter from snow squalls is their strikingly regular type. During one period of observation this variation type may be repeated for many hundreds of times within a very short time interval. By comparison one finds that the corresponding variation features of atmospherics emitted from thunderstorms at c orresponding distances are characterized by a much more pronounced irregularity. That this must be the case follows from the shifting variation types which always characterize lightning discharges. Also in cases where the sources of lightning discharge have been situated at considerably greater distances than those within the squalls of snow clouds we find a more pronounced irregularity in those atmospherics which are a consequence of flashes of lightning.

It must be remarked that in all the following measurements the E method has been used for the vertical component of the electric field.

In order to illustrate the difference referred to above, a few oscillograms, obtained from the two stations Funbo-Lövsta (Uppsala) and Orsa, at a distance of about 300 km from each other, are reproduced in Fig. 9—10. Simultaneous records of atmospherics were taken at these two stations. Fig. 9 represents atmospherics of the long duration type. In this case the source was situated somewhere in Central Europe at a distance from the Uppsala station of about 1,500 km. Similar variation types from snow squalls have never been observed. In Fig. 10 we have instances of another case with a distance of about 500 km from the source to the Uppsala station. The source was located

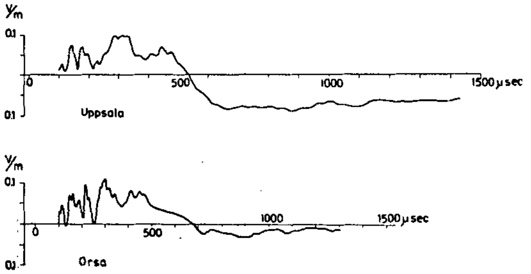


Fig. 9. Simultaneous records of atmospherics at two stations separated by a distance of 300 km.

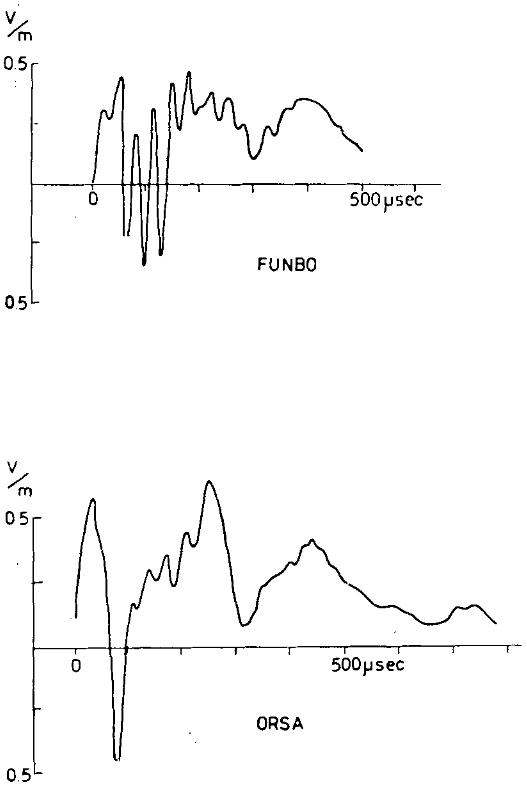


Fig. 10. Simultaneous records of atmospherics at two stations separated by a distance of 300 km.

in the southern part of Sweden. If we compare these oscillograms of typical irregularities with the following oscillograms from snow squalls having regular variation forms, we shall find a very prominent difference.

We shall now illustrate a situation which is very interesting with regard to the numerous repetitions of atmospherics of approximately similar type. This occurred on November 1st, 1948—a day characterized by a cold front located over the North Sea. During this day we observed a very intense production of atmospherics from the front. Most of them were of such a regularity and variation form as to exclude the possibility that they might be caused by lightning discharges. Of about 300 atmospherics recorded during a continuous period of only ten minutes, the ones illustrated by Fig. 11 a, b show variation types of such a resemblance as to give the impression that all have been produced by a similar process in a special regular way.

We shall give an instance of another case. On the 1st of March 1949 a snow storm was sweeping over Denmark, the northern part of Germany and on into Poland. Recording with a direction finder we observed a great number of atmospherics emanating from the directions mentioned. In Fig. 12 a, b some layed-out oscillograms are reproduced. There is not the least impression that any of them could have been generated by lightning discharges. They are typical of snow squalls. The measured values of the field forces agree well in their order of magnitude with the calculated field force values of table 2 at distances of 1,000 kilometres.

During the past winter season we have been on the look-out for a situation in which a more restricted region of snow squalls appeared not too far away from the observation station. As a further condition it was stipulated that no other sources of disturbances should interfere by producing atmospherics of the same or a higher order of magnitude.

Such a situation occurred on the 22nd of November, 1948. On this day and the next we observed from the Uppsala station a stable and characteristic bank of cumulo-nimbus clouds clearly visible between 50° and 190° from the field station Funbo-Lövsta at a distance of 10 kilometres from Uppsala. A picture of this cloud-bank is reproduced in Fig. 13. The situation was observed to be very appropriate for carrying out investigations with the aim of ascertaining whether the stable cloud-bank of a cumulo-nimbus type was producing atmospherics of the special type mentioned above.

Hence, at Funbo-Lövsta measurements of the variation of the electric field by the above mentioned *E* method were started. Efforts

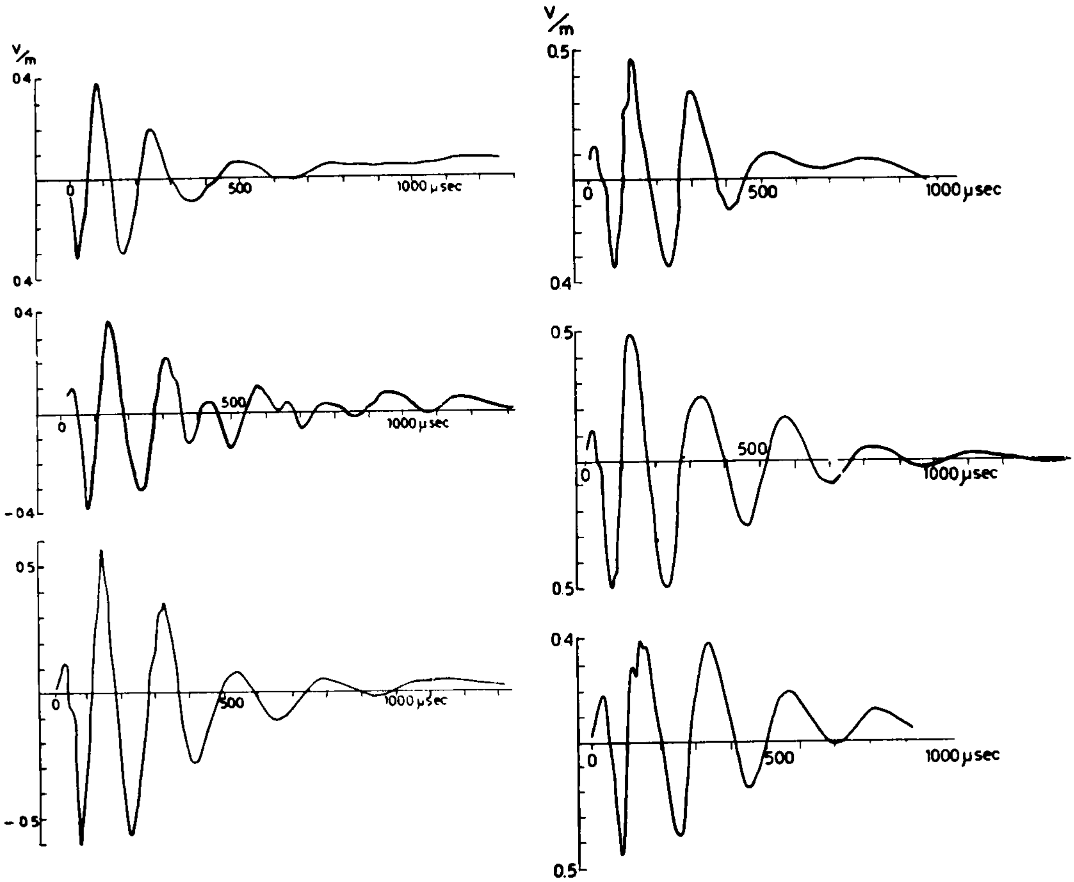


Fig. 11 a, b. Characteristic types of 300 atmospherics of similar variation type which emanated from fronts in the North-Sea during a period of 10 minutes.

were made to concentrate the records on such types of atmospherics as emanated from a certain region of the cloud-bank. This was possible by simultaneous measurements of the source of the atmospherics with the direction finder.

During the observation periods of the day in question the sources of the atmospherics of the special variation form and characterized by a high intensity level were located at directions from 160° to 175° and, in some few cases, up to 180°. The level of the field force variation of the atmospherics was very suitable in excluding records of atmospherics from other sources and distances. The latter could thus be pressed down to the zero-band of the oscillograph. The amplification was regulated in such a way that about 20 % of the recorded atmospherics resulted in a full deviation on the fluorescent screen of the oscillograph. It was not possible to avoid that some of the atmospherics became somewhat oversteered. This was necessary in order to permit recording also of the small amplitudes of the predischarges. In the case of lower amplitudes the predischarges were covered within the zero-band of the oscillograph, and thus the record begins with the main discharge. To avoid this difficulty it would be necessary to operate simultaneously two oscillographs regulated at different levels of sensitivity. Reproductions of the original records are given in Fig. 14—15. In Fig. 14 the amplitude level was too high, which was necessary to obtain the predischarges in question.

Some examples of layed-out records of the atmospherics are reproduced in Fig. 16 where two atmospherics are shown having a typical

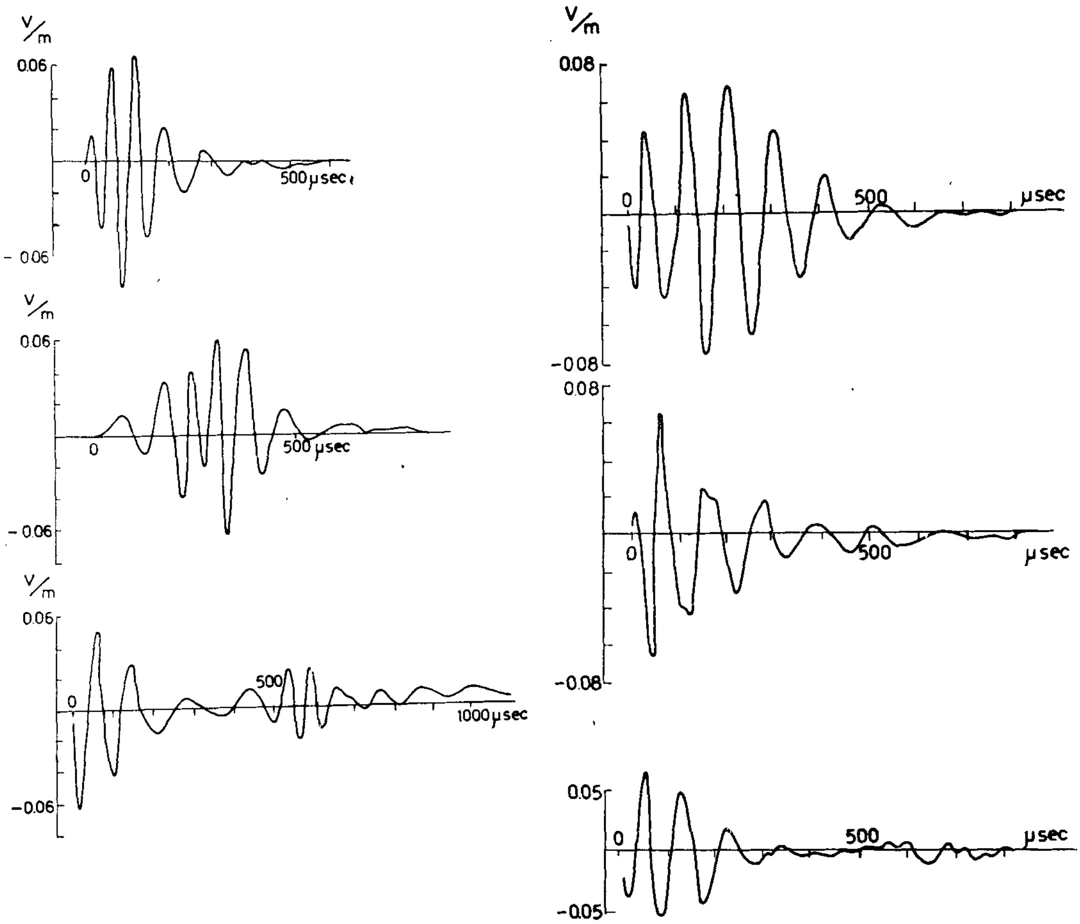


Fig. 12 a, b. Atmospherics from snow-storm front.

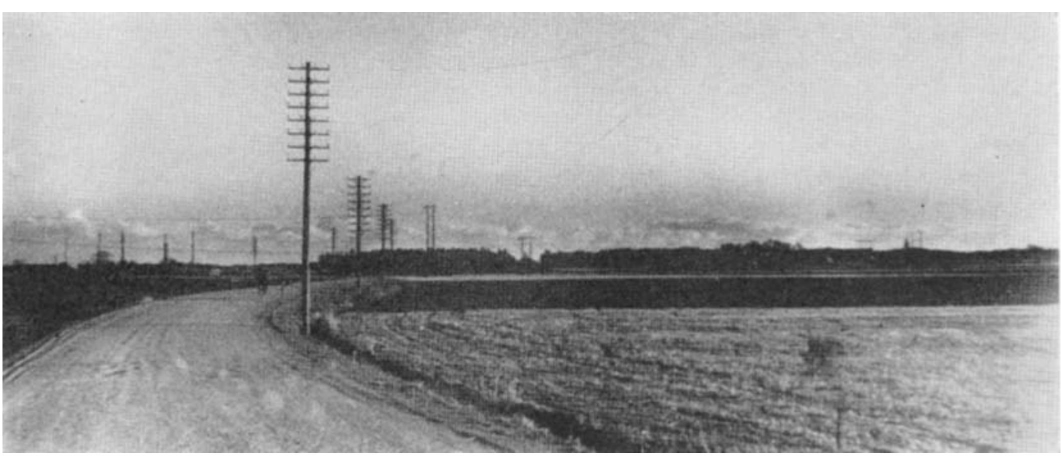


Fig. 13. A bank of cumulo-nimbus clouds over the Baltic Sea, photographed from the Institute.

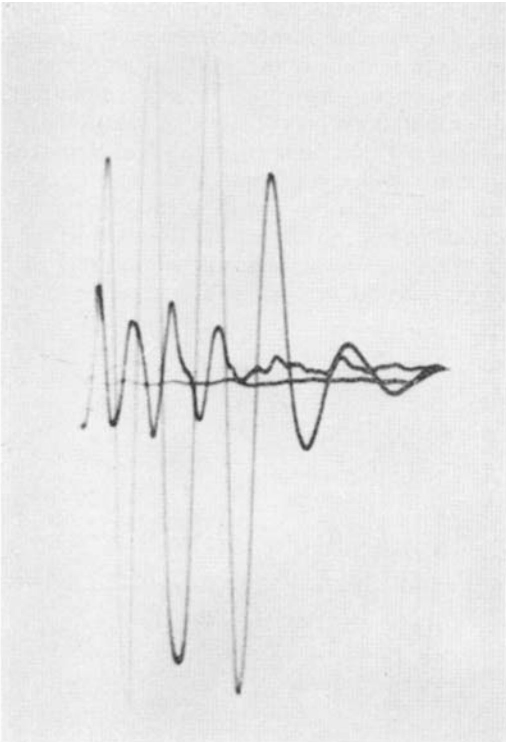


Fig. 14.

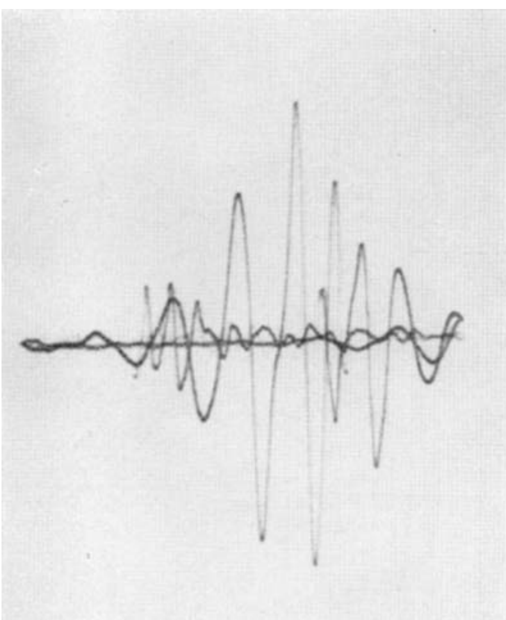
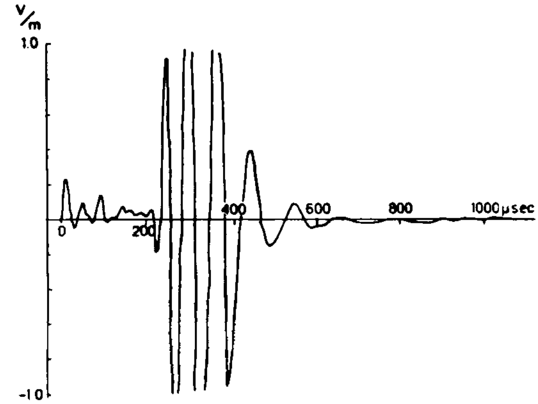


Fig. 15.



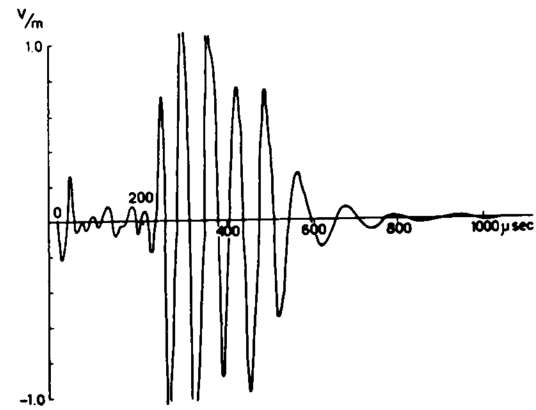


Fig. 16.

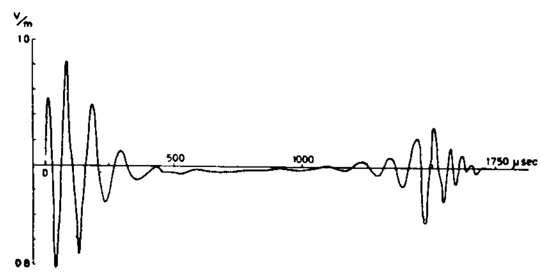


Fig. 17.

Fig. 14. Original oscillograms of atmospherics from snow-storm cloud.

Fig. 15. Original oscillograms of atmospherics from snow-storm cloud.

Fig. 16. Layed-out records of atmospherics from snow-storm cloud with predischarges.

Fig. 17. Layed-out record of atmospherics from snow-storm cloud of long duration.

initiating period with small amplitudes and lasting about 250 μsec. This period is followed by the main discharge with high amplitudes and regular variation forms. The total duration attains about 1,000 μsec. An interesting variation type of the rather long duration of approximately 1,750 μsec. is reproduced in Fig. 17. In this case we have two discharges in the same channel. Examples of the characteristic regular variation form of the atmospherics are shown in Fig. 18—19. If we compare this regular variation form with the characteristic lightning discharge variations of Fig. 9—10, the marked difference becomes evident.

In order to obtain a general survey of the weather situation during the day of observation we have from the Swedish Meteorological and Hydrological Institute received the observations from some of the nearly meteorological stations on the Swedish east coast and from adjacent stations on the coast of Finland. It is to be noted that none of the stations reported lightning discharges. Some of them, especially Utö, reported snow squalls at the observation periods $07^{h}00$ and $19^{h}00$, and during intervening observation periods this station reported cumulo-nimbus clouds and a cloudiness of $^{5}/_{10}$—$^{7}/_{10}$.

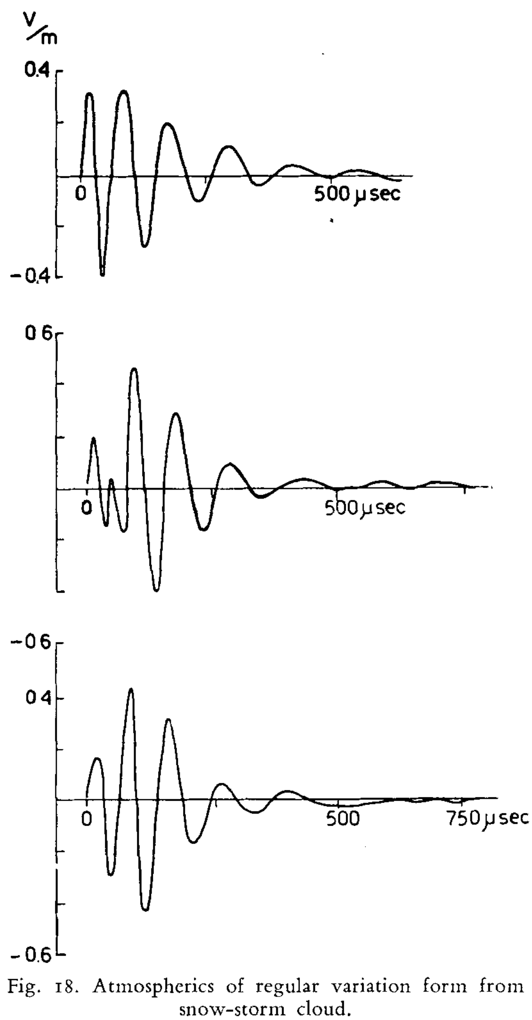


Fig. 18. Atmospherics of regular variation form from snow-storm cloud.

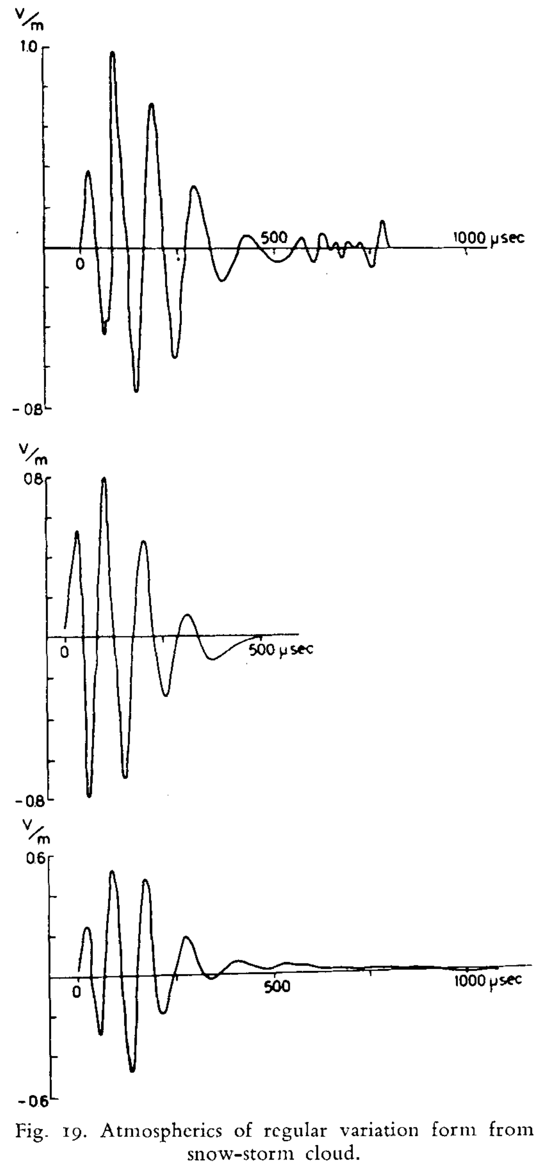


Fig. 19. Atmospherics of regular variation form from snow-storm cloud.

From an examination of the values received by the direction finder it follows that the source of the recorded atmospherics was situated within a comparatively narrow region not too far away from the Swedish meteorological station Utö. The distance from the Uppsala station is estimated to be at the order of 120 to 150 kilometres. These distances agree rather well with the amplitude values of table 2, from which follow amplitudes of the vertical field force dE/dh of the order of 0.5 volts/metre.

The following general conclusions appear to be acceptable: As a sometimes important source of atmospherics during winter seasons in countries of higher latitudes clouds of the cumulo-nimbus type bringing heavy snow squalls must be taken into consideration. From different points of view, it seems evident that such squalls must be the site of considerable electric charges per unit of volume and extending over considerable volumes. There is no reason why the intense electric fields arising from these charges should not produce disruptive electric discharges. Compared with the ordinary lightning discharge channels the discharges within snow squalls are of a lower intensity and a shorter spark length. But there is no physical reason why these discharges should not, in spite of their weaker character, be intense enough to produce typical electric disturbances in the form of atmospherics.

Evidently the first experiments dealt with here, in which a method of localizing the emission of atmospherics from snow squalls was used, must be completed by simultaneous records from stations located at varying distances from the source of emission. It must be of a special importance to try to operate in the vicinity of the source. It is also necessary to localize the site of separate discharges by a simultaneous operation using two direction finders along a suitable base line.

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