LIGHTNING FLASHES AND ATMOSPHERICS*

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Abstract

Since last general assembly extensive studies on characteristics of atmospherics radiated from lightning discharges have been made experimentally and theoretically all over the world and the remarkable progress has been attained, e. g. their frequency spectra have been obtained for almost all frequency ranges from ELF to UHF for every stage of ground and cloud discharges.

Propagation characteristics of VLF waves and atmospherics have been made clear for ELF and VLF ranges, e. g. the attenuation was found almost the same for frequency range 4-10 kc and about 7 to 9 db/1,000 km at 6 kc and decreases to about 1 to 3 db/1,000 km on frequencies higher than 10 kc for atmospherics and these values are fairly well coincident with those obtained for radio waves.

The intensity and phase characteristics of VLF waves and atmospherics have been investigated at normal and abnormal propagation conditions such as solar flares, geomagnetic storms, nuclear explosions, etc.

1. Introduction

This paper is written to survey the general feature of the developments made on the study of atmospherics since last General Assembly of URSI at London in 1960.

The atmospherics propagate through the space between the ionosphere and the earth in the wave guide transmission mode or in the ray mode reflecting between them. The frequency spectrum of atmospherics at the source, which depends on the characteristics of lightning discharges and geographic features, will be very useful in the study of propagation characteristics of LF and VLF waves without installing expensive transmitters.

Although the intensity and phase of VLF waves are disturbed by the solar flares, the geomagnetic storms and the allied phenomena, their intensity does not change appreciably to disturb the radio communications on VLF waves. Generally speaking,

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the VLF waves propagate long distances steadily with very low attenuation in all cases, and so they are very useful to the international comparison of the frequency standards, to the radio method of navigation, and really atmospherics on VLF range emitted from meteorological disturbances such as thunderstorms, typhoons, tornadoes, fronts, troughs, etc. are indispensable to the modern weather forecasting.

2. Lightning flashes as sources of atmospherics.

Ishikawa(1) reported that in regular peaked and quasi-sinusoidal type atmospherics the polarity of first pulse discriminate whether the origins are ground or cloud discharges, i. e. the former positive and the latter negative. Takagi(2) investigated discharges inside a thundercloud and suggested that the process of an intracloud discharge involves a slow streamer, which develops simultaneously up-and-downwards from the boundary layer between the two main opposite charged portions, and fast dart type streamers, which trace back along the slow streamer channel from a local charge centre tapped by the arrival of the slow streamer. Takeuti(3) showed that a cloud discharge often gives an indiret chance for initiating a ground discharge process. Kitagawa(4) found that in the vicinity of the lightning channel the thunder wave front propagates very fast as a shock wave. Within the range of about 500 m, the propagation velocity is higher than the sound velocity, i. e. more than 1,000 m/s in the immediate vicinity, and diminishes gradually down to the ordinary velocity. The initial velocity and the range of supersonic velocity propagation vary appreciably depending upon the energy of the associated stroke. Takagi and Takeuti(5) observed atmospherics on 100 kc - 500 Mc within the distance of 30 km from the source, and found that the intensity decreases generally inversely proportional to frequency, but on frequencies more than about 3 Mc it decreases more rapidly and shows much more fluctuations than that on lower frequencies. The radiation from a discharge is usually composed of many intermittent pulses associated with electrostatic pulses, though in the vicinity of the source it sometimes indicates a continuous radiation of long durations over 0.1 s. The radiation from a leader process of ground discharge is remarkable on any frequency, and that from dart leaders for subsequent strokes is not essentially distinguished from that of junction process filling up an interstroke period, especially on high frequencies. The return stroke produces, in general, the most intensive radiation on the frequencies less than 1 Mc, but its radiation is indistinguishable from that of the leader strokes on the frequencies higher than 10 Mc. The process of an intracloud discharge is similar to that of junction process between strokes of a ground discharge, and consequently on high frequencies, continuous radiations are observed both in cloud and junction discharges. After the initial burst of activity the pulses become more and more spaced in time. With increasing frequencies, the intermittent impulsive radiations change gradually into continuous radiations but on frequencies higher than 100 Mc they occur very often associated with electrostatic pulses.

Horner[6] made observation of atmospherics in the vicinity of source on 6 kc and 11 Mc, and found that at 6 kc the largest pulses could be attributed to return strokes, but some of the smaller pulses may have been from return strokes as well as from parts of cloud discharges. Therefore the latter may have characteristics comparable with those of the former. At 11 Mc the return stroke radiates negligible energy, and although the stepped leader discharge appears to be a minor source of energy, the main sources have not been quantitatively identified with any of the well-known lightning processes.

Recently Horner and Bradley[7] observed atmospherics on 6, 10, 45, 550 kc, 11, 200 and 400 Mc and concluded that waveforms at 45 kc are impulsive as on lower frequencies, while those at 550 kc are more similar to high frequency atmospherics. The most marked change in character, therefore, appears to take place between 45 and 550 kc. Atmospherics from cloud and ground discharges become more similar as the frequency is raised, and this is one factor tending to reduce the variation in amplitude and energy at higher frequencies.

Employing models assumed to be typical of multiple and single ground discharges, Watt[8] calculated the expected radiation field frequency spectra from 1 c/s to 100 kc. The radiation spectra obtained from 1 to 100 kc for observed ground discharge field variations normalized to 1 km are seen to agree within expected limits with calculated values. The models employed indicate that below 300 c/s multiple discharges produce much more energy than a single discharge, and that inter-and intracloud discharges may produce as much energy as ground discharges.

Malan[9] made simultaneous recordings of electrostatic field changes and radiation on 11 frequency bands from 3 kc to 12 Mc, and reported the salient points regarding the radiation field of ground discharge as follows. At 3 kc the radiation is confined to the return strokes. This remains true up to about 20 kc except that preliminary and interstroke pulses occasionally appear with amplitudes 1% to 2% of those of the return strokes. With increasing frequency up to about 1-2 Mc, return strokes still have the largest amplitude, but radiations from other parts of the discharge increase progressively. On 4-12 Mc the latter surpasses the return strokes in amplitude. On these higher frequencies the radiation is intense and continuous during the course of the first few strokes of a flash, except for pauses varying from 2 to 20 ms immediately following a return stroke as Takagi observed too.

The intracloud discharges responsible for sudden bursts of bright luminosity are usually super-imposed in sporadic fashion on the slow field change. On frequencies from 3 to 10 kc there are usually only 1 to 3 very small radiation pulses which are associated with rapid but not necessarily the largest K field changes. On 4-12 Mc the radiation becomes practically continuous and the K pulses can no longer be distinguished from the rest of the radiation. The cloud discharge[5] has high frequency characteristics somewhat similar to the J process in the ground discharge and it is generally composed of slow J-like streamers and many rapid local streamers. On frequencies higher than 100 Mc, continuous and intermittent radiations independent of any process like stepped leaders are observed. Lightning flashes within 5 km show very often a continuous radiation, which has a duration larger than 100 ms, accompanied by an electric field of complicated variation.

3. Propagation of Atmospherics.

Taylor[10] computed daytime attenuation characteristics by comparing the amplitude spectra of atmospheric waveforms recorded at four widely separated stations. The results of these attenuation measurements were presented for the band of frequencies from 3 to 30 kc and involving distances of 1,000 to 10,000 km. It was found that the attenuation was about 7 to 9 db per 1,000 km at 6 kc and decreases to about 1 to 3 db per 1,000 km on frequencies greater than 10 kc. The difference in attenuation rate of west-to-east propagation relative to east-to-west propagation was about 3 db per 1,000 km less for frequencies lower than 8 kc and about 1 db per 1,000 km less from frequencies higher than 10 kc. These results are fairly well coincident with those obtained for radio stations by Wait.

Jean[11] calculated propagation attenuation rates for frequencies below 1 kc in the ELF region (30 to 3,000 c/s) from the spectra of atmospherics observed at widely-spaced stations. Data are presented for east-west propagation under sunset approaching the eastern station. Under these conditions, the attenuation rates are about 1 db per 1,000 km at 75 c/s and they increase with increasing frequency, attaining about 3 db per 1,000 km at 200 c/s. The attenuation rates observed seem to be consistent with a two-layered ionosphere model with its lower region 90 km above the earth.

Hepburn[12] made an extensive study on smooth type atmospheric waveforms and found that a fixed ionosphere height of 83 km may be equally acceptable for the analysis of day- and night-time traces, although it is not yet approved generally; at a distance between 1,750 and 2,000 km an abrupt transition from peaked to smooth type waveforms was observed and the method of analysis applied to the peaked waveforms observed at 1,500 to 1,750 km yielded significant results in conformity with sferics data; his calculation of attenuation coefficients, somewhat different from other observers, has provided an additional evidence of a very close similarity between the day time and night-time propagation conditions for these waveforms, in that negligible relative attenuation was found in the range 4-10 kc.

4. SEA due to Flares and Nuclear Explosions.

Pierce[13] deduced attenuation coefficients for propagation under SID conditions from records of atmospheric noise for the frequency range of 3.5 to 50 kc. Comparing these with the values under normal daytime circumstances, he found that the advent of SID implies little change in attenuation between about 12 and 20 kc; above this range there is an even more pronounced increase in the attenuation coefficients. At first he made a ratio recorder which indicated the intensity ratio of 35 kc to 9 kc to discriminate between source effects independent of the SID and propagation influences solely attributable to the SID. Later he improved the recorder to indicate the intensity ratio of 35 kc to 6 kc to obtain satisfactory results.

On the occasion of nuclear explosion at Johnston Is. on 9 July 1962, SEA phenomena were observed at Toyokawa and Hiraiso Stations. At Toyokawa 27 kc suddenly increased 0.5 db and 21 kc 3.5 db above normal values at the moment of explosion, while 10 kc decreased 2 db; these indicate that the explosion generated remarkable SEA phenomena. At that time Kamada[14] found 150% increase of electron density on D layer. At Hiraiso the frequency spectrum (1-100 kc) was taken too, and they found that the lowest observable frequency suddenly increased from 3 to 6 kc at the instant of explosion.

The nuclear explosion on 9 July 1962 generated a remarkable variation on the intensity and phase of VLF receiving signal at Bagneux Station as reported by Decaux[15] in the following. Except the waves from Rugby (GBR), they propagated through the ionosphere; on 9 July their phase indicated the advance corresponding to the lowering of D, the reflecting layer, and a decrease of duration by about 10 μs for NAA (14.7 kc, Cutler, Maine) and for NLK (18.6 kc, Jim Creek, Washington), and 35 μs for NBA (18 kc, Balboa, Panama), and a retardation of 18 μs for GBR (16 kc, Rugby, England). At Issy-les-Moulineaux they observed the amplitude increase of NBA corresponding to every phase advance. Decaux tried several explanations on these phenomena, but he postponed the conclusion for the future study.

On the occasion of nuclear explosion on 9 July 1962 Zmuda[16] observed the following perturbation on the relative phase of three frequency-stabilized VLF transmissions on propagation paths shielded by the earth from the direct effects of the explosion. The temporal variations of these three disturbances differ in major respects. On the NPG (Jim Creek, Washington) to APL/JHU (Silver Spring, Maryland) path, the onset and maximum were essentially instantaneous, a characteristic which generally fits the burst-related neutron decay model of Crain and Tamarkin[17] in which sudden ionization in the D region is produced by neutron-decay electrons geomagnetically guided into the lower ionosphere. In addition, the NPG-APL variation shows a secondary perturbation having a 10-second period and stemming from a hydromagnetic disturbance associated with temporarily trapped neutron-decay protons of 0.4 MeV. In contrast to the NPG-APL perturbation, and among other differences, the perturbations to the transmissions from NBA (Balboa, Panama) and WWVL (Boulder, Colorado) are marked by a delay in the onset and maximum. The disturbance observed for the NBA-APL path, which lies almost along a geomagnetic meridian, resulted from ionization of the lower ionosphere by electrons that were produced in the radioactive decay of fission fragments and that formed an artificial radiation belt. Here there is a good qualitative agreement between the temporal variation of the VLF perturbation and the energy obtained in the stream of trapped fission-decay electrons drifting azimuthally from the burst region over Johnston Island to the NBA area. The temporal VLF phase variation for the WWVL-APL path (which lies along a line of nearly constant geomagnetic latitude) indicates that the major part of this perturbation is due to ionization resulting from the effects of geomagnetically trapped neutron-decay electrons. A relatively early and small part of this disturbance also results from the contribution of trapped fission-decay electrons.

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