BELLCOMM, INC.
1100 Seventeenth Street, N.W. Washington, D.C. 20036

SUBJECT: Lightning Discharges and Sferics
Case 710

DATE: February 23, 1968

FROM: W. R. Sill

MEMORANDUM FOR FILE

INTRODUCTION

In the earth's atmosphere electrical phenomena (electric fields, lightning discharges, etc.) are commonly associated with strong convective motions in clouds. Observations show that thunderstorm clouds are typically positively charged near their tops and negatively charged near their bottoms. The mechanisms producing the space charge and the attendant electric fields are poorly understood. In fact, there is some question as to whether precipitation is involved in the generation of the space charge or whether the formation of the space charge and electric fields causes precipitation.

The presence of electric fields associated with dust devils would indicate that water is not necessary or is not the only mechanism for the production of space charge. It would seem reasonable therefore to expect some electrical phenomena in the atmospheres of those planets which have clouds and/or high wind velocities.

Lightning Discharges

The discharge process begins with the formation of weakly ionized pilot streamers which advance in steps of 10-100 meters in times of the order of 10 to 100 μsec. The pilot streamer is followed by a highly ionized leader carrying a current of several hundred amperes and traveling at a velocity of approximately 100 m/sec. The advance of the leader is followed by the formation of a new pilot streamer and the sequence pilot-leader-pilot is repeated every 10 to 100 μsec, over a period of about 1 msec. The short time scales involved in these current motions give rise to radiated energy at high frequencies (up to 10 MHZ). In particular the repetition of the strong current pulses in the leaders at intervals of 10 to 100 μsec results in considerable energy being radiated in the 20 to 50 KHZ region of the spectrum.

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If one of the leaders reaches the ground a return stroke of high intensity (10^4 amps) starts toward the cloud. The time of travel for the return stroke from the ground to the cloud bottom (1-2 km) is about 50 to 100 μsec. This part of the discharge radiates considerable energy in the 5 to 10 KHZ portion of the spectrum. However, lightning discharges do not always reach the ground and in tropical latitudes where the cloud bottoms tend to be high there are many discharges within clouds or from cloud to cloud. In discharges of this type (no ground return stroke) the intense band of radiated energy between 5 and 10 KHZ is absent.

The time occupied by that part of the discharge process described above is a little over 1 msec (pilots and leaders - 1 msec, return stroke .1-.5 msec). However at least half of the cloud-ground discharges are composed of multiple strokes separated by approximately 100 msec so that the total time for the complete discharge process can be as large as 200 to 500 msec. Observations of sferics have shown that the energy at the lower frequencies (10 to 50 KHZ) from the leaders and return strokes arrives in a series of discrete pulses while at the higher frequencies (>1 MHZ) the energy arrives almost continuously over the period of the complete discharge (200-500 msec).

Observations of the Spectra of Sferics

The electromagnetic radiation produced by lightning discharges ranges in frequency from the visual to a few HZ. The study of sferics (the longer wavelengths) encompasses the region from 10 HZ to 20 MHZ with a preponderance of observational data in the range from 1 to 100 KHZ.

The average amplitude spectrum of nearby (30 to 50 km) lightning discharges typically exhibits a broad maximum between 5 and 10 KHZ and a minor peak or plateau near 30 KHZ. Above 50 KHZ the spectrum falls off as f^{-1}. From the discussion in the previous section we can attribute most of the energy in the 5 to 10 KHZ region to ground return strokes and the energy above 30 KHZ to the precursors (pilot streamers and leaders).

The spectrum as outlined above is essentially the same as the source spectrum. However for distances greater than a few hundred km the source spectrum will be modified by the response of the earth-ionosphere waveguide. This waveguide has a maximum attenuation of -20 db/1000 km at 4 KHZ; above this frequency the attenuation falls off rapidly to a minimum of -2 to -5 db/1000 km near 20 KHZ. Above 20 KHZ the attenuation increases slowly so that it is -10 db/1000 km at 100 KHZ. The major effect of the waveguide is to introduce a sharp minimum near 4 KHZ in the spectrum of discharges which originate at distances greater than a few hundred km.

The observed spectra of distant lightning discharges exhibit a steady decrease in amplitude between 1 and 4 KHZ by a factor of 10, a broad maximum between 7 and 20 KHZ and a rate of decrease of amplitude above 20 KHZ roughly proportional to f^{-1}.

In addition to the waveguide attenuation the field has an inverse dependence (d^{-1}) on the distance to the storm center. The measured amplitudes in a 1 KHZ band at a distance of 10 km from the source are given in Table 1 (Horner, 1965).

The Frequency of Lightning Discharges

Horner (1965) estimates the time-area density (N) of the number of discharges in a typical storm as

$$N = 5.0 \quad 10^{-6}/km^2 - sec$$

For a storm of $10^4 km^2$ ($10^6 km^2$) this results in an average separation between discharges of 20 sec (.2 sec). At the higher occurrence rate the time between discharges (200 msec) becomes of the same order as the total time occupied by the discharge (200-500 msec) and the resolution in time of individual discharges is not possible. However, the low frequency energy (10-100 KHZ) of the discharge is present in discrete pulses of a few msec duration and these will be separated in time. A detector with a resolution of 1 to 10 msec should be able to resolve these discrete, low frequency pulses.

SUMMARY

Electric phenomena (space charge, electric fields, lightning, etc.) are to be expected on any planet with clouds and/or high wind velocities and convective motions.

If the discharge process is similar to that in the earth's atmosphere the optimum frequencies (from the radiated power viewpoint) at which to observe sferics would fall in the range between 10 KHZ and 100 KHZ. For a planet like Venus where the cloud bottoms may be quite high (20 km) the discharges are more likely to be within the clouds. In this case the peak radiated energy, due to the leaders, should be near 30 KHZ.

The frequency range 20 to 50 KHZ is also desirable from the standpoint of the time resolution of individual events since the energy at these frequencies is distributed in a series of discrete pulses of short duration (2 msec).

Several aspects of the ground-ionosphere waveguide of the earth and Venus are similar; for example, the planetary radii and the altitude to, as well as electron density in the lower ionosphere. The thickness of the two waveguides (70-90 km) is similar providing the surface material of Venus is a reasonably good conductor. However, the electron collision frequency in the lower ionosphere of Venus is greater than that of the earth's ionosphere and this would lead to greater attenuation factors.

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Attachment
Table 1

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ABSTRACT

Electric phenomena (electric fields, space charge and lightning) are to be expected in any planetary atmosphere that has clouds and/or high wind velocities. The characteristics of the electromagnetic radiation from lightning discharges on earth are reviewed and from this it is concluded that the optimum frequency band for the detection of sferics (the low frequency electromagnetic radiation) on Venus lies between 20 and 50 KHZ.

TABLE 1

CHARACTERISTICS OF SFERICS IN A 1 KHZ BAND

AT 10 KM FROM THE SOURCE

Frequency	Peak Amplitude (Millivolts/meter)	Flux (Joules/meter^2)
10 KHZ	1600	$3 \cdot 10^{-6}$
10 MHZ	1.1	$2 \cdot 10^{-11}$
100 MHZ	.1	10^{-13}