DAYTIME ATTENUATION COEFFICIENT OF VLF WAVES DEDUCED FROM THE ELECTRIC FIELD INTENSITY OF ATMOSPHERICS

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This paper describes the attenuation coefficient of very low frequency (VLF) propagation deduced from the electric field intensity of atmospherics. The received atmospherics are applied simultaneously to three narrow band receivers tuned at respective frequencies, and their amplified and integrated output voltages are automatically recorded with recording ammeters. In spite of rather small changes between levels of respective integrated field intensities at night, certain characteristic variations due to the differences of attenuation are found in the daytime. It can, therefore, be seen that the attenuation coefficient of VLF radio waves may be estimated approximately using the data of the field intensity of atmospherics. But owing to difficulties of estimation of locations of respective origins, it appears that the results deduced here are not always of high validity.

Now as regards the receiving system, the vertical aerial of 10 m long is employed and is followed by the amplifier whose overall gain is 150 dB. The frequency band is about 500 c/s at 6 dB down. In particular, the output at the intermediate frequency stage is applied to a detection circuit with the discharge time constant of 80 seconds. Owing to the integration circuit having an enough large time constant compared with intervals of received atmospherics, the amplified output voltages may be considered to indicate a certain average level proportional to the field strength of input signals.

A typical diurnal variation of the electric field intensity of VLF atmospherics is depicted in Fig. 1. Variations in the daytime show the characteristic features for

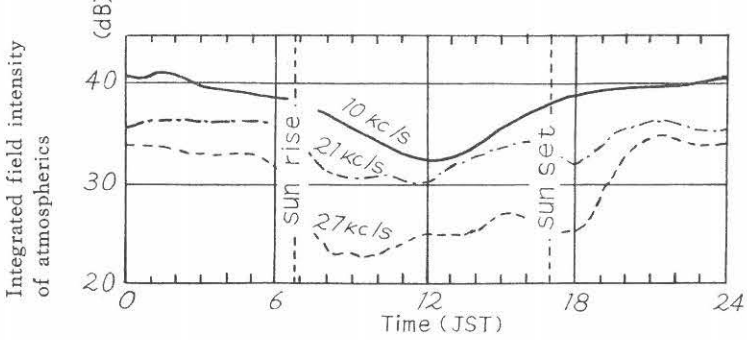

Fig. 1. Diurnal variation of monthly average of field intensity of atmospherics.

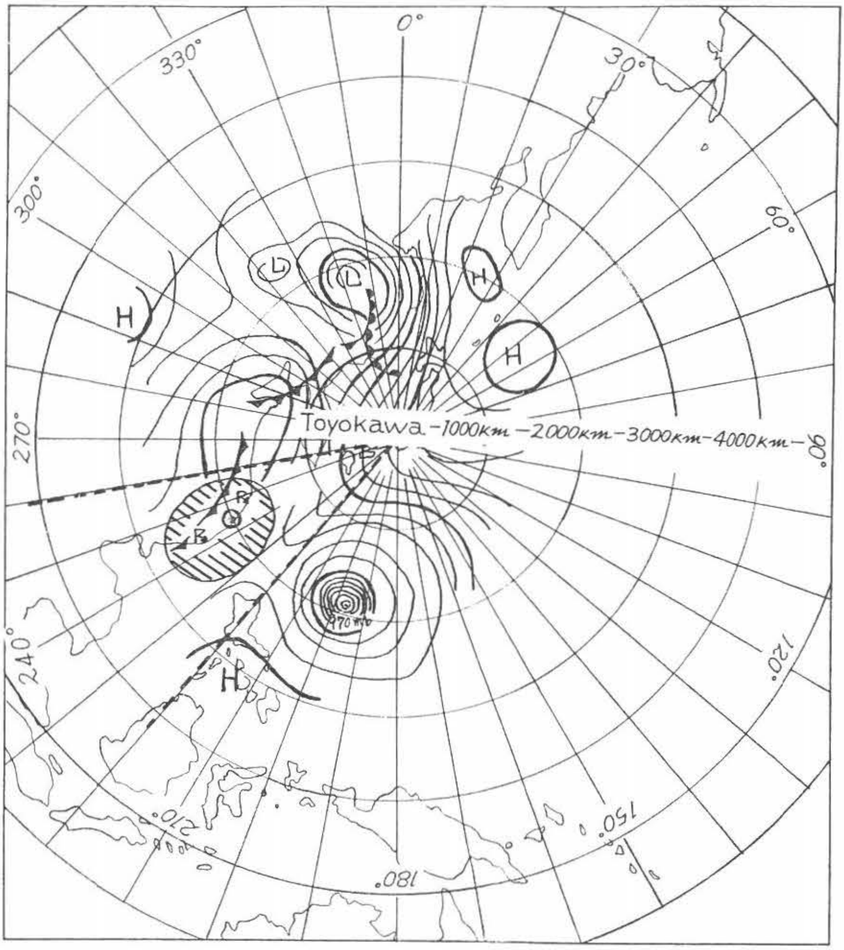

Fig. 2. Location of an origin deduced from the record with the unidirectional narrow sector recorder and from the weather map.
Sep. 15, 09h, 1957.

respective curves, because there are differences of attenuation of VLF waves for respective frequencies. Taking into account a lightning discharge having the amplitude frequency spectrum $A \cdot \phi(f)$, the received electric field intensity $E(f, D)$ at a distance of D from origin is shown by the following expression,

$$E(f, D) = \frac{A \cdot \phi(f)}{\sqrt{D}} \cdot e^{-\alpha(f) \cdot D}$$

where A is a coefficient proportional to the intensity at the origin, and $\alpha(f)$ denotes the so-called attenuation coefficient at a frequency of f. Next, considering the reference frequency denoted by f_0, the ratio of the field intensity at a frequency of f to that for reference frequecy can be expressed by :

$$\frac{E(f, D)}{E(f_0, D)} = \frac{\phi(f)}{\phi(f_0)} e^{-[\alpha(f) - \alpha(f_0)]D}$$

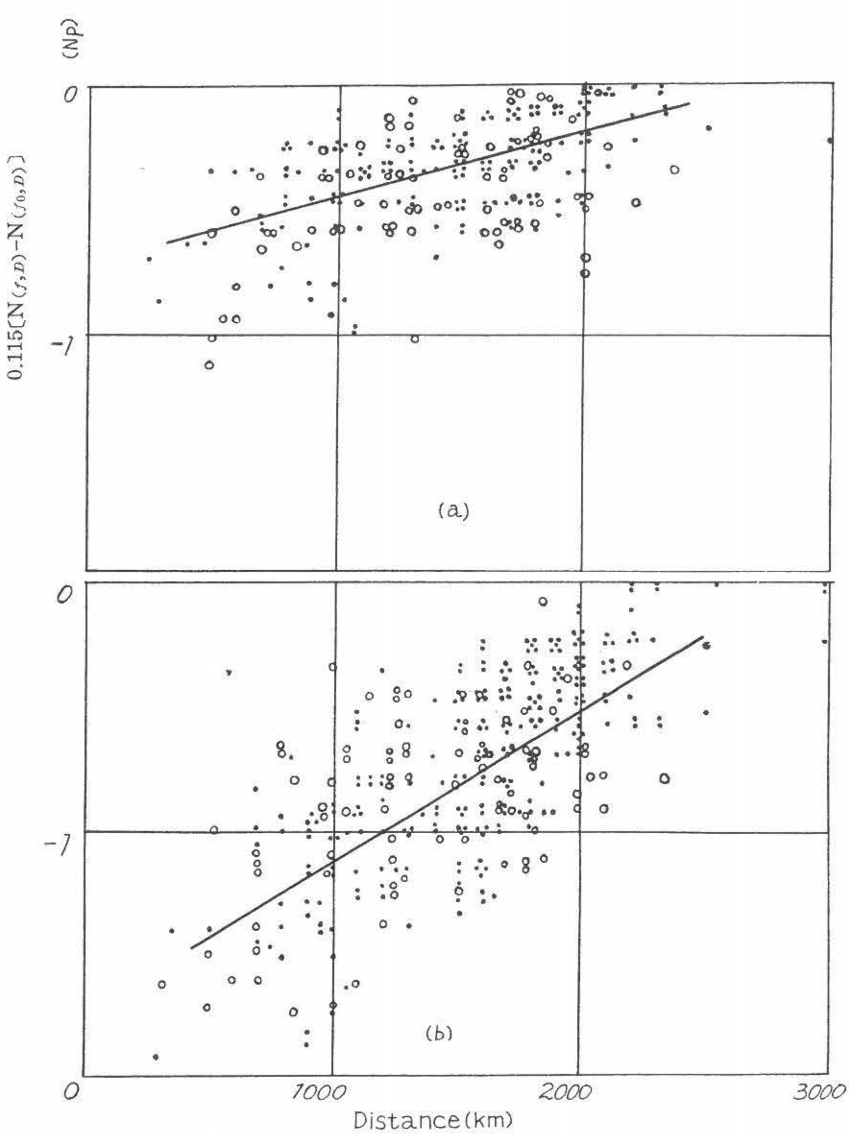

Fig. 3. Relation between the level differences of electric field intensity of atmospherics and the distances from origins. (o winter season, • summer season)

because identical sources are employed for both frequencies. Again, the record of integrated field intensity of atmospherics is usually shown in dB, so the next expression is rather convenient for our purpose,

$$ln\left[\frac{E(f,\ D)}{E(f_0,\ D)}\right]=ln\left[\frac{\phi(f)}{\phi(f_0)}\right]-[\alpha(f)-\alpha(f_0)]D$$

and by setting 20logE=N(dB), then

$$0.115\,[N(f,\ D)-N(f_0,\ D)]=ln\,\frac{\phi(f)}{\phi(f_0)}-[\alpha(f)-\alpha(f_0)]D\cdots\cdots\cdots\cdots(1)$$

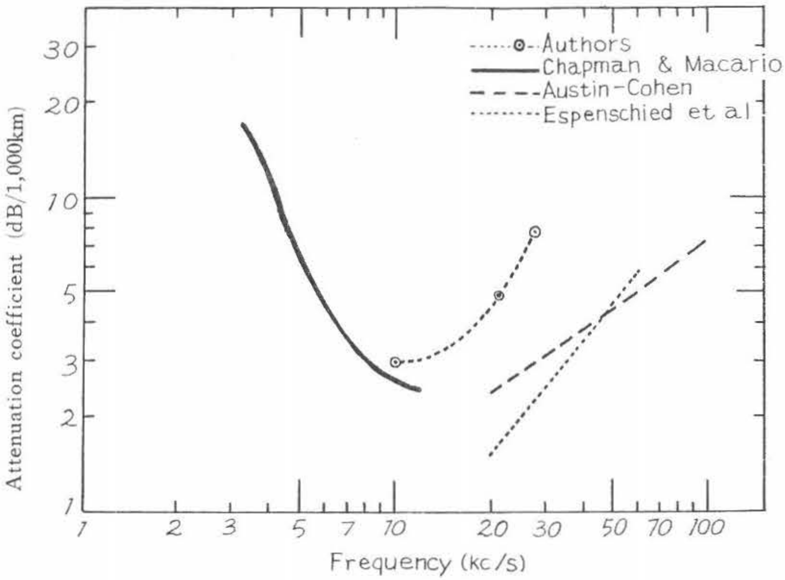

Fig. 4. Attenuation coefficient of VLF waves.

is obtained. Though the frequency spectra at origins $\phi(f)$'s do not seem to be constant for respective discharges, it is permissible to assume that $\phi(f)$'s are, on an average, a constant value at respective frequencies in the case of employing a great number of data.

Then differences of attenuation for respective frequencies $\alpha(f)-\alpha(f_0)$ can be estimated by using the expression (1) provided that distances from origins D's are known. As regards the estimation of distances from origins, that is, locations of atmospherics, the records of the narrow sector recorder in continuous operation in our Institute and the Daily Weather Maps published by Japan Meteorological Agency are used. An example is shown in Fig. 2, and the sector marked by two dotted lines in which numbers of arrival of atmospherics predominate, contains two symbols of lightning discharges as well as the cold frontal line. The approximate distance from origin in this case is, therefore, estimated as about 2,000 km. Thus Fig. 3 shows the relationship between the value of the left side of the expression (1) and the traversing distance D. These are plotted with the use of the data observed during three years (1955-1957) — 366 examples in summer and 147 in winter. There is no significant difference between summer and winter. Fig. 3 (a) illustrates the difference of the integrated field intensity for 21 kc/s from that for reference frequency of 10 kc/s, and in the same manner, figure (b) shows the case of 27 kc/s. As can be expected, respective regression strait lines shown in figures (a) and (b) can be drawn even though they show a considerable wide scatter of the reading. Thus the difference of attenuation coefficient per 1,000 km for two frequencies can be obtained from Fig. 3 as follows.

$$\alpha_{21}-\alpha_{10}=0.23$$

$$\alpha_{27}-\alpha_{10}=0.53$$

The attenuation coefficient at a frequency of 10 kc/s, however, can be deduced from another observational result illustrated in Appendix. Attenuation coefficients for 21 kc/s and 27 kc/s can, therefore, be estimated on the basis of attenuation coefficient of 3 dB/1,000 km for 10 kc/s. The estimated results against frequency are shown in Fig. 4 together with those of Chapman et al (1), values computed from formulae by Austin-Cohen and by Espenschied et al. Results obtained by the authors do not show a very good agreement with those obtained by others, but this may have resulted from the fact that the data which were available were based on the observation at 09h JST to coincide with the hour adopted in the Daily Weather Maps. At around 09h the integrated field intensities for 27 kc/s and 21 kc/s are, in general, comparatively smaller than that for 10 kc/s as shown in Fig. 1. So it seems quite natural that the values of attenuation coefficient obtained by the authors come to be more or less large. But the trend of the curve is in good agreement with other curves.

Finally, the authors wish to express their sincere thanks to Prof. A. Kimpara, Director of the Research Institute of atmospherics, for his constant encourgement and advice. They are also indebted to Associate Prof. Kamada and others for their helpful discussions.

Appendix The attenuation coefficient at a frequency of 10 kc/s,

Locations of origins by triangulation are made with the usual crossed loop type direction finders tuned at a frequency of 10 kc/s. The instantaneous direction of the arrival of atmospherics is indicated on the cathode ray tube, and in this case the maximum amplitudes of the trace are assumed to be proportional to the 10 kc/s components of received atmospherics. Now the frequencies of arrival (the numbers of reception per unit time interval) distribution against amplitudes are studied with the use of some of the directiion finding data observed in Aug. 1959. They are classified into two groups, that is, 900-1,200 km and 1,800-2,200 km. The 192 atmospherics are dealt here. As is easily seen, Fig. 5 shows that the number of received atmospherics de-

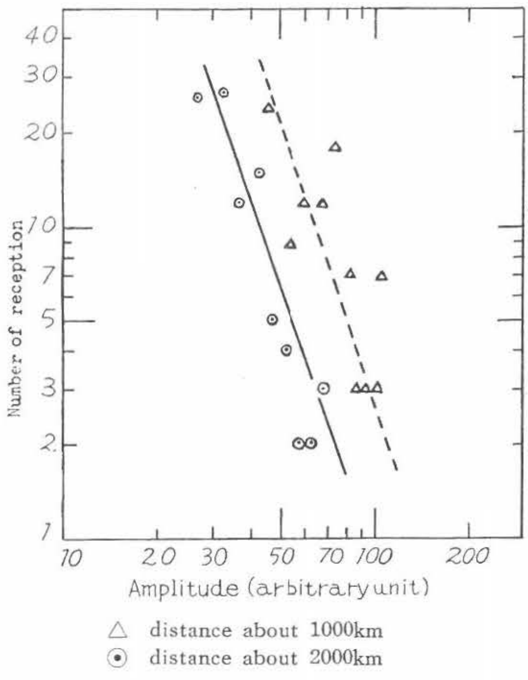

Fig. 5. Frequency distribution of amplitudes of received images in the case of the direction-finding of atmospherics at 10 kc/s.

creases linearly with increasing amplitude in log-log scale. Because two regression straight lines can be drawn for respective plots, the separation between two straight lines along abscissa should represent the difference of the received amplitude per 1,000 km. The value of about 3 dB corresponding to the separation shows that the attenuation due to the propagation over long distances is approximately 3 dB per 1,000 km.

References

(1) Chapman F. W. and Macario R. C. V.: Nature, **177**, 4, 516. (1956)