Discrimination of Intracloud Discharge Signals Using the Aspectum of the Digital Natural Observation Method

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1. Introduction

There are two principal types of lightning discharges – flashes which occur between the thundercloud and the earth (cloud-to-ground discharges: CG discharges) and flashes within the thundercloud (intracloud discharges: IC discharges)[1]. To locate lightning strike position many systems based on the radiation field time-of-arrival technique are now under operation. In this system the electric field signal radiated from IC discharges have to be rejected because they do not cause power lines outrages, set forest fires, or produce the variety of other deleterious effects attributable to cloud-to-ground lightning. To obtain the exact strike position, it is necessary to use only the signals radiated from CG discharges and reject the signals from IC discharges from all the obtained data. This must be proceeded automatically with signal processing in real time.

Electric field signals radiated from the both types of lightning discharges are transient pulses and don't have clear periodicity. Moreover, various kinds of signals are observed simultaneously, so the signal waveform is provable to be complicated. For a signal analysis method for distinguishing such unsteady fluctuation signals, the method to detect the characteristics of instantaneous variation would be effective. The present study adopts the Digital Natural Observation Method (DNOM). This method is an analytical method recently advocated by Professor Emeritus Taizo Iijima of Tokyo Institute of Technology as a novel technique for signal analysis [2][3].

This is an entirely new signal analysis method that incorporates instantaneous variation of waveforms. This waveform analysis technique decomposes a signal into coefficients that express the gradient (differential coefficient) of the instantaneous variation of the signal waveform, whereas the Fourier analysis method and the maximum entropy method decompose the signal into frequencies. The authors clarified that the DNOM would enable to divulge the characteristics of unsteady fluctuation signal that cannot be detected in frequency analysis [4],[5]. It is possible to evaluate the power of the instantaneous variation of the observed signals using the aspectum that is defined in the DNOM. In this paper, the method to discriminate the electric field signals radiated from IC discharges is examined using the aspectum of the DNOM.

2. Digital Natural Observation Method

The Digital Natural Observation Method (DNOM) is a novel transform technique which addresses the instantaneous nature of a signal waveform. The DNOM is summarized succinctly below.

An identical operator I and a delay operator D are defined as follows, respectively, using arbi-

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trary time series data $f(n)$:

$$If(n) = f(n), \tag{1}$$

$$Df(n) = f(n-1). \tag{2}$$

Consequently, the following two operators can be defined using these operators, respectively, as:

$$\varGamma = (1-\lambda)I + \lambda D, \tag{3}$$

$$\varLambda = \lambda I - \lambda D, \tag{4}$$

where λ is a weighting factor satisfying $0 < \lambda < 1$. Its normal value of λ is assumed as 1/2.

Next the following operator is assumed:

$$X_m{}^{(M)} = \varGamma^{M-m}\varLambda^m \quad (m = 0,1,2,\ldots,M), \tag{5}$$

where the degree and the order are represented as M and m, respectively.

Then the following new time series is defined as

$$n_m{}^{(M)}(n) = X_m{}^{(M)} f(n), \tag{6}$$

where $n_m{}^{(M)}(n)$ are time-series data of the M th order, called a fundamental observation value corresponding to the time-series $f(n)$. They represent the instantaneous variation of the observed waveform at time n. Transforming the time series $f(n)$ into the fundamental observation time series $n_m{}^{(M)}(n)$ as in Eq. (6) is referred to as natural observation forward transform.

Note that Eq. (6) can be reverted completely from the time-series of the M th order to the original time series $f(n)$ conversely by the following equation.

$$f(n) = \sum_{m=0}^{M} \binom{M}{m} n_m{}^{(M)}(n). \tag{7}$$

Equation (7) is termed a natural observation inverse transform. Here, $\binom{M}{m}$ represents binomial coefficient. Moreover, Eq. (6) and Eq. (7) are referred to collectively as a Natural Observation Transform.

Next the aspectum is defined in Eq. (8), which expressed the instantaneous power at the order m in the DNOM. And, it is possible to decompose the instantaneous norm by the square of aspectum, as it is shown in Eq. (9).

$$A_m{}^{(M)}(n) = \sqrt{\binom{M}{m}\left(\frac{1-\lambda}{\lambda}\right)}\left|n_m{}^{(M)}(n)\right|. \tag{8}$$

$$\| f \|_n^2 = \sum_{m=0}^{M} \left\{ A_m{}^{(M)}(n) \right\}^2. \tag{9}$$

3. Observation of electric field signals radiated from lightning discharges

In electric field observation on the ground surface, the electric field signals not only from the CG discharges but also from the IC discharge are observed. In the research of lightning discharges, it has been required that which type of the discharge is distinguished on analyzing the observed signals. As the example, when the lightning strike position of the CG discharge is decided by the electromagnetic field observation, the signals from IC discharge are also observed almost simultaneously with the signals from the CG discharge. In lightning location systems it makes the location accuracy of the lightning strike position lower. Therefore, for improvement of the location accuracy the signals from the IC discharge must be clearly distinguished and removed from all the observed signals. In addition, it is very useful if this procedure is real-time and automatic. To realize this procedure the signal analysis using the DNOM, which is essentially the real-time analysis method, is very useful [6].

4. Observed electric field signals and aspectum

Observed electric field signals and its aspectum are shown in Fig.1 and Fig.2. Here, Fig.1 and Fig.2 show electric field signals radiated from the IC discharge and the negative CG discharge, respectively. The parameters to calculate the aspectum are $M = 50$, $m = 0,\ldots,6$ and $\lambda = 1/2$ (the normal value). The origin of time axis is shown as the time that recorded the maximum value in both figures. These figures show that the return stroke of the CG discharge and the small variation signal are detected as an instantaneous power by the aspectum.

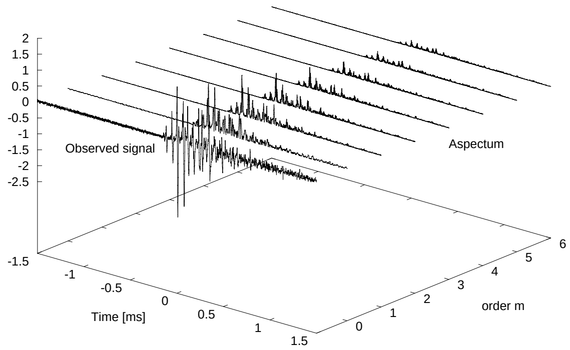

Figure 1 Observed signals and aspectum. (IC discharges)

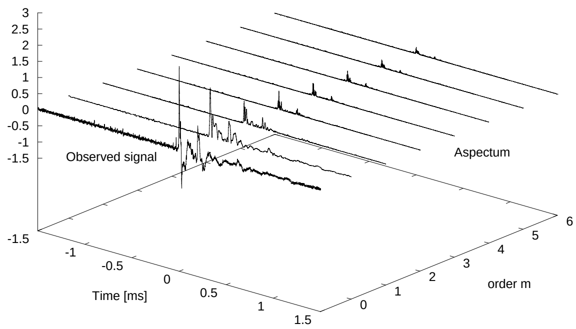

Figure 2 Observed signals and aspectum. (negative CG discharges)

5. The discrimination method of the lightning discharge type by the aspectum

To separate the IC electric field signal radiated from all the lightning discharge signals the observed waveform is transferred into the fundamental observation time series and the aspectum as instantaneous power. Using the aspectum we define P as Eq. (10),

$$P = \frac{Max\left[A_1^{(M)}(n) \right]}{Max\left[A_0^{(M)}(n) \right]}, \qquad (10)$$

where $Max\left[A_m^{(M)}(n) \right]$ is the maximum aspectum value of M-degree and m-order.

We calculated the aspectum of 200 discharges of observed data in the case of three discharges types (negative CG lightning, positive CG lightning and IC discharges) at Honjo observation point, and P was obtained using the aspectum for each type respectively. Figure 3 shows the count number of each P. In this figure, (a), (b) and (c) show the negative CG discharges case (P_n), the positive CG discharges case (P_p) and the IC discharges case (P_i), respectively. Here, the average of P_n, P_p and P_i are 0.42, 0.40 and 0.84 respectively. As shown in Fig. 3 the clear difference exists between the P distribution of the IC discharges (P_i) and the both ones of CG lightning (P_n and P_p). This result indicates that we can discriminate the IC discharge signals from all the observed signals using the aspectum of the DNOM.

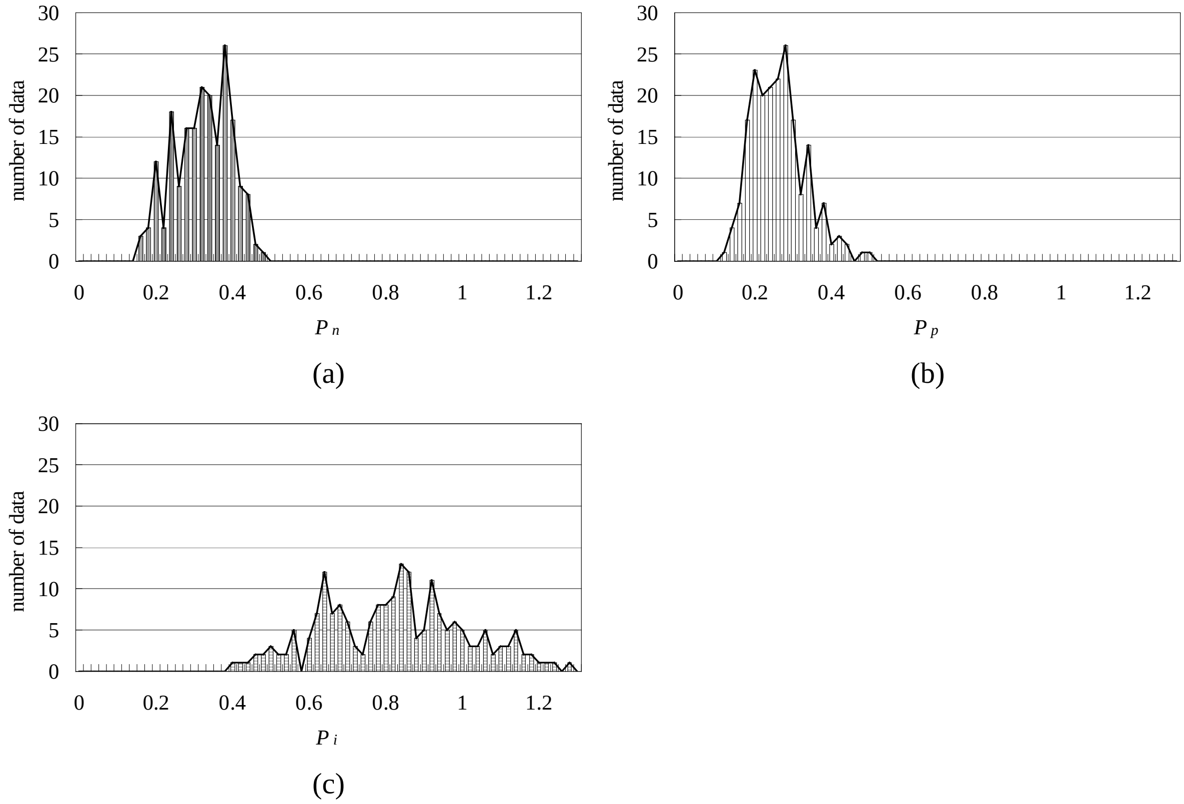

Figure 3 P versus number of data. (a) negative CG discharges case (P_n), (b) positive CG discharges case (P_p) and (c) IC discharges case (P_i)

6. References

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