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LIGHTNING CHANNEL DETERMINED BY THUNDER

Minoru NAKANO

Abstract

It is shown that thunder measurement is a useful way for lightning channel reconstruction, especially for that within a thundercloud. The directions of channels within a cloud of C-G discharges are examined by the thunder technique. They orient mainly along the wind direction at 300 mb in accordance with a three dimensional model of cumulonimbus.

1. Introduction

Lightning channels within a thundercloud are remained in ambiguous features because the optical technique could not be used. The position of charges in a thundercloud can be determined by simultaneous observations of electrostatic field-changes due to a lightning discharge at several stations, assuming that a discharge involves positive and negative point charges. Ogawa and Brook (1969) has discussed an orientation of a channel of a cloud to ground discharge by the measurement of the electrostatic field-changes, but it is not usually easy to find a channel shape by this method, partly because a channel shape within a cloud is much influenced by charge distribution, and partly because it is troublesome to plan the simultaneous observation with high time resolution at several stations.

It has been shown by some workers that thunder is generated by the thermal expansion of high temperature channel core, the temperature of which depends on the energy of the lightning discharge currents, and that the power spectrum of thunder depends on the dissipated energy through a channel (Dawson etal. 1968, Few 1969). Thunder is characterized by pearls and rumbles, pearls are the sudden loud sounds which occur superposed on a background of prolonged rumble. Uman et al. (1968) have shown that pearls and rumbles of thunder are caused by the tortuous and branched nature of channels, assuming that thunder is the sum of acoustic signals generated by the segments of the tortuous and branched channels with various source intensities. According to their results, it is possible to draw a lightning channel by thunder. Recently, Few (1970) has reported a method of a channel reconstruction by thunder measurements and has given an example.

In this paper, some examples of lightning channels within a cloud determined by a similar technique as reported by Few are shown, and some natures of channels within a cloud are discussed.

2. Measurement and method of analysis

Thunder measurements were made in summer 1970 and 1971 with three uni-directional microphones whose frequency response was almost flat between 100 Hz and 750 Hz. The positions of microphones used in summer 1970 are shown in Fig. 1. VLF radio signals were recorded simultaneously in order to determine the delay time of thunder. The energy of thunder almost lies below 150 Hz (Bhartendu 1967, Few 1969), but it is sufficient to give signals above 100 Hz for calculating the cross-correlation function between signals at the three microphones. The distances between each of microphones can be suitably chosen by taking account of the dimensions of lightning channels and the time differences between signals at each microphone. In our case, these were 8～30 meters.

The thunder from a discharge process involves several or more pearls continuing about 0.5 sec which are caused by the interference of sound waves emitted from adjacent segments of channels. Therefore, the sources of pearls can be located by

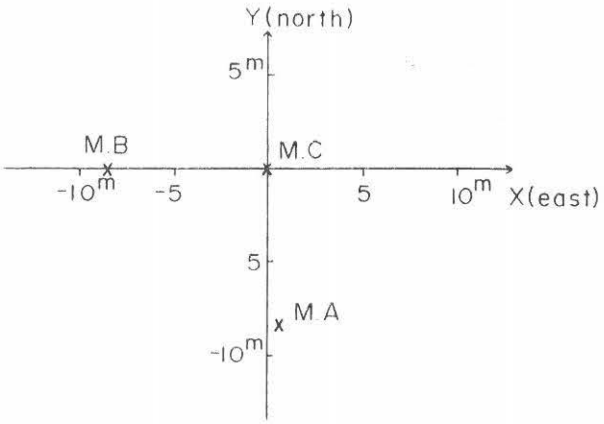

Fig. 1. Position of microphones in summer 1970. Microphones are shown by M. A, M. B and M. C.

the simple calculation with the time differences between pearls at each microphone, if the sound velocity is given.

The data recorded with a magnetic taperecorder were digitized by sampling with 1.04 KHz, and the time difference refered to a pearl was determined by computing the cross-correlation functions during 0.48 sec of data including the pearl. This time interval 0.48 sec was chosen according to the results that durations of pearls were most frequently about 0.5 sec. Pearls were identified by the reproduced waveforms of thunder. The location of source of a pearl could be calculated with time differences mentioned above and with the delay time from the corresponding VLF radio signal. Although the actual distribution of the sound velocity is rather complicated and the ray path is refracted by inhomogeneity, the ray paty was actually calculated assuming the standard atmosphere. In this case, the sound velocity changes linearly with height, that is, $V=Vo(1+aZ)$, where a is a constant value and Z the height. The error due to this approximation will be discussed in the later section.

3. Results and discussions

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It is possible to locate only the origins of pearls whose amplitudes are relatively large compared with the noise caused by wind and rain, so only sevsral pearls in a thunder were usually located. The signals of pearls generated at upper part of clouds were rather weak because of an attenuation through propagation, therefore, whole channels could not be reconstructed.

Examples of channels are shown in Fig. 2. (A) and (B) are C-G discharges and (C) is I·C discharge. The type of discharge was identified from an examination of the corresponding electrostatic field-changes. In Fig. 2, open circles represent the channel segments located as the sources of pearls of thunder. The number of points is not enough to picture continuous channels, but it will be supposed that channels are probably pictured by connecting successively these points. It is noted that in (A) and (B), the channels are not vertical but inclined at a height of about 3 km, and in (C), the channel is horizontal. As the relation between the direction of a channel above 2 km in height for C-G discharge and the wind direction at nearly the top of clouds is much interested in connection with charge distribution in thunderclouds, the averaged direction of channel whose length is longer than about 2 km projected on a horizontal plane was examined for the data on Aug. 7 1971. The result is shown in Fig. 3. The direction of storm motion and the wind direction at 300 mb are shown by arrows. The direction of storm motion was taken for the direction of

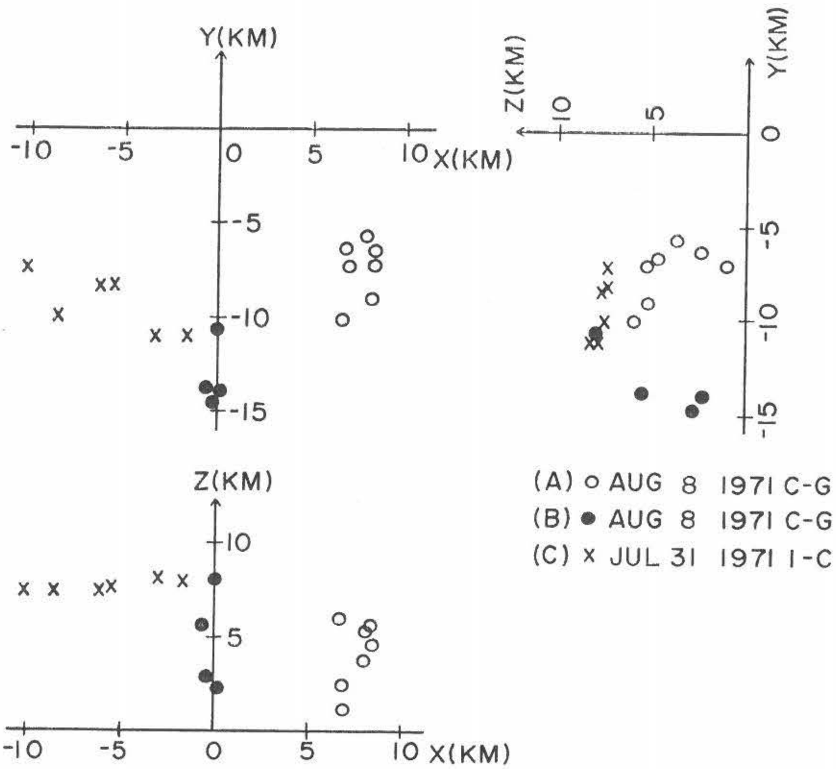

Fig. 2. Examples of lightning channels. Each point represent the channel segments as the origins of pearls. X, Y and Z are eastward, northward and upward respectively, our observatory is taken as the origin of coordinates, and figures are given in kilometers. (A) and (B) are C-G discharges and (C) is I·C discharge. Error estimation is given text.

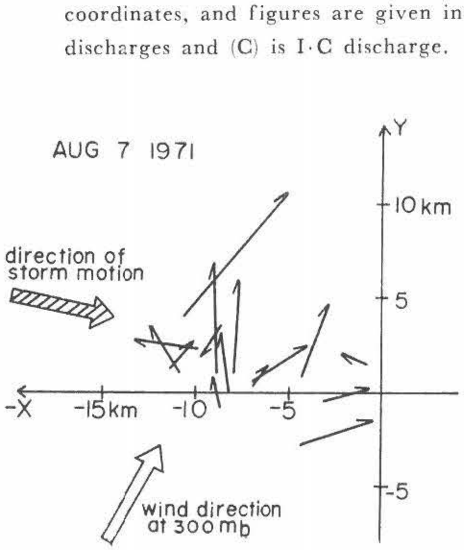

Fig. 3. Direction of channel above 2 km in height of C-G discharge projected on a horizontal plane. The direction of each arrow shows a direction of increasing height.

the movement of rainfall areas observed by 3-cm radar with a PPI scope and as to the wind direction at 300 mb, the data measured at 0^h GMT at Tateno meteorological observatory were used. The distance from Tateno to our observatory is about 90 km. Fig. 4 shows the distribution of deviations of channel direction from the wind direction. The directions of channels within clouds seem to be related with the wind direction at nearly the top of clouds. This tendency in Fig. 4 is consistent with a three dimensional model of thunderstorm clouds that a thunderstorm motion directs to righthand side of the wind direction at upper atmosphere (nearly from 500 mb to 300 mb levels) and that, as updrafts are dragged by the wind, an anvil is formed along the direction of wind.

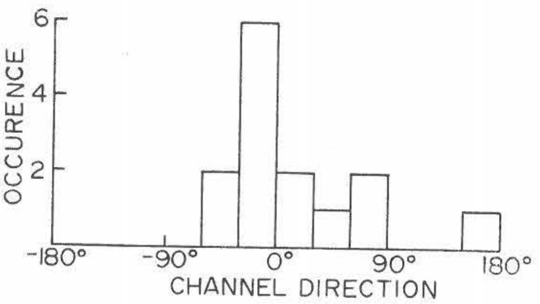

Fig. 4. Histogram of channel directions relative to the wind direction at 300 mb. The angle between a channel direction and the wind direction is positive counterclockwise.

The time variation of the channel directions is shown in Fig. 5. It is noted that channels are bent toward the wind direction at cumulus or mature stage of the storm and toward the direction of storm motion at dissipating stage. Ogawa and Brook (1969) have obtained the result with the measurements of electrostatic field-changes that a C-G discharge is oriented primarily along the direction of storm motion. As present results cannot be generalized because the data were not enough to do fully statistical treatment, this discerpancy will have to be examined for various storms in future.

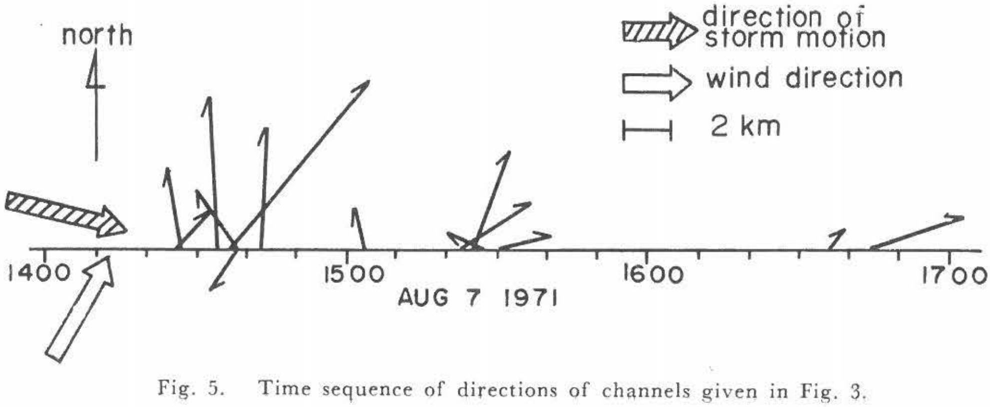

Fig. 5. Time sequence of directions of channels given in Fig. 3.

3. 2. Error estimation

As the sound wave is refracted by the wind shear and by the gradients of temperature and density, it is necessary to estimate, first, the deviation from the ray path in the standard atmosphere. The error due to the gradient of temperature was examined by ray-tracing for a simplified model in which the sound velocity was given by the following expression, $V = Vo\ (1 + aZ)\ (1 + b \sin (kX))$, where Z is the height, X is the horizontal distance and a, b and k are the constants. This development is based on a model of the mature stage in a thunderstorm cell (Byers and Braham 1949). Though a ray was traced for various initial incident angles and for various constant values of b and k, the deviation from the case of the standard atmosphere (this corresponds to $b = 0$) was less than about 500 meters for a propagation of 10 kilometers. It may be supposed that the effect of the gradient of density is smaller than that of temperature. The effect of wind shear is small because the sound velocity is much larger than wind velocity. We may conclude that the resultant error by these effects is less than a few percent. Next, it must be considered the effect that the wave front may be affected by the ground. This effect can be avoided if the location of a microphone is high enough in comparison with the wavelength of received signals. In our case, the height of microphones are about 1.5 meters and the wavelength of main signals is about 3 meters. The resultant error may perhaps be small, but no estimation of this effect is given at present. It is also necessary to estimate an error caused by a determination of a time difference. The error due to electronic circuits was less than 0.3 msec which was examined with white noise, and this error was corrected in locating origins of pearls of thunder. Cross-correlation functions often lost a sharp peak, caused by wind and rain and perhaps by the distribution of sources of acoustic signals. Therefore, we used only data of which cross-correlation function has a sharp peak with half-width less than 5 msec, then accuracy of a time difference is limited by a digitizing period, which was 0.96 msec. A change of a incident angle $\Delta\theta$ due to a change of a time difference Δt is given approximately, $|\Delta\theta| \sim V\, \Delta t / R \sin\theta\ (\theta \gg \Delta\theta)$, where V is the sound velocity, R is the distance between two microphones and θ is the incident angle measured from a line connecting two microphones. Putting $R = 10$ m, $C = 340$ m/sec, $\Delta t = 0.5$ msec and $\theta = 45°$, we have $\Delta\theta \sim 1.4°$, that is, the error is about 250 meters for a propagation of 10 kilometers. As an accuracy of a time difference is nearly 0.5 msec, the resultant error is also less than a few percent.

3. 3. Concluding remarks

The form of lightning channel within a thundercloud can be determined by thunder measurements. A channel of a C-G discharge was not vertical but was inclined within clouds, that seemes to be related with the wind direction at upper atmosphere. It is possible with thunder measurements to discuss the relation between the location of a lightning channel and the area of rainfalls, and this is remained as a future problem.

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