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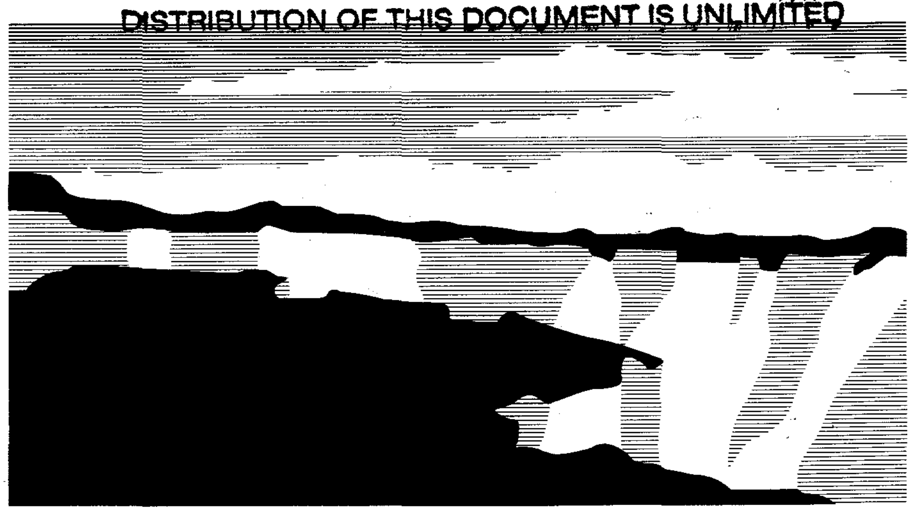

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HF Echoes from Ionization Potentially Produced by High-Altitude Discharges

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1. Introduction

In this paper we report on recent radar measurements taken during the month of October 1994 with the LDG HF radar in the Ivory Coast, Africa as part of the International Equatorial Electrojet Year. The purpose of this experimental effort in part was to study the effects of thunderstorms on the ionosphere. At the same time, we decided to carry out a set of experiments of an exploratory nature to look for echoes that could potentially arise from ionization produced in the mesosphere. The two leading candidates for producing transient ionization in the mesosphere are meteors and high-altitude discharges. Each is discussed in the context of our measurements.

2. Experimental Setup

The R4FEL HF radar used in our experiments was developed at the Laboratoire de Détection et de Géophysique (LDG) of the Commissariat a l'Energie Atomique (CEA). It was conceived by *Herbreteau* [1] and was installed at Korhogo, Ivory Coast (9^{0}24'62" N, 5^{0}39'38" W), for the International Equatorial Electrojet Year. This location is particularly well suited for studies of the equatorial ionosphere and lightning. The frequency of stormy days per month ranges from 20-25 during the April-October period [2], [3].

The LDG radar [4] operates in the frequency range from 1-30 MHz and is composed of two spiral antennas (each 100 m in diameter) for transmission and reception. At the frequencies used in these experiments the antenna lobe, full-width at half-maximum power is approximately 50^0. However, the combination of antenna sensitivity, transmitted power, and low noise background in the Ivory Coast permits the recording of echoes over a cone of approximately 140^0. Two pulses separated by 50 μs are transmitted at two different frequencies every 5-10 ms. This procedure permits management of two parallel elementary sounding cycles. The pulses have a Gaussian envelope with a selectable full-width at half-maximum of 10 - 20 μs or 40 μs and a peak power of 5 kW.

The large number of possible parameter- and task- combinations permits performance of a wide variety of investigations [4]. The experiments described in this paper used a specific 'lightning' mode that consists of envelope detection at one sounding frequency over a range of 1000 km. The time and range resolutions were 70 ms and 1.67 km, respectively.

Goniometer measurements of spherics were used to determine the location of thunderstorms. Sensors composed of two crossed-loop antennas with bandwidths of 1 kHz-8 MHz were used to detect lightning signals and to determine their angle-of-arrival. Data taken at two or more widely separated sites permitted identification of the source location. One sensor was placed at the main station D : Korhogo. Two additional stations B and C were located at 17 and 19 km from D with azimuthal directions BD and CD relative to magnetic north of 159^0 and 211^0, respectively. The transmission of time-of-arrival and azimuthal data from stations B and C to the main station was performed using unidirectional radio links. If an event was detected by two or three stations, the location was determined. This system yields maps of storm positions within about 400 km of the main station.

3. Measurements

Experiments designed specifically to look for echoes from high-altitude discharges were performed on five occasions over a period of ~10-15 minutes each Two additional control experiments were performed after the thunderstorm season. Despite the measurements of Rumi [5] at high frequencies (28 MHz), we decided in this initial set of experiments to operate only at frequencies below 3 MHz in order to maximize our chances of obtaining an echo. One nighttime and two daytime cases clearly showed signatures that could be associated with ionization produced by lightning discharges. One additional daytime experiment showed evidence for oblique reflections originating at large ranges (several hundred kilometers). The remaining daytime experiments showed no evidence of isolated transient events or were contaminated by sporadic-E which made it difficult to identify such events.

In all cases, the radar was operated at 2.2, 2.5, and/or 2.8 MHz. The echoes turned on in several interpulse times of 70 ms and were generally correlated with strong lightning activity prior to onset. Returns lasted several hundred ms at night and 1 - >10 s during the day, The angles of arrival of spherics detected at three goniometer stations were used to determine the distance to thunderstorms.

Detailed range-time plots of the echoes will be presented for all cases along with goniometer maps showing the locations of lightning spherics as a function of time.

4. Interpretation

Two potential sources of transient ionization in the upper atmosphere are meteors and high-altitude discharges associated with thunderstorms. In the case of meteors, there are some basic inconsistencies between the characteristics of meteor echoes and our observations. At the most probable altitudes for meteor intercepts, ambipolar diffusion dominates the density decay and yet the data show a much longer event duration during the day than at night. Reflection virtual heights (of 82 km) that are much lower than the most probable heights were measured on occasion. Finally, the echoes identified in our measurements are correlated with lightning activity. High-altitude discharges termed sprites can produce significant transient ionization of the mesosphere according to theoretical calculations based on runaway air breakdown [6], [7], [see also, companion papers presented at this meeting]. A plot showing the computed electron density profile along the symmetry axis of a sprite simulation is shown in Figure 1.

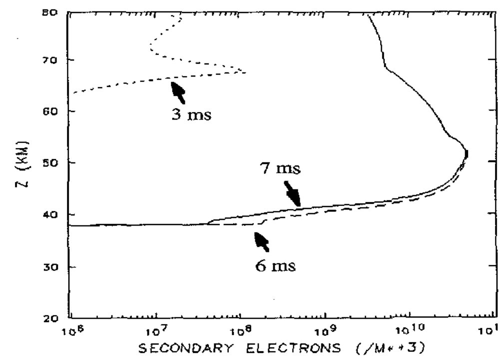

Fig. 1

The data are consistent with specular reflections from an ionization layer produced by a sprite like event at 55-65 km altitude and having minimum electron densities of $6x10^4$-10^5 cm^{-3}. The duration of the ionization is consistent with attachment, detachment, and recombination times in the nighttime and daytime mesosphere at these altitudes.

Detailed comparisons between theory and experiment will be presented along with ray-tracing calculations showing the detailed reflection geometry for a range of frequencies. The self-consistent temporal evolution of the full 2-d electron density profile is included in these calculations.

5. References

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