LIGHTNING ACTIVITY OF RADAR-OBSERVED STORMS

by

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ABSTRACT

A sferics direction finder is used to study the lightning activity of radar-observed storms. Seven different storms are discussed with the main emphasis placed on changes in sferics activity and its relationship to thunderstorms as defined by radar. It is found that an increase in the number of sferics detected can be related either to the position of the storm relative to the station or to the development of the storm.

The bearings of the events are plotted on weather radar maps and brief statistical analysis indicates that a relatively small portion of the storm is electrically active.
ACKNOWLEDGEMENTS

This study was conducted under the supervision of Professor E.J. Stansbury to whom the deepest gratitude is expressed for his assistance and encouragement.

I would also like to express my thanks to the members of the Stormy Weather Group and, in particular, to Mr. P. Seidenfuss for his contribution in the construction of the equipment.

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INTRODUCTION

The term "sferics" is a contraction of the word atmospherics meaning the radio frequency electromagnetic radiation originating principally in thunderstorm lightning discharges. Electromagnetic waves at radio frequencies reaching the earth from outside the atmosphere, of solar or other origin, are sometimes included within the meaning of the term.

Sferics have variously been known as clicks, grinders, sizzles, X's, strays, parasites, and by other names.

Since any acceleration of electric charge leads to emission of electromagnetic radiation, and since the several processes involved in the propagation of lightning lead to very large charge accelerations, the lightning acts like a huge transmitter of electromagnetic waves.

The electromagnetic signals produced by lightning have been studied by a number of investigators.

In the 1920's interest developed in the possibility of obtaining meteorological information from remote regions by means of sferics measurements, and networks of sferics direction finding stations were operated. The observation of sferics has taken several forms: determination of direction of arrival, measurement of intensity and rate of occurrence, and display of the wave form of individual sferics. Rate of occurrence of a particular waveform or frequency of sferics has been associated with particular types of storms with doubtful results till now.
The study described here was undertaken during the Summer of 1971, as one of a series of studies aiming to relate sferics activity to precipitation patterns observed on weather radar. The basic plan of the work involved simultaneous observations of the thunderstorm producing the signals by radar and a sferics direction finder. The study is concerned with the count rate of sferics pulses and their relationship to thunderstorms as defined by radar. A total of seven different storms will be discussed.
The first sferics recorder was demonstrated by Popoff\(^{(1)}\) at a meeting of the Russian Physico-Chemical Society in St Petersburg on May 7, 1895. On July 30, 1895, he recorded numerous lightning flashes from a nearby thunderstorm and on August 23 and 25, 1895, similar records were obtained although no thunderstorm was recorded nearby. The principle of the recorder was the cohesion induced in iron filings between two platinum plates in a glass tube (Brandy coherer) when feeble electric currents activated the coherer, thus closing the circuit of a relay to produce a vertical mark on a recorder sheet mounted on a drum and at the same time activating a trembler which decohered the filings. Tommasina\(^{(2)}\) developed a similar device in Italy and he defends his invention over Popoff's claim to priority. Using an improved carbon coherer he was able to detect thunderstorms at distances greater than 400 km. In 1900 Boggio-Lera\(^{(3)}\) won prizes in Italy for hail warning using a modified Popoff's device. The approach of the storm was indicated by his apparatus several hours in advance of the arrival of the more familiar meteorological symptoms.

Turpain\(^{(4,5)}\) in France about 1903, developed apparatus of considerable elaboration for recording disturbances more or less quantitatively, and made a series of observations establishing the value of sferics observation in the forecasting of thunderstorm conditions.

Evidence for lightning as a source of sferics was established by J. Erskine Murray\(^{(6)}\) in 1911. "At every flash and absolutely simultaneously with it an ordinary X was audible".
In 1915, R. Whiddingon(7) in England suggested the use of a radiogoniometer to determine the direction of arrival of sferics with a view to the location of thunderstorms by simultaneous observations. Despite the $180^\circ$ ambiguity, the goniometer failing to discriminate the source of the vector which it located, this method opened up the prospect of a new and valuable method of investigation. Austin(8) and Reichelderfer(9) in the U.S. contributed to the directional study of sferics in later years.

At the beginning of the 1920's investigators were not familiar with the part played by lightning discharges in causing atmospherics. It was not until cathode-ray oscilloscopes were used to study the variations of the discharge that the analysis of atmospheric disturbance was placed in a quite different position.

The cathode-ray oscilloscope in sferics observation was introduced by R.A. Watson Watt and E.V. Appleton(10) in 1923. Two years later, a relation between sferics and meteorological conditions, such as thunderstorms, precipitation, barometric pressure and fronts, was established in 87% of 490 cases by Watt.(11)

During the middle and later 1920's two types of directional detectors were developed.

The first group of instruments consists of the so-called radio goniographs or briefly, goniographs. They make use of the directional properties of a large loop antenna. In order to determine the direction of an incoming signal, the loop antenna is turned until its vertical plane contains the point from which the disturbances come; when this occurs
the signal strength is at its maximum. The two main disadvantages of this method are the 180° ambiguity in the direction of the source and the problems associated with the adjustment of the antenna for maximum signal considering the very small duration of the events. It is possible to avoid the ambiguity of location by combining the loop antenna with an ordinary open antenna. The signals in the open antenna are 90° out of phase with those in the loop, and by combining them it is possible to locate the source of the signals without ambiguity.

Two sophisticated directional finders based on the above principle were developed by Lugeon (12) (1928) in Switzerland and by Bureau (13) (1931) in France. Both of them developed complicated recording systems. Goniographs were used to analyze sferics in groups rather than individual events.

The second type of direction finder uses the cathode-ray oscilloscope as a direction indicator, and can be used for the study of individual events.

The direction finder with cathode-ray oscilloscope was introduced by R.A. Watson Watt and F.J. Herd (14) in 1926. The method employs two loop antennae with their planes perpendicular. A signal arriving at the antennae in a direction making an angle $\phi$ with the plane defined by one of them gives rise to potentials in the two antennae which are proportional to $\cos \phi$ and $\sin \phi$ respectively. The two potentials are applied to the pairs of deflection plates of the oscilloscope causing the beam to move at an angle $\phi$ to the direction associated with the plane from which $\phi$ is measured. If one of the antennae is oriented north-south and the other east-west, then the
direction of arrival can be determined. This system gives rise to the same difficulty with regard to ambiguity of direction, as was mentioned in connection with the goniometers.

Apparatus of this type have been used by investigators\(^{(15-18)}\) for sferics research in many countries. The first direction finder of this type used in Canada was reported by J.T. Henderson\(^{(19)}\) in 1935.

In later years more sophisticated instrumentation has been developed for the improvement of the cathode ray directional finder (CRDF). Maidens,\(^{(20)}\) for example, has designed for it an automatic selecting device making random selection of sferics signals exceeding a limiting value, and emitting an audible warning note so that bearings can be read. Horner\(^{(21)}\) has re-designed the CRDF used by the British Meteorological Office with the main emphasis in the new design placed on simplification and convenience of operation.

The usual method of determining range involves the simultaneous use of two or more time-synchronized stations. With two or more such stations, the range can be calculated accurately by triangulation and this method has been developed into complex systems for the location of disturbances at long range.\(^{(22,23,24)}\) The same technique can be used for short range studies, similar to the present one, but not much work has been done yet.

In spite of all the work that has been done, there has been no systematic use of a lightning location system in conjunction with a weather radar that has been successful in locating lightning discharges with sufficient precision to relate them to a specific part of a complex storm system. The present work is a step toward that goal.
1. **General Considerations**

The phenomena of atmospheric electricity can be divided into two main groups, associated with fine weather and stormy weather respectively.

In recent years there has been much research in atmospheric electricity and both of the two main groups have received attention from a large number of investigators. It has been shown that the electrical properties of the atmosphere and every phase of weather process are closely inter-related. It is now well known that atmospheric electrical reactions are associated with precipitation, inversions, fogs, fronts, air masses, etc.

Atmospheric electrical processes show both global and local variations and therefore extensive observations with regard to several elements at different places in a synoptic manner are necessary in order to establish a correlation between these processes and meteorological events.

1.2 **Non-stormy Weather Atmospheric Electricity**

Periods of fine weather create a quasi-steady situation during which there are only small changes in the phenomena of atmospheric electricity.
Measurements of the electric field at different heights above the earth's surface have shown that the field decreases considerably above a few meters and measurements of conductivity showed a corresponding increase above this height. The change in conductivity must be regarded as the fundamental fact, and the decrease in field as a consequence of it. The increase in conductivity is due to the greater effect of cosmic rays at greater altitudes, and the more rapid decrease close to the earth's surface is due to the disappearance of small ions of high mobility and their replacement by larger and slower ions. A change in the conductivity of the lowest portions of the atmosphere has little effect upon the overall resistance of the atmosphere but does have a considerable effect on the measured field at or near the earth's surface. This dependence on the conductivity of the air implies variation of the field with time, place and altitude.

1.2.1 Potential Gradient of the Atmosphere

The potential gradient \( E \) at any place in the atmosphere can be expressed in the form

\[
E = \frac{W}{R} V
\]

where \( W \) is the specific resistance of the air,

\( V \) is the existing potential difference between the earth's surface and ionosphere, and

\[
R = \int_{O}^{H} Wdh
\]

the resistance of a vertical air column of 1 cm\(^2\) cross-section between the earth's surface and ionosphere.
For the above equation to be valid a stationary equilibrium must exist between the particular quantities. This is true for regions which do not lie in the area of field generating activities. In such regions and for all practical purposes only vertical gradients are considered.

The average values for undisturbed regions of the potential gradient show a strong dependence on the type of the air mass present in that area as indicated below

<table>
<thead>
<tr>
<th>Air mass</th>
<th>Volts/meter (at the earth's surface)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arctic air</td>
<td>282</td>
</tr>
<tr>
<td>Polar continental air</td>
<td>201</td>
</tr>
<tr>
<td>Continental air</td>
<td>159</td>
</tr>
<tr>
<td>Polar maritime air</td>
<td>117</td>
</tr>
<tr>
<td>Maritime air</td>
<td>79</td>
</tr>
</tbody>
</table>

Differentiation of equation 1.1 produces the relationship:

$$\frac{1}{E} \frac{dE}{dt} = \frac{1}{V} \frac{dV}{dt} + \frac{1}{W} \frac{dW}{dt} - \frac{1}{R} \frac{dR}{dt}$$  \hspace{1cm} 1.2

which relates the changes of E to those of the basic quantities W, R, and V.

Therefore daily or seasonal variations of the potential gradient can be associated with daily or seasonal variations of the basic elements W, R and V and hence related to meteorological variations through the water-vapor content and temperature of the air.
1.3 Stormy Weather Atmospheric Electricity

The huge capacitor formed by the surface of the earth and the highly conducting layer of the ionosphere leaks continuously because of the finite conductivity of the atmosphere located between these two spherical surfaces.

The fact that a permanent electric field exists in the atmosphere implies the existence of a recharging mechanism. It is known today that the mechanism which maintains the atmospheric electrical field is of a meteorological nature and it is based on the charge-generating effect of the thunderstorm activity. Assuming an air-earth current density of $3.5 \times 10^{-12} \text{ A/m}^2$, the total fine-weather current of the whole earth would be $1800 \text{ A}$. With a $1.3 \text{ A per storm}$, $1400$ storms would be sufficient to balance the fine-weather current.

An additional contribution might be expected from point discharges during showers which never reach the stage of lightning and which, therefore, would not be included in thunderstorm activity.

1.3.1 The Thunder Cloud

The most important problems of the thunder cloud are the determination of the arrangement of the charges in the cloud and their magnitude. Despite the fact that both problems have received considerable attention, their answers are rather uncertain. One of the first contributions in this subject is that of Simpson. He concluded that, in general, a thundercloud has a positive charge in the upper layers, a negative charge in the lower part and very frequently a small
region of positive charge in the base. This lower region of positive charge is usually found in the neighbourhood of the active center of a storm and is associated with heavy rain, which is nearly always positively charged.

Kuettner's work confirms the opinion of Simpson and he specifies the average position of the charges as follows:

(i) The center of the local positive charge in the lower cloud is accurately fixed at the freezing point. This charge seems to have a horizontal extent of less than 1 km, placed in the center of precipitation and lightning.

(ii) The main negative charge is concentrated, on the average, near the -8°C level and occupies a larger area than the lower positive charge, in the vertical as well as in the horizontal direction.

(iii) With regard to the main positive charge, its position was found to be higher than the negative charge and its area to be quite extensive.

The centers of the local positive charge in the cloud base and of the negative charge above are probably bound to the same vertical air column (lightning-precipitation-downdraft center), while the center of the high positive charge is located outside this air current, following at a distance somewhat behind it. The negative charge center is apparently the starting point of most lightning.

A model of a possible charge distribution is given in Fig. 1.1.
Fig. 1.1 Model of charge distribution in a thunderstorm (after Kuettner)
The true magnitude of the separated electric charges is not well known. A frequent assumption is that the total cloud charges are not of a different order of magnitude than the charges dissipated by lightning strokes. In other words, the average cloud charge is of the order of 40-80 C. Recent measurements, however, have indicated the existence of charge centers of a few hundred coulombs in the thunderstorm structure.

1.3.2 Charge Generation

The quantities of electric charge involved in lightning discharges indicate an effective electrostatic-generating mechanism on a large scale. Such a mechanism must involve two basic processes. One of these is the separation of positive and negative charges. The second is the gross segregation of these charges.

Any theory of charge generation must be consistent with the main features of the thunderstorm. (29,30,32-34)

(i) In a large, extensive cumulonimbus the charge is generated and separated in a volume bounded by the -5° C and the -40° C levels and having a typical radius of say, 2 km.

(ii) The negative charge is centered near the -5° C isotherm while the main positive charge is situated some kilometers up; a subsidiary positive charge may also exist near the cloud base, centered at or below the 0° C level.

(iii) The process must give a rate of separation of charge up to several amperes.
(iv) The charge generation and separation processes are closely associated with the development of precipitation, particularly in the solid form.

(v) Sufficient charge must be generated and separated to supply the first lightning flash within about 12 to 20 minutes of the appearance of precipitation particles of radar detectable size.

(vi) If the process operates in nimbo-stratus clouds, it must do so much less effectively than in cumulo-nimbus clouds.

A number of theories have been developed over the years with little success. Some of them are briefly discussed below.

Assuming that gravitation is the cause of charge segregation, the different theories can be classified simply according to the origin of the charges.

In one class of the theories, the process involved is concerned with the attachment, to particles of different sizes, of the natural ions that exist in the region, these having been originally produced by cosmic rays, radioactivity, etc.

In the other class are theories according to which some process produces positive and negative charges from bodies previously neutral.

The rate at which charge can be separated according to a theory of the first class is limited by the supply of ions, while there is no such limit in the case of theories of the second class.
One of the first theories that has been widely discussed is that of Wilson\textsuperscript{(35)} who suggested that the separation of charge in thunderclouds might be due to ion capture by water drops. In a positive potential gradient, falling water drops can acquire a negative charge if the positive ions move more slowly than the drops. A variation of this theory is that proposed by Wall\textsuperscript{(36)}.

In general, there are serious drawbacks in this theory, the main one being the fact that the mechanism fails, by orders of magnitude, to account for the electrification in an average thunderstorm.

Theories that gained more ground are theories of the second class. The theories of this kind involve impacts of ice particles, frictional processes such as liquid-gaseous, liquid-solid or solid-solid surface interactions and interactions involving a change of state.

Two important theories falling in this category are those involving glazing or riming processes. On the basis of experimental work on the production of charges in the glazing process, Workman and Reynolds\textsuperscript{(37,38)} suggested that, in a suitable temperature range, supercooled cloud droplets meeting falling ice particles will be frozen in part and the remainder of the water will splash off, carrying away positive charge and leaving the ice particles negatively charged.

Mason\textsuperscript{(39)} put forward a theory similar to that of Workman and Reynolds, but the positive charge was considered to go into the air as ions, rather than to be carried off by the water splashing off. The essential process is then riming, in which the whole of the water droplet is frozen, rather than glazing, in which some remains unfrozen and splashes off.
In favor of riming or glazing theories is the fact that they give a mechanism by which the charge on the precipitation particles can be transferred to cloud particles, since the impact of cloud drops on an ice particle splashes off negative charges thus separating the charge.

If the segregation of the charge is not by gravitation, then it is necessary to find some other form of relative motion of different particles that can affect the separation in space. It is well known that in the thundercloud there is certainly relative motion of different parts of the cloud, these being an up-draught in some parts and a down-draught in others; if it were possible to find some way in which charges of one sign become attached to particles moving in the up-draught and charges of opposite sign to those moving in the down-draught, then it would be possible to get relative velocities of separation many times those possible by gravitational action.

Theories based on this idea do not account for the fact that electrical activity occurs almost as soon as precipitation is observed and probably well before the down-draught has become established.

All the theories of charge generation and separation which have been advanced during the last fifty years are open to objection on quantitative grounds and/or because they do not fit the known facts about the meteorological and electrical behaviour of thunderstorms as listed at the beginning of this section. The only mechanism suggested by laboratory experiments and which appears to fit, in a qualitative manner, the observed facts, is the charge generation associated with riming.
The possibility of having two or more processes in operation in different regions of the cloud must be considered. Nevertheless, it is unlikely that a number of different processes should be of approximately equal importance; it seems more logical to look for one process to which can be ascribed the main separation of charge in the thundercloud, other processes perhaps playing minor parts.

Localization in space and time of the lightning discharge by means of sferics measurements may give more direct evidence to what the most important method of charge generation may be.

1.3.3 The Lightning Discharge

The structure of the visual lightning flash was first elucidated using the Boys camera (a rotating lens camera). The first main feature of the results is that what appears visually as a single lightning flash is usually not a single discharge but a number of separate processes following one another. It is convenient to distinguish between the visual "flash" and its component "strokes". The general results show that a flash contains from 1 to 40 main strokes and that each main stroke is preceded by a leader stroke. The first leader stroke proceeds downwards in steps and shows considerable branching. The average time taken by a step is about 1 \( \mu \text{sec} \) while steps are separated by 30 to 100 \( \mu \text{secs} \). When the leader stroke reaches a region from 5 to 50 m from the ground, a streamer from some point connected to the earth comes up to meet it and then an upward moving stroke commences. This is much brighter than the leader stroke and follows it in its path.
time interval, there may be a second leader stroke, followed by a main stroke, and then in many cases, a third and further strokes. The leaders to strokes after the first no not show steps except rarely at the lower end of the stroke, and they usually follow the same track as the first main stroke. Such unstepped leaders are termed "dart" leaders. The difference between the stepped leader to the first stroke and the dart leaders to subsequent strokes lies in the fact that, for the latter, an ionized path already exists, whereas in the first stroke it is necessary for the insulation of the air to be broken down.

The first attempt to explain the delay which causes this step in the leaders was made by Schonland. He put forward two possible explanations: according to one view, there must be a drift of electrons down the channel, but some electrons are captured by atoms and positive ions, so that time is required for the fresh supply of electrons to advance before there is a sufficient potential gradient to carry the current further. In the alternative view, the time is required for positive ions to gather below the tip of the leader and so to give sufficient potential gradient at the tip.

The field strength necessary for local ionization by collision is about 30,000 v/cm and such a field can exist close to points, trees, etc. But when the approaching leader causes a considerable increase in potential gradient, the region in which the value of 30,000 v/cm is reached becomes larger and upward streamers can progress from points, trees and even small projections on the ground. One of these upward streamers will ultimately join with the leader and give the point of fall of the lightning flash.
As soon as the leader, in one of its branches, reaches the earth, there will be an ionized path, acting as a good conductor. The charge in the leader then quickly travels to earth, being "drained" away, starting from the bottom of the leader; the main stroke thus appears to travel upwards. As soon as the main stroke reaches a breaking point the charge in the branch is drained back, and the main stroke, which appears to be travelling up the main path, appears to travel down the branches.

Some basic characteristics of the lightning discharge are given in Table 1.1.

<p>| TABLE 1.1 |</p>
<table>
<thead>
<tr>
<th>Characteristics of Lightning Discharge (41,42)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average number of strokes in a discharge</td>
</tr>
<tr>
<td>Maximum number of strokes in a discharge</td>
</tr>
<tr>
<td>Average time interval between strokes</td>
</tr>
<tr>
<td>Average total duration of a discharge</td>
</tr>
<tr>
<td>Average current value of a stroke</td>
</tr>
<tr>
<td>Maximum current value of a stroke</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Return-Stroke Channel Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time after Initiation of Plasma Channel (sec)</td>
</tr>
<tr>
<td>---</td>
</tr>
<tr>
<td>1</td>
</tr>
<tr>
<td>30</td>
</tr>
<tr>
<td>3 x 10⁴</td>
</tr>
</tbody>
</table>

A complete discussion of the problems associated with the lightning discharge is beyond the scope of this section.
1.4 **Atmospherics**

There have been numerous reports of the close association of thunderstorms of different types with atmospherics. Considerable emphasis has been given in the investigation of atmospherics as a tool for locating and identifying severe thunderstorms and potential tornadoes by expressing the sferics parameters in various forms for comparison with thunderstorm activity. (42-46)

A correlation of weather development and electrical activity can be done by combining weather radar and sferics operations. Measurements of radar reflectivities and atmospherics can be compared and possible relationship between them can be used to establish an association between atmospherics and storm intensity. (47,48)

In addition to the use of atmospherics as a tool for the location and classification of thunderstorms, the localization of lightning in space and time within the storm can shed some light on the growth and development of thunderstorms.

Location of lightning areas by means of atmospherics has been used in forest fire protection (49) and could be useful in telephone and power lines maintenance.

1.4.1 **Detection of Atmospherics**

Since the acceleration of electric charges in the lightning discharge shows no definite periods, the radiation is in the form of a pulse which, when split up into Fourier components, show a very wide
range of frequencies. Thus, when a tuned receiver is used, atmos-
pherics will be observed no matter what frequency is used, although the
relative intensities of the effects at different frequencies depend on
the nature of the pulse and on the propagation of the different
frequencies from the source to the receiver.

In sferics direction finding systems the choice of the
operating frequency depends on many factors.

While the peak of the energy radiated by a lightning discharge
is generally placed at a frequency of about 10 kc/sec, Jones, Calkins and
Hughes\(^{(50)}\) claim that the peak value of radiated electromagnetic energy
may be found in the frequency band from 100 to 200 kc/sec with a maximum
value in the neighbourhood of 150 kc/sec. Their work is related to
lightning discharges associated with severe storms in the vicinity of
the detecting system.

At a distance of \(\lambda/2\) from the loop antenna, where \(\lambda\) is the
wavelength of the radiation, the induction field is large enough to
affect the directional characteristics of the antenna. At a distance
of one wavelength the radiation field predominates, but to ensure that
the induction field is negligible, a distance of several wavelengths is
required. Thus, it is preferable to use a rather high frequency in the
case of very short range detection systems.

The AM band is quite suitable from the antenna point of view
but since this is a fully occupied broadcasting band, background effects
may create a problem.

The shortwave band is not considered suitable as the ionospheric
wave plays an important role in the propagation at these frequencies and
considerable polarization errors may result. Also, fading of the signal is quite common at these frequencies and hence the reliability of the system is diminished.

Higher frequencies in the microwave band may be used, the main disadvantage being that the intensity of the signals becomes quite weak at these frequencies and hence high gain systems must be used.

Since our sferics system is a short range one some of the above factors are not applicable.
2.1 Experimental Set-Up

Basically, the instantaneous atmospherics direction finder consisted of two mutually perpendicular loops the planes of which were oriented vertically in the north-south and east-west directions, two preamplifiers, the indicating cathode-ray tube, and the camera.

The antennae were located on the roof of Burnside Hall, a 14-storey building on the main McGill campus. A RG-62U coaxial cable was used to connect the antennae outputs to the system located inside the building.

The block diagram of the set-up is shown in Fig. 2.1.

2.1.1 Operating Frequency

The frequency band of the direction finder was from 40 - 170 kc/sec. This band was selected by using two filters at the input of the preamplifiers. The frequency response of the filters with a terminating resistance equal to the input impedance of the preamplifiers is shown in Fig. 2.2.

The avoidance of possible interference from commercial stations and the fact that the radiated energy is large enough to give good results without need of high gain amplification, make the selection of this frequency band advantageous.
Fig. 2.1 Experimental set-up
Fig. 2.2 Frequency response of the filters
2.1.2 Directional Antenna

The loop antennae used with the direction finder were built by Aerospace Research Inc. Their diameter is 41 inches and they have 10 turns of insulated copper wire. Each loop is wound in an aluminum container that is sealed to keep out moisture.

The alignment of the antennae was done by using a transit and the known orientation of the building. The accuracy of this alignment was better than ± 1 degree.

2.1.3 The Preamplifiers

Since the analysis of the atmospherics is directly related to the weather radar echoes, collection of data originating from thunderstorms beyond the range of the radar (~ 200 km) was undesirable. For signals originating within the 200 km range the output of the antennae was large enough for the input of the amplifiers of the oscilloscope without preamplification but high sensitivity was necessary. It was decided to use low gain preamplifiers in order to be able to operate at medium sensitivities where the oscilloscope was stable over long periods of time.

The diagram of the preamplifier is shown in Fig. 2.3.

The gain of these preamplifiers was about 5 and it was constant over the entire bandwidth of the filters.

Since the final indicating device (cathode-ray oscilloscope) requires voltages whose x and y components are in phase and whose magnitudes
Fig. 2.3 Preamplifiers
bear a direct relationship to the bearings of the received signal, the preamplifiers must be identical. A difference in gain will result in a faulty direction, while a difference in phase will give an ellipse instead of a line in the oscilloscope.

Care was taken to ensure that both channels were identical.

2.1.4 The Cathode-Ray Oscilloscope

A modified Hewlett-Packard cathode-ray oscilloscope was used as the direction indicator of the sferics. The modifications are shown in Fig. 2.4. The output of the two preamplifiers was fed into the vertical and horizontal inputs of the oscilloscope. A sensitivity of 5 mV/cm was used in both channels and it was kept constant throughout the whole experiment.

Under steady conditions (zero voltage at the input) the intensity level, the trigger level, and the sweep mode were so adjusted that no spot appeared on the screen. The triggering level was sufficiently high to eliminate possible triggering due to noise signals. When a signal was received, the trigger generator was activated, raising the intensity of the CRT beam, and the line bearing the directional information was formed on the scope. To ensure triggering a spike was created by using the two differentiators connected to the grids of 6BQ7A (V9, Fig. 2.4b).

The oscilloscope face was photographed by a 16 mm camera having a film capacity of 50 ft.

Photographs of typical oscillograms are shown in Fig. 2.5.
Fig. 2.4 Modifications of the Cathode Ray Oscilloscope
Fig. 2.5 Photographs of typical oscillograms

(a) Regular type of oscillogram

(b) 'Splash' type of oscillogram
Fig. 2.5 Photographs of typical oscillograms

(a) Regular type of oscillogram

(b) 'Splash' type of oscillogram

Fig. 2.5 Photographs of typical oscillograms
2.1.5 Triggering System

Each time the oscilloscope triggers, a 5 volt amplitude square pulse appears at the anode of V11 of Fig. 2.4. This pulse was used to activate the switching circuit shown in Fig. 2.6 that controls the camera and the illumination of a clock. The sequence of the events is the following: The arrival of the sferic triggers the scope and at the same time a square pulse appears at the input of the switching circuit. This pulse turns on the silicon controlled rectifier (SRI) that switches on a light illuminating a clock located in front of the oscilloscope. The camera, whose shutter is open, photographs the scope and the clock so recording the event and the time it occurs. This sequence required \(~2\) msec. The opening of the SRI turns on the transistor T2 that switches on the second silicon controlled rectifier (SR2) connected in series with the solenoid operating the film driving mechanism of the camera. In this manner a new frame comes in and the system is ready for the next event. This sequence requires 200 msec. Therefore, two events separated by 202 msec, will be recorded on different frames.

2.1.6 McGill Weather Radar

The McGill Weather Radar located at Ste Anne de Bellevue, 19 miles from the sferics station, has the specifications shown below:

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wave length</td>
<td>10.4 cm</td>
</tr>
<tr>
<td>Peak power</td>
<td>1.0 MW</td>
</tr>
<tr>
<td>P.R.F.</td>
<td>60 sec(^{-1})</td>
</tr>
<tr>
<td>Horizontal Beam Width</td>
<td>0.85°</td>
</tr>
</tbody>
</table>
ALL CAPACITORS IN µF

T1 : 2N3643
T2, T3 : 2N2160

Fig. 2.6 Camera and screen illumination control
Vertical Beam Width: 0.86°
Minimum detectable level: -100 dBm
Pulse duration with 13:1 pulse compressor: 3.9 sec
Antenna rotation period: 10 sec
Maximum usable range: 200 km

The photographic output of the radar is in the form of a rectangular display (AZLOR) the coordinates of which are linear azimuth (0-360°) and log range from 25 Km to 200 Km. Constant altitude PPI displays are transmitted to Dorval Airport by telephone and copies of these are available but are of lower quality.

2.1.7 Errors and Limitations

The systematic errors of this work can be grouped into three categories, namely, site, instrumental, and observation errors.

(a) Site Errors

The main source of error was the position of the detector. The antennae were located at the top of a fourteen-storey building a few hundred feet away from Mount Royal hill and surrounded by a number of skyscrapers. In such a location one has to expect large site errors.

It is difficult to assign an uncertainty in the direction of arrival of sferics since we do not have any experimental indication of the order of magnitude of site errors. Nevertheless, by examining the position of a particular storm (September 11th) and the bearing of sferics originating from that storm, we believe that the site error is not very large.
(b) Instrumental Errors

Errors arising from misalignment of the loops or mismatching of preamplifiers and amplifiers, are rather small. The uncertainty in bearing which results is not more than ± 2°.

(c) Observation Errors

It was estimated that it was possible to read the direction of the trace from the film with a standard deviation of ± 1°.

A major limitation of the detector was its maximum counting rate of 3 counts/sec. In many instances two or more strokes were registered in the same frame. These strokes could have originated from different events occurring within the repetition time of the receiver. The maximum counting rate registered properly by the detector was 3 counts/sec.

The detector was also unable to differentiate between intracloud and cloud-to-ground discharges as well as between distant intense discharges and relatively weak nearby discharges.

2.2 Measurements and Results

The data collected from seven different storms during the Summer of 1971 will be discussed. The duration of these storms varies between 2 and 15 hours. In some cases discontinuities exist in the measurements mainly because of malfunctions of the film-driving mechanism of the camera.
The direction of the traces was measured by projecting the film on a glass covered table and using a protractor. Except for very short traces this technique was quite accurate.

In addition to the direction the length of each trace was recorded. It should be mentioned that since the amplitude of the pulse received at the antennae depends upon the distance of origin, sferics length measurements have real meaning only if they are range normalized. Nevertheless, some information can be obtained in certain cases where the origin of atmospherics is well defined.

Since the present study is concerned with the count rate of sferics and their relationship to thunderstorms as defined by radar, a proper representation was necessary. The fact that the photographic output of the radar was in AZLOR form and the sferics station was not located at the radar site (at the x-axis of the film), the direction of arrival of a sferic represented on this film becomes of a parabolic shape. A large number of sferics would be represented, therefore, on this film by a family of parabolas, their common vertex being the sferics station location. To avoid such a misleading representation the CAPPI's were used in spite of their lower quality.

The sferics were grouped into 5° azimuth sectors and the sferics activity was indicated by a polar histogram pointing in only one direction, in spite of the 180° ambiguity. The activity shown on each CAPPI is for a period of 10 minutes while the time between successive CAPPI's is 30 or 60 minutes depending on the development of the particular storm. Activities of less than five events are not plotted.
on the CAPPI's but the boundaries of active sectors are indicated with broken lines. Dotted areas represent areas of higher radar reflectivity.

Using this representation the results from each particular storm can be tabulated in the following way: sectors with both sferics and radar echoes, sectors with sferics but not radar echoes, and sectors with radar echoes but not sferics.

In addition to this type of statistical classification, counting rate vs. time graphs as well as histograms of the frequency of occurrence of a particular amplitude over a period of 10 minutes are used in order to study the relationship between sferics activity and storm intensity or position.

The small number of storms does not permit a reasonable statistical analysis but some main characteristics will be pointed out in the following paragraphs.

The sferics-radar correlation indicates a relatively small portion of the storm to be electrically active since only 16% of the sectors with weather echoes indicated sferics activity. Sferics activity from sectors without weather echoes is not observed very often and when it is observed, is usually limited to a few events, an effect that can be neglected. The only exception is the storm of the 26th of July in which reasonable activity (a few events/min.) was observed within a 15° echo free sector over a period of three hours. The most logical explanation is that the system was able to detect activity beyond the 200 km range.

The variation of the counting rate with time must be considered carefully. In general, the recorded activity increases as the storm
approaches the station. The assumption that small amplitude intra-
cloud discharges not detectable at large distances from their point of 
origin can be picked up by the detector as the storm moves towards the 
station, explains the peak appearing in the counting rate. Such an 
explanation would imply a reasonable increase in the relative number of 
the small amplitude events registered by the detector. This is ob-
served in the storms of July 24th, 26th, 29th and possibly the 11th of 
September. Nevertheless, this is not always true. A sharp increase 
in the counting rate is also associated with an increase in the proportion 
of large amplitude atmospherics as in the case of September the 29th and 
it is probably related to the development of the storm.

2.2.1 The 24th of July, 1971

The station started recording sferics activity at 1200 EST 
despite the fact that weather had been present for a number of hours 
within the radar range. At 1205 EST the sferics activity showed a 
sharp increase reaching a maximum of 40 counts/min. by 1225 EST and then 
dropped exponentially to a value of approximately 10 counts/min. 45 minutes 
later. During the next hour the activity fluctuated about that value. 
The activity ended at 1935 EST while weather echoes were still present. 
The variation of the sferics activity with time is shown in Fig. 2.7. 
The histograms of Fig. 2.8 indicate that the peak activity resulted from 
small amplitude sferics that the detector was able to register from 
nearby discharges.
Fig. 2.7 Variation of the counting rate with time, 24 July 1971
Fig. 2.8 Variation with time of the frequency of occurrence of relative amplitude of sferics, 24 July 1971
Fig. 2.9a Precipitation patterns and distribution in azimuth of sferics activity, 24 July 1971
Fig. 2.9b Precipitation patterns and distribution in azimuth of sferics activity, 24 July 1971
<table>
<thead>
<tr>
<th>Number of sectors with sferics and radar echoes</th>
<th>Number of sectors with sferics but not radar echoes</th>
<th>Total number of sectors with radar echoes</th>
<th>Number of sectors with sferics and radar echoes at time ( t = 1205 \text{ EST} )</th>
<th>Number of sectors with both sferics and radar echoes at time ( t + \Delta t ) **</th>
</tr>
</thead>
<tbody>
<tr>
<td>46</td>
<td>0</td>
<td>414</td>
<td>12</td>
<td>21</td>
</tr>
<tr>
<td>(11.1%)</td>
<td></td>
<td>(100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Period of statistical information: 5 hours

** \( \Delta t = 30 \text{ min.} \)
The precipitation patterns and the distribution in azimuth of the sferics are shown in Fig. 2.9. The recorded signals came from a very small portion near the edge of the storm located above the station. The possibility of receiving signals from activity centers beyond radar range was excluded since the change in bearing from NW to N over a period of 90 minutes of the main activity was comparable with the speed of the storm.

The entire SW sector was inactive though most of the weather echo was inside that sector. This peculiarity, probably related to site errors, was observed in most of the storms.

The sferics-radar correlation analysis is given in Table 2.1. Sectors with sferics but not radar echoes were not observed in this storm.

2.2.2 The 26th of July, 1971

The storm of the 26th of July is different from the previous storm in the sense that sferics activity was present for more than three hours before the appearance of weather echoes within radar range. The sferics-radar correlation given in Table 2.2 indicates 2 sectors with sferics activity but no radar echoes. Sferics activity started at 0757 EST and ended at 0600 EST July 27th, while weather existed within the radar range till late in the morning of July 27th. Between 0757 EST and 1930 EST the activity was less than 10 counts/min. The maximum activity (20 counts/min.) occurred around 2035 EST at the time the storm was passing over the station. The variation of the activity as a function of time is shown in Fig. 2.10. The histograms of Fig. 2.11
TABLE 2.2
Sferics-Radar Correlation, 26 July 1971*

<table>
<thead>
<tr>
<th>Number of sectors with sferics and radar echoes</th>
<th>Number of sectors with sferics but not radar echoes</th>
<th>Total number of sectors with radar echoes</th>
<th>Number of sectors with sferics and radar echoes at time $t = 1130$ EST</th>
<th>Number of sectors with both sferics and radar echoes at time $t + \Delta t$ **</th>
</tr>
</thead>
<tbody>
<tr>
<td>85</td>
<td>22</td>
<td>552</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(15.4%)</td>
<td></td>
<td>(100%)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* Period of statistical information: 15 hours

** $\Delta t = 1$ hr.
Fig. 2.10 Variation of the counting rate with time, 26 July 1971
Fig. 2.11 Variation with time of the frequency of occurrence of relative amplitudes of sferics, 26 July 1971
Fig. 2.12a Precipitation patterns and distribution in azimuth of sferics activity, 26 July 1971
Fig. 2.12b Precipitation patterns and distribution in azimuth of sferics activity, 26 July 1971
Precipitation patterns and distribution in azimuth of sferics activity, 26 July 1971
indicate that the small peak in the activity at about 2030 EST was
due to small amplitude signals and could be related to the position of
the storm relative to the station as indicated in Fig. 2.12. The
SW sector was once more inactive despite the existence of weather in
that sector.

A careful study of the storm history given in Fig. 2.12 reveals
that the recorded activity originated in four different active centers
designated as A, B, C, and D respectively. Center A was beyond radar
range and its activity stopped between 1630 EST and 1730 EST. Center B
was active for more than 7 hours with peak activity between 1730 EST and
1830 EST. Center C was active for about 2 hours and gave most of the
activity around 1630 EST. Finally, the last center remained active
for approximately 3 hours and gave the peak activity indicated in Fig. 2.10
at about 2030 EST.

2.2.3 The 29th of July, 1971

The sferics activity of this storm appeared a number of hours
after the appearance of radar echoes. The counting rate that was less
than 10 counts/min. over a period of three hours shows a sharp increase
at the moment the storm was over the station. Unfortunately the reason
for the abnormal end of the activity is not certain. It is likely that
the system did not register activity but the cause is unknown.

The variation of the counting rate with time is shown in
Fig. 2.13. The histograms of Fig. 2.14 indicate that the peak activity
at 1015 EST was due to small amplitude signals and, as in the previous
Fig. 2.13 Variation of the counting rate with time, 29 July 1971
Fig. 2.14 Variation with time of the frequency of occurrence of relative amplitudes of sferics, 29 July 1971
Fig. 2.15 Precipitation patterns and distribution in azimuth of sferics activity, 29 July 1971
<table>
<thead>
<tr>
<th>Number of sectors with sferics and radar echoes</th>
<th>Number of sectors with sferics but not radar echoes</th>
<th>Total number of sectors with radar echoes at time $t = 0900$ EST</th>
<th>Number of sectors with both sferics and radar echoes at time $t + \Delta t$ **</th>
</tr>
</thead>
<tbody>
<tr>
<td>35</td>
<td>0</td>
<td>240</td>
<td>7</td>
</tr>
<tr>
<td>(14.6%)</td>
<td>(100%)</td>
<td></td>
<td>10</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>15</td>
</tr>
</tbody>
</table>

* Period of statistical information: 1-1/2 hours

** $\Delta t = 30$ mins.
storms, was related to the position of the storm relative to the station. The precipitation patterns and the distribution in azimuth of the sferics shown in Fig. 2.15 indicate that probably most of the recorded activity between 1000 EST and 1030 EST came from the heavy precipitation area of the storm marked with the capital letter A. We believe that the small activity indicated in the SW sector came from the weather in the NE sector.

The sferics-radar correlation given in Table 2.3 indicates that all the recorded activity came from sectors with weather radar echoes. The maximum number of active sectors (15) was recorded at approximately 1030 EST, the moment the activity was maximum (Fig. 2.13).

2.2.4 The 11th of September, 1971.

This is practically the only storm for which the directional properties of the system were used to differentiate activities originating from two different centers of activity. While weather appeared at 0730 EST, the station started to register activity at 1014 EST. The variation of the activity over a period of eight hours is shown in Fig. 2.16. By following the direction of the arrivals of the sferics it was possible to associate the two main peaks of Fig. 2.16 with two different activity centers. These two activity centers are identified as A and B respectively in the graphical representation of sferics activity and radar echoes shown in Fig. 2.17. The activity of the individual centers is shown in Figs. 2.18 and 2.19. It should be mentioned that the activity of Fig. 2.16 includes sferics with no directional information (nearby discharges or sferics with very small amplitude) while the plots of
Fig. 2.16 Variation of the counting rate with time for total activity, 11 September 1971
Fig. 2.17a Precipitation patterns and distribution in azimuth of sferics activity, 11 September 1971
Fig. 2.17b Precipitation patterns and distribution in azimuth of sferics activity, 11 September 1971
Fig. 2.17c Precipitation patterns and distribution in azimuth of sferics activity, 11 September 1971
Fig. 2.17d  Precipitation patterns and distribution in azimuth of sferics activity, 11 September 1971
Fig. 2.18 Variation of the counting rate with time for activity originated in activity Centre A, 11 September 1971.
Fig. 2.19 Variation of the counting rate with time for activity originated in activity center B, 11 September 1971
Fig. 2.20 Variation with time of the frequency of occurrence of relative amplitudes of sferics originated in both activity centers, 11 September 1971
Fig. 2.21 Variation with time of the frequency of occurrence of relative amplitudes of sferics originated in activity center A or B, 11 September 1971
### TABLE 2.4

**Sferics-Radar Correlation, 11 September 1971**

<table>
<thead>
<tr>
<th>Number of sectors with sferics and radar echoes</th>
<th>Number of sectors with sferics but not radar echoes</th>
<th>Total number of sectors with radar echoes</th>
<th>Number of sectors with sferics and radar echoes at time $t = 1400$ EST</th>
<th>Number of sectors with both sferics and radar echoes at time $t + \Delta t$ **</th>
</tr>
</thead>
<tbody>
<tr>
<td>82 (21.25%)</td>
<td>4</td>
<td>385 (100%)</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>?</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>16</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>17</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>11</td>
</tr>
</tbody>
</table>

* Period of statistical information: 8 hours

** $\Delta t = 1$ hr.
Figs. 2.18 and 2.19 indicate activities of sferics with a specific direction of arrival. This is the reason why the heights of the peaks in Figs. 2.18 and 2.19 are different from those of Fig. 2.16. The variation of these non-directional discharges with time is shown under the same Figures.

The variation with time of the frequency of occurrence of relative amplitudes of sferics for both activity centers and for activity centers A and B separately is shown in Figs. 2.20 and 2.21 respectively. Due to the existing 180° ambiguity in the bearing of sferics, a small error was introduced in splitting up the total activity into activities of centers A and B, in particular from 1800 EST to 1900 EST.

The sferics-radar correlation given in Table 2.4 indicates four sectors with sferics but not radar echoes.

2.2.5 The 15th of September, 1971

This is another case where a small activity was recorded some time before the appearance of weather radar echo. A reasonable increase of the counting rate appeared at about 1730 EST reaching a maximum at 1940 EST. This variation is shown in Fig. 2.22 and the frequency of occurrence of sferics with a particular amplitude in Fig. 2.23. Fig. 2.24 shows the precipitation patterns and distribution in azimuth of sferics. Looking at the sequence of the 3.0 km CAPPI's we observe that the peak of the activity was moving with a speed less than that of the existing weather within radar range. This suggests the possibility of associating the sferics with activity centers located outside the radar range.
Fig. 2.22 Variation of the counting rate with time, 15 September 1971
Fig. 2.23 Variation with time of the frequency of occurrence of relative amplitudes of sferics, 15 September 1971
Fig. 2.24a Precipitation patterns and distribution in azimuth of sferics activity, 15 September 1971
Fig. 2.24b  Precipitation patterns and distribution in azimuth of sferics activity, 15 September 1971
Of course, such an assumption does not explain the change in the direction of the peak activity between 1930 EST and 2000 EST. On the other hand, since a storm was located above the station at that time, it is possible for the recorded bearing to be incorrect. Between 1930 EST and 2000 EST the station recorded 412 events out of which 190 appeared on the oscilloscope as very large splashes without directional information. It should be mentioned that the storm was a very low one and what appears in the CAPPI's is the upper part of the storm.

The activity ended long before the dissipation of weather.

2.2.6 The 19th of September, 1971

On the 19th of September the activity remained very small over the entire active period (approximately ten hours). Some of the characteristics of the storm are shown in Fig. 2.25.

Once more, activity was recorded some time before the appearance of weather within radar range.

2.2.7 The 29th of September, 1971

The station started recording sferics activity at 1205 EST although weather had been present for a number of hours within the radar range. At 1205 EST the sferics activity showed a sharp increase reaching a maximum of approximately 30 counts/min. by 1230 EST and dropped to a value of approximately 5 counts/min. 30 minutes later. For the next two hours the activity fluctuated about that value. The activity ended at 1600 EST while weather echoes were present for some hours.
ACTIVITY STARTED AT 1145 EST
ACTIVITY ENDED AT 2105 EST
WEATHER APPEARED AT 1330 EST
WEATHER ENDED ON 20 SEPTEMBER 1971

Fig. 2.25 Variation of the counting rate with time, 19 September 1971
The time variation of sferics activity is shown in Fig. 2.26 and the graphical presentation of the sferics activity at different azimuths in Fig. 2.27. Fig. 2.28 shows the histograms of the frequency of occurrence of sferics with a particular amplitude.

The peak activity was registered at the time the storm was above the station but contrary to the previous storms it was due to large amplitude sferics.

What is peculiar in this storm is the fact that the registered signals originated in a 15° sector that remained almost unchanged over the entire active period though the main part of the storm moved to the SE.
Fig. 2.26 Variation of the counting rate with time, 29 September 1971
Fig. 2.27 Precipitation patterns and distribution in azimuth of sferics activity, 29 September 1971
Fig. 2.28 Variation with time of the frequency of occurrence of relative amplitudes of sferics, 29 September 1971
CHAPTER 3
DISCUSSION AND CONCLUSION

Because of the limited period of observation covered by the measurements, no general conclusion can be based upon the measurements described here. Data from two or more thunderstorm seasons is needed for a reasonable statistical evaluation. Nevertheless, findings from the small number of thunderstorms show that sferics analysis of thunderstorms is capable of providing important complementary and supplementary information to that obtained by radar.

Nearly all sferics activity detected by this equipment can be related to precipitation echoes within radar range and, in general, precipitation echoes were detected before the sferics activity appeared. The life cycle of the weather echoes and sferics activity seems to be unrelated, but usually sferics activity appeared some time, occasionally a number of hours, after the appearance of weather radar echoes and ended long before the complete dissipation of weather.

In general, the direction finder registered peak activity whenever the storm passed over or approached the station, but in at least one of the storms the sferics production rate seems to be related to the development of the storm rather than to the position of the storm relative to the station. The sferics amplitude analysis indicated that for the general case the peak activity was associated with small amplitude events not detectable at large distances from their point of origin and we believe that they originated in small intracloud discharges. For the particular
case mentioned above, where a possible relationship between storm development and electrification is indicated, the peak activity was due to large amplitude events.

In this particular study site errors in the bearing of sferics do not permit a study of a possible correlation between centers of high sferics activity and areas of high radar reflectivity. Despite the inaccuracy in bearings, it is believed that most of the activity originated in areas within the storm rather than in areas near the edges of the storm.

It is logical to assume that sferics activity increases with an increasing number of sectors having precipitation echoes and this is indicated from the precipitation patterns and sferics activity plots.

Since the increase in the number of sectors with weather is sometimes due to the formation of new cells (for example, the 26th of July), the increase in the sferics activity may be associated with the instability causing the new cells formation.

Generally speaking, the results obtained with weather radar and medium frequency sferics detection system in combination appear to present a useful technique in the study of thunderstorms. Echoes from lightning strokes are sometimes observed on weather radar but discharges within heavy precipitation are not generally detectable because of the intense precipitation echoes. A sferics system, however, suffers from no such limitations and, hence, could be used as an additional research tool in thunderstorm investigation. With an accurate sferics system, one might be able to determine which of the portions of the storm are
electrically active at any time, thereby shedding considerable light on the electrical development of the various cells within a given storm.

The sferics system, as it now stands, is capable of determining the direction of arrival of sferics signals to a good accuracy provided it is relocated in order to minimize or possibly eliminate site errors. With small modifications the repetition time of the counter can be reduced and hence increase the time resolution of the system. On the other hand, in a network operation one could obtain more accurate measurements and carry out more complete studies by means of triangulation techniques.

It is also possible that benefit could be derived from the analysis of wave forms of sferics that indicates the relative frequency of cloud-to-cloud, cloud-to-air, and cloud-to-ground discharges. The receipt, for example, of an unusually large ratio of intracloud to cloud-to-ground wave forms emanating from an area may be indicative of the degree of vertical development of the storm. A simultaneous recording of both direction and wave form could possibly be done with the use of a dual beam oscilloscope instead of the model used in the present work.


49. R.C. Murty, "Lightning Detection Studies", University of Western Ontario, Physics Department, Special Report, August 1966.