

**A lightning occurrence position specifying device and
A lightning occurrence area estimation method**

Background Art of the Invention

Technical Field

[0001]

The present invention relates to an art specifying a lightning occurrence position and estimating a lightning occurrence area.

Description of the Related Invention

[0002]

When a charge separation in a thundercloud proceeds and an electric field intensity makes grow, an electric breakdown occurs in the atmosphere as being an insulator and a lightning discharge occurs.

[0003]

The lightning discharge occurs in various directions between positive charges and negative charges in thunderclouds, between thunderclouds and the other thunderclouds, between thunderclouds and the ground, or the like. That is, the lightning discharge occurs not only in a downward direction, but also in a lateral direction and an upward direction. In particular, the lightning discharge directing from thunderclouds to the ground is called as a lightning strike. It is reported that a number of lightning discharges in the thunderclouds and between thunderclouds is more than a number of lightning strikes, and the ratio thereof is about 10 to 1. There are a negative lightning strike discharging the negative charge of the thunderclouds to the ground and a positive lightning strike discharging the positive charge of the thunderclouds to the ground in the lightning strike.

[0004]

In Japanese summer, it is said that a number of the negative lightning strikes are more than a number of the positive lightning strikes, and a layer of the negative charge is considered to be around 7 to 10 km above the ground.

[0005]

According to a non-patent literature 1 (An introduction of Atmospheric electricity, edited by Society of atmospheric electricity of Japan, (Corona Publishing Co., 2003), a leader of the lightning strikes (progression of the above electric charge) progresses in a step from the thundercloud to the ground, and the one step is 10 to 200 m in length, about 105 m/s in speed, and 30 to 125 μ sec in time interval. It is empirically known

that a progression of the leader follows a flashing light and a lightning peal. It is said that these knowledge is obtained by an observation research of the lightning strike by a high-speed image measurement described in the non-patent literature 1.

[0006]

It is known that a progression of the leader is the movement of electric charge in the atmospheric air and the progression makes an electromagnetic wave radiate. A non-patent literature 2 (an operational VHF Broadband Digital Interferometer for Lighting Monitoring", IEEJ Trans. FM, Vol. 124, No. 12, 2004, (pp. 1232 to 1238) written by Takeshi Morimoto, Akimasa Hirata, Zen Kawasaki, Tomoo Ushio, Akinori Matsumoto, and Lee Jong Ho) and a patent literature 1 (Japanese Patent Unexamined Laid-open Publication No. 2001-4731) pay attention to the electromagnetic wave with an impulse, in particular, in VHF (Very High Frequency) broadband of electromagnetic wave radiated from the lightning leader. Then, they disclose an art detecting a direction vector (an azimuth angle and an elevation angle) directing to a position of the leader seen from the received position, based on the phase difference among electromagnetic waves received from an antenna arranged at a plurality of positions. However, a distance from the received position to the lightning position, that is, the progressing position of the leader cannot be obtained by this measurement method. Each of the azimuth angle and the elevation angle obtained from a plurality of observation points, that is, an intersection of the direction vector is the occurrence position. (This method is called as an intersection method.)

[0007]

In case of optically observing a lightning strike phenomenon by an image measurement from the ground, it is good for a lightning strike between the thunderclouds and the ground. However, in principle, a lightning progressing between thunderclouds and upwards from the thunderclouds has been overshadowed by the thunderclouds, and it is difficult to get an image or a picture. On the other hand, according to the methods described in the non-patent literature 1 and patent literature 1, a leader of the lightning progressing between thunderclouds and upwards from the thunderclouds falling into a shadow of the thunderclouds can be observed from the ground because a noticeable electromagnetic wave in the frequency band becomes transparent between thunderclouds.

Summary of the Invention

(Problems to be solved by the Invention)

[0010]

In any of the above prior art, it is, however, difficult to observe a distance between the lightning occurrence position and the observation position in case of separating therebetween. In case of optical observation of lightning strike, it is, ordinarily, difficult to watch a flashing light as a distance to the observation position extends owing to a thunderstorm and hard to get a direction vector to the lightning occurrence position exactly. In electromagnetic wave, the attenuation thereof in the atmospheric air becomes remarkable, as its frequency becomes a high-frequency. A reachable distance of the electromagnetic wave in the VHF broadband is considered to be at most 10 km or so, depending on the intensity of the lightning leader. In either case of an observation of images, pictures, or electromagnetic wave measurement in the VHF broadband, it is required for some means to observe the lightning occurrence position in a wide area ranging tens of kilometers or more.

[0011]

Accordingly, the present invention is to provide an art measuring and estimating effectively the lightning activities, in particular, the occurrence position in a wide range of area.

(Means for solving the Problems)

[0012]

To solve the above problem, a lightning occurrence position measurement system of the present invention estimating an occurrence position of signals (including, for example, a lightning peal or the like) following an occurrence of lightning flashing light, electromagnetic waves, or the other lightning is configured by a plurality of lightning discharge observation devices (a measurement device receiving a physical quantity of signals following the above lightning occurrence and outputting the direction vector to the lightning occurrence position) and at least one lightning occurrence position specifying device.

A plurality of the lightning discharge observation devices are arranged in the lightning observation area to receive signals radiated from the lightning through receiving elements and send an azimuth angle and an elevation angle showing an arrival direction of signals, received time of the signal, position data of the received point, and an identification data identifying a sender to the lightning occurrence position specifying device.

The lightning occurrence position specifying device receives an observation data including the time series of the elevation angles, the azimuth angle, the time, the identification data, and the position data. Then, the lightning occurrence position specifying device judges whether a time interval of the time series of the elevation angles and a value of the elevation angle are similar or not, among the time series of the elevation angles that the identification data received from the lightning discharge observation device are mutually different. Furthermore, the lightning occurrence position specifying device specifies the lightning occurrence position with use of the observation data (received time and time series of the azimuth angles and the elevation angles) that a plurality of the identification data judged to be similar are mutually different.

[0 0 1 3]

The present invention can provide an art specifying and estimating the lightning occurrence position effectively in a wide range of lightning observation area.

Brief Description of Drawings

[0 0 1 4]

Figure 1 is a view showing an example of a configuration of a lightning occurrence position measurement system.

Figure 2 is a view showing an example of functions of a lightning occurrence position specifying device.

Figure 3 is a view showing an example of received data.

Figure 4 is a view showing an example judging a similarity of time series of an elevation angles. Figure 4A shows in case of judging as being similar, and Figure 4B shows in case of judging as being not similar.

Figure 5 is a view showing an example of procedure specifying a lightning occurrence position.

Figure 6 is a view showing an example of processing flow of the lightning occurrence position specifying device.

Figure 7 is a view showing an example displaying the lightning occurrence position.

Figure 8 is a view showing an example of arrangement of lightning discharge observation devices.

Figure 9 is a view showing an example of received data in a modification.

Figure 10 is an example of device position data memorized in a memory section of the lightning occurrence position specifying device in the modification.

Figure 11 is a view showing an example of processing flow of the lightning occurrence position specifying device in the modification.

Embodiment for carrying out the Invention

[0015]

An embodiment for carrying out the present invention (called as "this embodiment") will be described with reference to the drawings.

[0016]

(A configuration of the lightning occurrence position measurement system)

An example of a configuration of the lightning occurrence position measurement system in this embodiment will be described with reference to Figure 1.

As shown in Figure 1, the lightning occurrence position measurement system 1 is configured by a lightning occurrence position specifying device 10 and a lightning discharge observation device 110 (110a, 110b, 110c) connected communicatably to the lightning occurrence position specifying device 10 through a network 11.

[0017]

A plurality of the lightning discharge observation devices 110 are arranged in a lightning observation area. The lightning discharge observation device 110 can obtain a direction vector (azimuth angle α and elevation angle β) to the lightning occurrence position observed from an observation point by providing an observation means of images and pictures of lightning flashing light with a 360-degree directional camera, a detection means of lightning peal with an omnidirectional microphone, a receiving means of electromagnetic wave radiated from the lightning with an antenna or the like. The lightning discharge observation device 110 is designed to memorize in connection with the time series of an azimuth angles α and an elevation angles β , the time of the time series, and the position data of the observation position. In addition, the lightning discharge observation device 110 memorizes the position data in case where a mounting position is already known. The lightning discharge observation device 110 may be provided with GPS (Global Positioning System) receiver (as not shown) to get the position data. The lightning discharge observation device 110 obtains the time by a clock synchronized with the other lightning discharge observation device 110, or the time synchronized with the GPS receiver.

[0018]

The network 11 may be configured by wire or wirelessly without being limited to a communication method. The lightning occurrence position specifying device 10 specifies the lightning occurrence position with use of data as to a direction of the lightning occurrence position received from a plurality of the lightning discharge observation device 110 through the network 11. The detail of the lightning occurrence position specifying device 10 will be later described. Although a number of the

lightning discharge observation device 110 are three in Figure 1, it is not limited to three devices and may be two devices, or four devices or more.

[0 0 1 9]

In Figure 1, when the lightning discharge observation device 110 set in a center of the circular area 13 shown by a broken line is arranged in a lightning observation area, the circular area 13 is used for covering the area. The detail of the circular area 13 will be later described.

[0 0 2 0]

(Thunder occurrence position specifying device)

An example of functions of the lightning occurrence position specifying device 10 will be described with reference to Figure 2.

As shown in Figure 2, the lightning occurrence position specifying device 10 is provided with a processing section 21, a communication section 22, and a memory section 23.

[0 0 2 1]

The communication section 22 receives data concerning a direction of the lightning occurrence position from the lightning discharge observation device 110, and sends the received data to the processing section 21. As shown in received data 301 of Figure 3, the received data has, at least, identification data identifying the lightning discharge observation device 110 of the sender, position data (for example, longitude, latitude, or the like) mounting on the lightning discharge observation device 110, the time series of the elevation angles β and the azimuth angles α , and the time of the time series. The processing section 21 memorizes received data 301 in the memory section 23. For example, in case where the network 11 is on IP (Internet Protocol) network, the identification data shown in Figure 3 may be an IP address of the sender. In case where the position of the lightning discharge observation device 110 is obtained from the IP address of the sender, the position data shown in Figure 3 is not required. On the contrary, when the position data can be substituted for the identification data, the identified data is not required.

[0 0 2 2]

Returning to Figure 2, the processing section 21 is configured by a CPU (Central Processing Unit) as not shown and a main memory to develop an application program memorized in the memory section 23 and to embody a similarity judging section 24 as later described, a lightning position specifying section 25, and a lightning predicting section 26 therein.

[0 0 2 3]

The similarity judging section 24 judges whether a time interval of the time series of the elevation angles β and a value of the elevation angle β are similar or not among the time series that the identification data are mutually different, that is, judges similarity thereof.

For example, Figure 4 plots schematically (shown by square mark $\square$) the elevation angles β of the direction vector according to the time series. Herein, Figure 4A shows a case of judging that the time series of the elevation angles β is similar. That is, when the time shifts a little in the predetermined time range, the time series of the elevation angles β at the lightning discharge observation device 110a shown in Figure 4A(a1) is considered to coincide approximately with the time series of the elevation angles β at the lightning discharge observation device 110c shown in Figure 4A(a2). Furthermore, a tendency of the time series of values of the elevation angles β (for example, a shape of lines linking values of the elevation angles β along the time series) is also considered to be similar.

[0 0 2 4]

It may be capable of using various statistical procedure in judging the similarity, and it may be, in particular, not limited. For example, by seeking for a correlation coefficient concerning the time series of two elevation angles β , it may be judged as being similar when the correlation coefficient concerning the time series of two elevation angles β is the predetermined value or more. That the correlation coefficients are similar each other means that signals radiated from the same lightning have been measured in plots (square mark $\square$ in Figure 4) shown in Figure 4A(a1) and Figure 4A(a2). That is, this means that the lightning occurrence positions are mutually same. The measured point corresponding to a plot around the time t_6 of Figure 4A(a2) does not exist in Figure 4A(a1). This shows a case as not observed by the lightning discharge observation device 110a on the ground that the lightning occurrence position exists comparatively close to the lightning discharge observation device 110c and far away from the lightning discharge observation device 110a. The plot may be treated as an outlier value in a process of statistical procedure and may be excluded from a judgment of similarity.

[0 0 2 5]

Figure 4B shows a case judged that the time series of the elevation angles β is not similar. That is, a tendency (for example, a shape of lines linking values of the elevation angles β along the time series) of the time series of the elevation angles β at the lightning discharge observation device 110a shown in Figure 4B(b1) is not similar to a tendency of the time series of the elevation angles β at the other observation point

shown in Figure 4B(b2) in case of shifting the time. Even if a tendency (for example, a shape of lines linking values of the elevation angles β along the time series) of the time series of values of the elevation angles β coincide with each other, it can be judged as the other lightning in case where the time shifts beyond the predetermined time range.

[0 0 2 6]

Returning to Figure 2, the lightning position specifying section 25 specifies the lightning occurrence position with use of the time series of at least two elevation angles β that the identification data judged as being similar by the similarity judging section 24 are mutually different, the time series of the azimuth angles α obtained together with the time series of the elevation angles β , and the position data. When the lightning occurrence position is specified, it extracts a pair of direction vectors among a plurality of direction vectors judged as being similar, calculates their distances (length of dotted line) to be minimal, and seeks for their middle point (provisional occurrence position of lightning). (See Figure 5) Furthermore, it calculates their distance (length of dotted line) to be minimal as to the other pair of direction vectors, and determines their middle point. Then, the position of the mean value is determined as the lightning occurrence position by calculating the mean value of their determined middle point (for example, latitude & longitude).

[0 0 2 7]

The feature of this method is not to seek for the lightning occurrence position from a plurality of the direction vectors in a lump, but the feature thereof is to exclude the direction vector obtaining the result extremely differed from the estimation position as an outlier value with use of a statistical procedure.

There is a method for using a minimal distance obtained based on, for example, the pair of direction vectors, as described above, as a judging method of direction vectors being such an outlier value. The minimal value obtained based on the pair of direction vectors including the direction vector being an outlier value becomes an extremely large value compared with the minimal distance obtained based on the pair of direction vectors being not an outlier value. Then, the direction vector being an outlier value can be easily judged.

[0 0 2 8]

The lightning predicting section 26 obtains the weather data (wind velocity, wind direction, temperature, atmospheric pressure, or the like) including a movement of clouds from an outside server (as not shown) or the like, and predicts a movement of the lightning occurrence position specified by the lightning position specifying section 25.

Then, a calculation estimating the lightning occurrence area is performed.

[0 0 2 9]

The memory section 23 memorizes the above-mentioned application program, data (for example, received data 301) received from the lightning discharge observation device 110, the result processed by the processing section 21, and the like. The memory section 23 may be built in the lightning occurrence position specifying device 10 and attached outside.

[0 0 3 0]

(An example of processing flow of the lightning occurrence position specifying device)

An example of processing flow of the lightning occurrence position specifying device 10 will be described with reference to Figure 6 (Appropriately referred to Figure 2).

In Step S601, the similarity judging section 24 of the processing section 21 gets the time series of the elevation angles β and the azimuth angles α , the time of the time series, the identification data, and the position data, received from the lightning discharge observation device 110 through the communication section 22 as observation data.

[0 0 3 1]

In Step S602, the similarity judging section 24 of the processing section 21 judges whether the time interval of the time series and a value of the elevation angle β are similar or not among the time series of the elevation angles β that the identification data are mutually different.

[0 0 3 2]

In Step S603, the lightning position specifying section 25 of the processing section 21 specifies the lightning occurrence position with use of the time series of at least two elevation angles β judged as being similar by the similarity judging section 24, and the time series of the azimuth angles α obtained together with the time series of the elevation angles β , and the position data.

[0 0 3 3]

When an example of the time series of the lightning occurrence position (square marks $\square$) specified by the Step S603 is schematically shown in a 3-Dimension together with the lightning observation area 60, it is shown in Figure 7. A plurality of the lightning occurrence positions plotted in Figure 7 show plots in Figure 4A(a1). In Figure 7, an axis of width direction in a horizontal plane shows a latitude, an axis of depth direction shows a longitude, and an axis of the height direction shows an altitude.

[0 0 3 4]

(Arrangement of the lightning discharge observation device)

An arrangement of the lightning discharge observation device 110 will be described with reference to Figure 8.

As shown in Figure 8, when the observation area 60 of the lightning is set, the circular area 13 shown by dotted lines is arranged to cover the observation area 60. In this description, covering the area does not mean covering all the places including exceptional places like shadows such as constructions, mountains, or places inside a tunnel, but covering an area as an observation area. In addition, the lightning discharge observation device 110 is set as a center of the circular area 13.

[0 0 3 5]

Figure 8 shows a case where the lightning discharge observation device 110 is set at a fixed observation point on the ground (including a roof floor of building). As the lightning discharge observation device 110 is designed to get the position data at any time in case of providing the GPS receiver 116, it may be equipped in a moving body such as a vehicle, an airplane, or a ship. In case where the lightning discharge observation device 110 is equipped in the moving body, the lightning discharge observation device 110 corrects the azimuth angle α according to a traveling direction of the moving body, calibrates the elevation angle β as a numerical value on the ground corresponding to an altitude, and thus sends to the lightning occurrence position specifying device 10.

As above mentioned, a great number of lightning discharges occur in the thunderclouds and between the thunderclouds. In particular, when the lightning discharge observation device 110 is equipped in an airplane so as to measure the electromagnetic wave radiated from the lightning, it is effective to improve the precision in case of specifying the lightning occurrence position. In case of being by sea, when the lightning discharge observation device 110 is equipped for measuring the electromagnetic wave radiated from the lightning, it is effective to improve the precision at the time of estimating the occurrence area of the lightning as a movement of thunderclouds approaching land can be precisely measured.

[0036]

(Modification)

Although the above-mentioned embodiment has been described in case where the lightning occurrence position specifying device 10 gets the position data from the lightning discharge observation device 110, it may be without receiving the position data when the lightning discharge observation device 110 is mounted at a fixed observation point on the ground. In the following, as a modification where the lightning occurrence position specifying device 10 receives a received data 901 such as identification data, the time series of the elevation angles β and the azimuth angles α , and the time of the time series as shown in Figure 9, it will be described focusing on point, which is different from the above-mentioned embodiment. (appropriately referred to Figure 1 and 2) In addition, as a lightning occurrence position measurement system and a lightning occurrence position specifying device in the modification are the same configuration as the above-mentioned lightning occurrence position measurement system 1 and lightning occurrence position specifying device 10, their figures will be omitted by using the same reference numerals.

[0037]

In case where the lightning discharge observation device 110 is mounted at a fixed observation point on the ground, the position data of the lightning discharge observation device 110 has been already known. That is, the memory section 23 of the lightning occurrence position specifying device 10 memorizes the received data 901 and the device position data 1001 (Refer to Figure 10) associating the identification data with the position data.

[0038]

A processing flow at the lightning occurrence position specifying device 10 will be shown in Figure 11.

In Step S1101, the similarity judging section 24 of the processing section 21 gets the time series of the elevation angles β and the azimuth angles α , the time of the time series, and the identification data, received from the lightning discharge observation device 110 through the communication section 22, as observation data.

[0039]

In Step S1102, the similarity judging section 24 of the processing section 21 judges whether the time interval of the time series and a value of the elevation angle β are mutually similar or not among the time series of the elevation angles β that the identification data are mutually different.

[0 0 4 0]

In Step S1103, the lightning position specifying section 25 of the processing section 21 seeks for the position data associating with the identification data of the time series of at least two elevation angles β judged as being similar by the similarity judging section 24. The lightning position specifying section 25 also specifies the lightning occurrence position with use of the time series of at least two elevation angles β judged as being similar, the time series of the azimuth angles α obtained together with the time series of the elevation angles β , and the position data associating with the identification data.

[0 0 4 1]

As above mentioned, the lightning occurrence position measurement system 1 in this embodiment and the above modification can judge the similarity among the time series of the elevation angles β measured at each observation point (set point of the lightning discharge observation device 110) and specify effectively the lightning occurrence position by using the time series of the elevation angles β and the azimuth angles α and the information data judged as being similar. The lightning discharge observation device 110 is set at a center of the circular area 13 having a predetermined radius, and the circular area 13 is arranged to cover the observation area 60. This arrangement is effective for an improvement of precision at the time of specifying the lightning occurrence position concerning the lightning discharge in and between thunderclouds. It can improve the precision of estimation of the lightning occurrence position and movement prediction of thunderclouds in the observation area 60.

[0 0 4 2]

The lightning occurrence position specifying device 10 may be configured to correspond to both a case receiving position data from an observation point of the moving body and a case not receiving position data from a fixed observation point by integrating a function of the lightning occurrence position specifying device 10 described in this embodiment and a function of the lightning occurrence position specifying device 10 described in the above modification.

CLAIMS

What is claimed is:

1 A lightning occurrence position specifying device connected to mutually communicatably to a plurality of lightning discharge observation devices through a network sending an elevation angle and an azimuth angle showing an arrival direction of signals radiated from a lightning as seen from an observation point of the lightning, received time of the signal, a position data of the observation point, and an identification data identifying a sender,

comprising:

a communication section receiving an observation data including a time series of the elevation angles, the azimuth angle, the time, the identification data, and the position data from the lightning discharge observation device;

a similarity judging section judging whether a time interval of the time series of the elevation angles and a value of the elevation angle are similar or not among the time series of the elevation angles that the identification data received from the lightning discharge observation device are mutually different; and

a lightning position specifying section specifying a lightning occurrence position with use of the observation data that a plurality of the identification data judged as being similar by the similarity judging section are mutually different.

2 The lightning occurrence position specifying device according to Claim 1, wherein

the lightning position specifying section is configured by selecting a pair of direction vectors among the direction vectors configured by the elevation angle and the azimuth angle judged to be similar, seeking for a middle point at the time of being minimal in a distance between the pair of direction vectors, calculating a mean value of positions of a calculated middle point, and specifying a position of the mean value as the lightning occurrence position, in the observation data that a plurality of the identification data judged as being similar by the similarity judging section are mutually different.

3 **The lightning occurrence position specifying device** according to Claim 1 or 2,
wherein

the lightning occurrence position specifying device is provided with a lightning predicting section predicting a movement of the lightning occurrence position specified by the lightning position specifying section based on weather data including a movement of clouds, and estimating the lightning occurrence area.

4 **The lightning occurrence position specifying device** according to one of Claims 1 to 3,

wherein

the lightning discharge observation device is provided in a center of circular area having a predetermined radius, the circular area being arranged to include an observation area of the lightning occurrence position.

5 **The lightning occurrence position specifying device** configured by sending an elevation angle and an azimuth angle showing an arrival direction of signal radiated from the lightning as seen from a lightning observation point, received time of the signal, a position data at the observation point obtained by a GPS (Global Positioning System) receiver, and identification data identifying a sender to the lightning occurrence position specifying device, to connecting communicatably to a lightning discharge observation device equipped in a moving body through a network,

comprising:

a communication section receiving an observation data including a time series of the elevation angles, the azimuth angle, the time, the identification data, and the position data from the lightning discharge observation device;

a similarity judging section judging whether a time interval of the time series of the elevation angles and a value of the elevation angle are similar or not among the time series of the elevation angles that the identification data received from the lightning discharge observation device are mutually different; and

a lightning position specifying section specifying the lightning occurrence position with use of the observation data that a plurality of the identification data judged as being similar by the similarity judging section are mutually different.

6 A lightning occurrence area estimation method used with a lightning occurrence position specifying device connected communicatably to a plurality of lightning discharge observation devices through a network sending an elevation angle and an azimuth angle showing an arrival direction of signals radiated from a lightning as seen from an observation point of the lightning, received time of the signal, a position data of the observation point, and an identification data identifying a sender,

wherein

the lightning occurrence position specifying device configured to comprise the steps of:

a step receiving the observation data having a time series of the elevation angles, the azimuth angle, the time, the identification data, and the position data;

a similarity judging step judging whether a time interval of the time series of the elevation angles and a value of the elevation angle are similar or not among the time series of the elevation angles that the identification data received from the lightning discharge observation device are mutually different;

a lightning position specifying step specifying a lightning occurrence position with use of the observation data that a plurality of the identification data as being similar by the similarity judging step are mutually different; and

a lightning predicting step predicting a movement of the lightning occurrence position specified by the lightning position specifying step and estimating a lightning occurrence area based on a weather data including a movement of clouds.