SLOW TAIL ATMOSPHERICS AND THEIR ORIGIN

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Abstract

Electro-static field changes and VLF pulses due to a lightning discharge were measured at the close-to-thunderstorm field site, while slow tail atmospherics and VLF pulses originating from that discharge, were simultaneously measured at the two distances, i.e., 350 km and 1000 km from the source discharge respectively. Coincident recording of, electro-static field changes and VLF pulses at the source, and slow tail atmospherics at the two distances were succeeded for return strokes, but it did not succeed for cloud discharges in 1969. The initial porality of the slow tail atmospherics coincidently obtained at the two distances are found to be positive. This indicates that the electric current flows from antenna to ground of the slow tail instrument, accordingly we get the evidence that the positive electricity, which is induced on the top of a vertical antenna at the source under the influence of negatively charged thunder-cloud base, is released to ground at the moment of cloud-to-ground discharge on-set. The result is consistent with the theoretical deduction which assumes the return stroke to be a downward vertical dipole moment on the ground.

1. Introduction

Schumann (1952) predicted the existence of extremely-low-frequency radio waves (below about 20 Hz), which resonate in the earth-ionosphere cavity. Since then, an appreciable number of measurements have been made on the ELF atmospherics (below about 1 kHz) (Jean et al. 1961; Chapman el al. 1966; Sao et al. 1966; Hughes 1967) and the mode theory of propagation applied to ELF range has widely been extended (Wait 1960, 1965; Galejs 1964). As a result, it is generally established that ELF atmospherics mainly originate from lightning discharges, nevertheless yet our knowledge does not seem to be sufficient to define the nature of the discharge which produce strong ELF atmospherics. Starting from his empirical formula for electro-static field change due to a lightning discharge, Pierce (1963) obtained the amplitude frequency spectra of radio waves being produced by various discharge mechanisms. Rao (1967a, 1967b) postulated the lateral corona current between the sheath, and the core, of the first return stroke to be a source of ELF atmospherics. But the both discussions they gave do not seem to have their direct experimental basis for the emisson of ELF atmospherics. Hill (1969) reported the current-moment spectrum of an average intra-cloud discharge approximately to be one order of magnitude larger than an average cloud-to-ground discharge spectrum in the important frequency range of ELF atmospherics from 10 to 100 Hz by analysing the electric field change which was obtained by Kitagawa and Brook (1960). Since a few years we have intended coincidently to observe the ELF atmospherics at a good distance from their origin, along with the corresponding electro-static field changes which are due to nearby lightning discharges at their origin field site (Ishikawa et al. 1968). The main purpose of this paper is to describe our coincident experimenal result and to investigate the mechanism of a lightning discharge which radiates strong slow tail atmospherics.

2. Experimental Procedure

In 1968, we used two obseration sites to make the simultaneous observation of ELF atmospherics (at Sakushima) in correlation with the observation of their origin lightning discharge (at Imaichi), and added another field site, Kagoshima, to observe slow tail atmospherics in 1969. The location of the three field sites are shown in Fig. 1. At Imaichi we limited our observation to the thunderstorms appeared close to the site, where we used a quasi electro-static field meter to record the field changes in the frequency range from 0.02 to 1000 Hz, and a VLF receiver whose receiving frequency is from 1 to 100 kHz. Both the two adopted the same size of a conventional vertical whip-type antenna of 1 m height. In

Fig. 1 The three field site locations.

1968, we recorded the VLF pulses with an AM magnetic tape recorder which is operated in the frequency range from 0.1 to 13 kHz at Imaichi, and replaced it in 1969 with FM recording whose operational frequency band was from DC to 1.25 kHz. Therefore VLF signals recorded at Imaichi in 1969 were not of the original signal but of the VLF detector output accordingly. At Sakushima at a distance 350 km from

Imaichi, and at Kagoshima rougly at a distance 1000km from Imaichi, we used the ELF receivers which responded to the electric field variation from 0.005 to 1 kHz and adopted ball antennae developed by Ogawa et al. (1966). The VLF receivers for the observation at Sakushima, and Kagoshima were of similar construction to the one used at Imaichi in 1969. All signals were recorded with FM magnetic tape recorder which operated in the frequency range from DC to 1.25 kHz in both field sites.

In 1968 the simultaneous observation at Sakushima was made exclusively on ELF atmospherics without VLF recording in correlation with the thunderstorm observation at Imaichi. The recording of JJY radio signals was added to the main items at each observation site to secure the reference time signals.

3. Experimental Results

In 1968, we used two field sites, Imaichi and Sakushima. At Imaichi we got the two different types of the data, that is, the electro-static field change and the VLF field change due to nearby lightning discharge. At Sakushima we recorded slow tail atmospherics individually correlated with the discharge at Imaichi. Table 1 shows the correlation of the slow tail pulses obtained at Sakushima (350 km distance) with the VLF pulses at Imaichi (the origin).

Table 1. Correlation of VLF pulses at the origin with slow tail pulses at 350 km. (19:16-19:18 7/22/1968)

	VLF pulses due to nearby lightning discharges (at Imaichi)	
	corresponded to slow tail pulse (at Sakushima)	not corresponded to slow tail pulse (at Sakushima)
No. of recorded VLF pulses with amplitude larger than 10 mm (at Imaichi)	77 (60.6%)	50 (39.4%)
No. of recorded VLF pulses with amplitude larger than 20 mm (at Imaichi)	33 (84.6%)	6 (13.4%)

The VLF pulses at Imaichi with the amplitudes larger than 10 mm (arbitrary unit, measured on an oscillogram) are found individually to correlate with slow tail pulses at Sakushima for about 61 percentages but the remaining 39 percentages do not seem to correlate with detectable slow tail atmospherics.

In contrast to this VLF pulses at Imaichi which corresponded one by one to the return strokes, are found all to correlate with slow tail atmospherics at Sakushima. We found 24 examples of this category out of 127 correlated records between the two field sites. As to the VLF pulses with amplitudes larger than 20 mm at Imaichi we found about 85 percentages to correlate with the slow tail pulses at Sakushima.

Fig. 2 shows the correlation of amplitude of slow tail pulse at Sakushima with amplitude of VLF pulse at Imaichi, where the return strokes are indicated with black

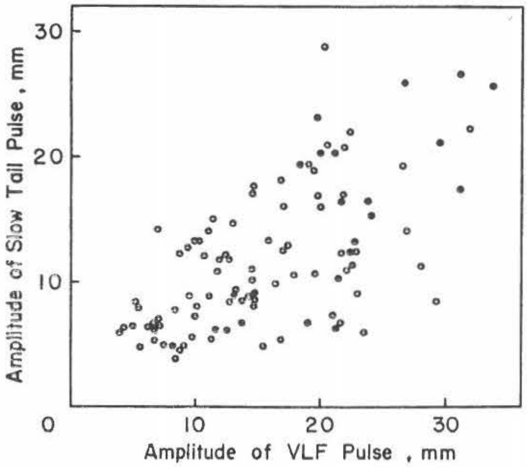

Fig. 2 Correlation of the amplitude of slow tail pulses at 350 km from the origin with the amplitude of VLF pulses at the origin. Black circles indicate the return strokes and white circles the other discharge than return strokes.

circles, and the discharges other than the return strokes are indicated with white circles. Although individual plots scatter on the figure, the general trend tells the reasonable correlation of amplitudes of VLF pulses at the origin with those of slow tail pulses at 350 km. The correlation coefficient of them is found to be 0.72. Thus we may conclude that the lightning discharge which radiates strong VLF pulse at the origin is also the strong radiator of slow tail pulse observed at 350 km distance.

Next we examined the multiple return strokes which produced slow tail pulses. Fig. 3 shows the correlation of amplitude of the initial positive swing of VLF pulses recorded at Imaichi, with amplitude of the initial positive swing of slow tail pulses observed at Sakushima. Black circles show the first return strokes and white circles the subsequent strokes. Darts on the segments indicate the developing stroke order. The correlation coefficient of this figure is found to be 0.56. We see the general trend of pointing of the darts on the figure that the majority of the segments, eventhough roughly, come to take more or less the same inclination, which indicates a significant correlation of the initial positive swing of slow tail pulses at 350 km with the initial positive swing of VLF pulses at the origin, so far we consider the return strokes involved in the

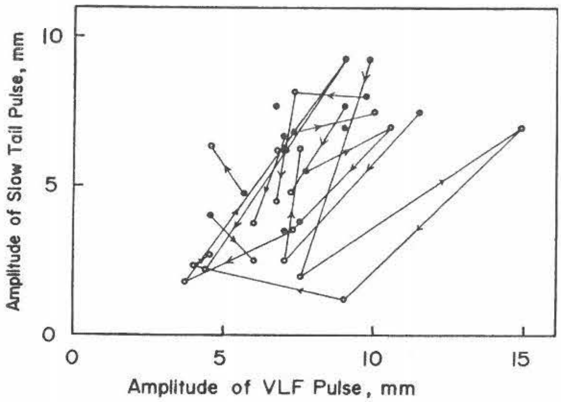

Fig. 3 Correlation of the amplitude of initial positive swing of slow tail pulses at 350 km distance with that of initial positive swing of VLF pulses at the origin.
Black circles indicate first return strokes and white circles subsequent strokes.

same ground discharge.

In 1969, the observation was made at the three sites, Imaichi, Sakushima and Kagoshima. Illustrated in Fig. 4 is an example of simultaneous record obtained at the three respective observation sites. At Imaichi we obtaind SFi and VLFi which are, respectively, the electro-static field change, and the detector output from the VLF receiver. The distance from observation site to lightning discharge was determined from the time delay of thunder from on-set of electric effect of the lightning, and it was estimated to be about 15.4 km from the site at Imaichi in the case illustrated. STs and VLFs are the slow tail pulses and the detector output of VLF receiver respectively, and were obtained at Sakushima (about 350 km distance) at the same moment as at Imaichi. STk and VLFk are respectively the slow tail pulses and the detector output of VLF receiver, and were obtained at Kagoshima (about 1000 km distance). Illustrated in Fig. 4 is the example of a triple stroke cloud-to-ground discharge, which produced the three step wise field changes on SFi record. It is noted that the first stroke which produced the strongest VLF pulse shown to the left edge on the VLFi record, radiated the weakest slow tail pulse observed at Sakushima as well, and the second stroke which produced the intermediate slow tail at Sakushima and Kagoshima, radiated the weakest VLF pulse at Imaichi, whereas the third stroke was the strongest slow tail radiator among the three. The amplitude of the first, second, and third stroke on SFi is 29, 50 and 144 V/m, and that on STs is 0.9, 3.3 and 7.9 mV/m, and that on STk is 0.14, 0.52 and 1.26 mV/m. The above fact is suggestive of the amplitude of slow tails correlateing not to the amplitude but to the differential of electro-static field changes observed at nearby-origin field site. The slow tails which radiated from lightning discharges at Imaichi and propagated 1000 km distance from Imaichi to Kagoshima,

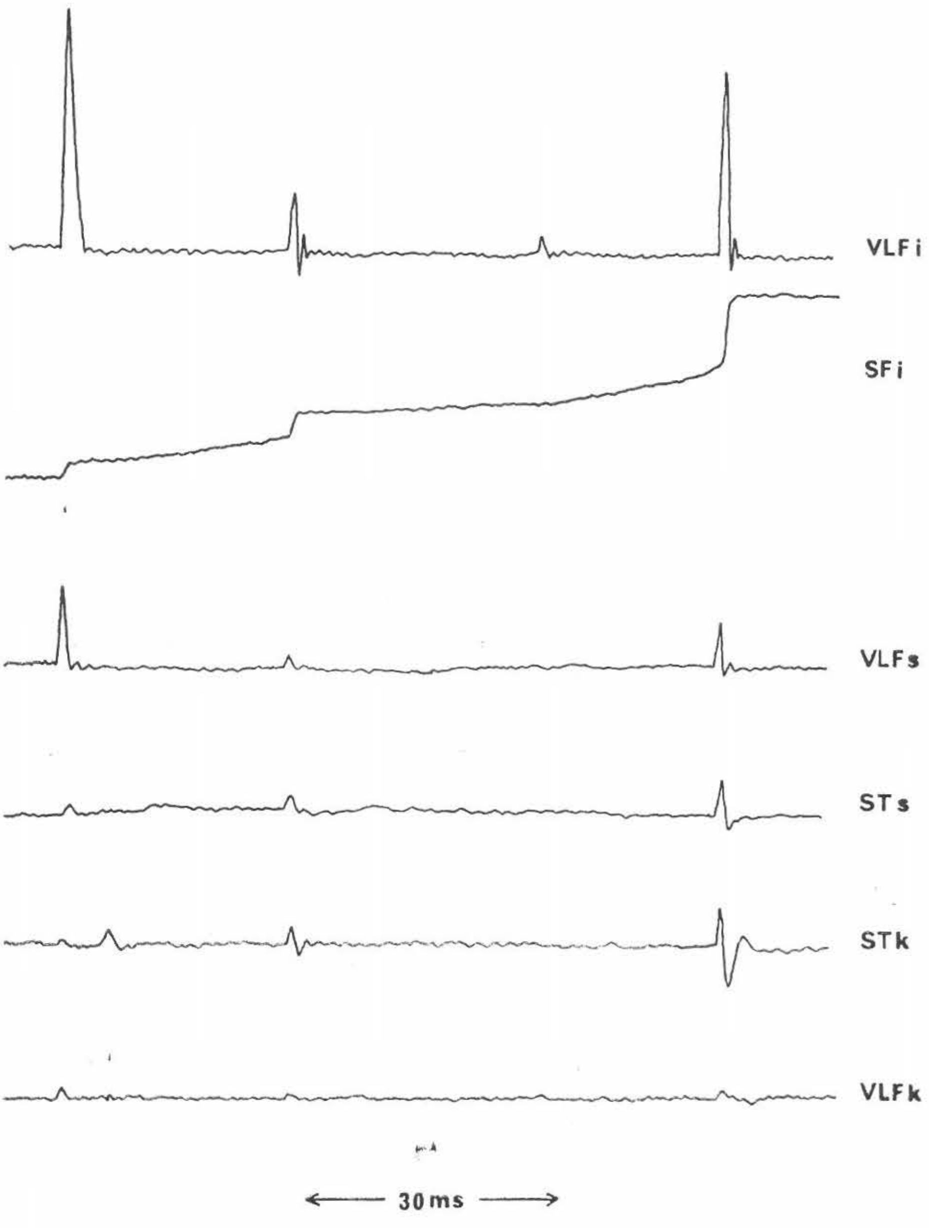

Fig. 4 The example of record of the simultaneous observation obtained at 14 h. 1 m. 38 s. July 26th, 1969, VLFi and SFi are the record at Imaichi, VLFs and STs the record at Sakushima and STk and VLFk the record at Kagoshima. Every records are positive to upward.

were picked up on the coincident running data, and finally we obtained 23 examples whose source discharges produced large electro-static field changes at Imaichi. Of these, 4 are the cloud-to-ground discharges, and 19 are the intra-cloud discharges determind from the recorded pattern of their electro-static field changes. Regarding the 19 intra-cloud discharge at Imaichi, the corresponding slow tails could be found on a few case on the Sakushima record, however, it did not succeed to find any trace of them on the Kagoshima record. Of the 4 cloud-to-ground discharges we mentioned, there are 13 return strokes being involved. The 13 return strokes at Imaichi are found all to produce slow tails at Sakushima, however 1 out of them are found not to produce any detectable slow tails at Kagoshima.

The polality of the initial swing of slow tail pulses are found all to be positive, provided that they are radiated from return strokes, and the shapes of them are noted to vary with the increase in propagation distance. At Sakushima, the slow tail pulses swing positive at first and then swing back to negative a little, while at Kagoshima they swing to positive at first and then swing back to negative with almost the same amplitude, thereafter swing back to positive a little.

The waveform of VLF detector output at Sakushima is quite similar to that obtained at Imaichi, whereas the amplitude of it observed at Kagoshima is very small compared with the other noise, at Kagoshima therefore we did not succeed to find more than 7 VLF example at Kagoshima out of 13 possible cases of return strokes recorded at Imaichi. Of these 7 examples, we see that the first peak of the slow tail pulse appears coincidently with the peak of the VLF detector output obtained at Sakushima and Kagoshima as well, within the reading errors (0.2 ms.).

Comparing the two data (ELF, VLF) obtained at the same field site, the separation time of the begining of VLF pulse from the first peak of the corresponding slow tail pulse is found to be from 0.8 ms. to 0.9 ms., and the mean value to be 0.84 ms. for Sakushima. The separation time for Kagoshima is similarly measured to be from 0.4 ms. to 0.7 ms. and the mean value to be 0.56 ms. Although the number of examples we examined are limited only to 7, it may be noted that the separation time at 350 km distance is seemingly longer then that at 1000 km distance. This seems to contradict with the theoretical expectation which would be obtained from the assumption that the separation time between VLF and slow tail atmospherics would result from the phase velocity difference of propagation between VLF and slow tail frequency band, if the propagation of slow tail atmospherics at two distances would be the same zero-order mode (Yamashita 1967). Thus the explanation of the separation time, which is also in a conformity with the trend of shape variation of slow tail pulse with propagation distance, would be that slow tails at Kagoshima are mainly consist of the radiation field, whereas to those at Sakushima, are added induction, and electro-static, fields as well in an appreciable magnitude.

4. Conclusion

The investigation of simultaneous records at the three field sites, leads to the following conclusions.

1) The amplitude of slow tails at 350 km propagation distance weakly correlates with the amplitude of VLF pulses recorded at the origin. The correlation coefficient of them is estimated to be 0.72.
2) Return strokes are the strong radiator of slow tail atmospherics.
3) The polarity of the slow tail atmospherics at 350 km and 1000 km distance is found to be positive when they are radiated from return strokes.
4) The first peak of slow tail atmospherics coincidently appears with the peak of VLF detector output observed at 350 km, and 1000 km, distances as well.
5) The separation time between the onset of a VLF pulse and the first peak of the corresponding slow tail pulse at 350 km distance i slarger than that obtained at 1000 km distance.

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