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ON THE ACCURACY OF DIRECTION FINDING METHODS FOR ATMOSPHERIC SOURCES IN SOUTH-EAST ASIA

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Abstract

In order to estimate the accuracy in fixing atmospheric sources in South-East Asia by means of the triangulation and the two-station's direction findings (DFs), we have made use of the measurements of the difference in propagation time at Toyokawa and Bangkok in Thailand.

As the results, it is found that atmospheric sources in South-East Asia can be located by the triangulation DF network with a rather small error: When a specific atmospheric source is fixed with its cocked-hat** area being less than $1 \times 10^4 km^2$, the error in estimating the distance from Sakushima is less than $\pm 15\%$. The corresponding error is less than $\pm 20\%$ for the fixed atmospheric source with its cocked-hat area of less than $5 \times 10^5 km^2$. Furthermore, the location of atmospheric sources in South-East Asia by means of only two stations among the DF network is made possible within an error in distance of less than $\pm 22\%$. But we have to make an appropriate choice on the combination of the stations; either Moshiri or Kagoshima is used along with Sakushima depending on the bearing angle measured at Sakushima.

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** "Cocked-hat" is named after the triangle whose vertexes are made by the intersection of the direction lines at three DF stations.

1. Introduction

Since 1968, the triangulation DF network with three stations of our institute has been used to locate atmospheric sources (Iwai et al.,1969, 1979). However, as is supposed, the accuracy and the rate in fixing atmospheric sources are depleted along the base lines of the DF network stations; i.e. in the region of South-East Asia where we expect high thunderstorm activities (Nishino et al.,1976).

In order to improve the fixing accuracy of atmospheric sources in South-East Asia, we have carried out simultaneous observations of atmospheric sources at VLF/ELF at Toyokawa and at Bangkok in the two autumnal seasons of 1979 and 1980. The simultaneity at both stations of ELF atmospherics (5-800Hz) was made possible using the NWC signal (22.3kHz±50Hz, MSK, 200bits/sec.) as a time reference (Iwai et al., 1980). Then the fixing of atmospheric sources was made based on the measurement of the propagation time difference at both stations along with the simultaneous measurement of bearing angle at Sakushima (we call this "TD" method). From the comparison of atmospheric sources fixed by the TD method with those by the DF network, the effectiveness of the TD method was reconfirmed for atmospheric sources in South-East Asia (Iwai et al.,1981).

In the present paper, the results based on the TD method are extensively used to evaluate the accuracy in fixing the atmospheric sources in South-East Asia by means of the triangulation and the two-station's DFs. This comparison is made for two time intervals (i. e., daytime : 0740-0745 UT and nighttime: 1240-1245 UT) using the observed data during Sep. 28 to Oct. 15, 1979.

2. The fixing error of the TD method

Fig. 1 shows the configuration of the three DF stations (Kagoshima, Sakushima and Moshiri), Toyokawa, Bangkok and NWC transmitting station. The triangulation DF network is usually able to locate atmospheric sources accurately except around the region of South-East Asia along the baselines of the DF stations.

If the propagation velocity of atmospherics is estimated, on the other hand, the location of atmospheric sources can be given by the

point of intersection of the hyperbolic curve corresponding to the difference between the propagation distances calculated from the arrival time difference of atmospherics to Toyokawa and Bangkok, and the azimuthal line measured at Sakushima.

The fixing error in locating atmospheric sources by using the TD method depends on the measuring accuracy of the arrival time difference, the accuracy in estimating the propagation velocity of atmospherics and the measuring accuracy of DF at Sakushima. In order to estimate the average propagation velocity of ELF atmospherics, 37 pairs were extracted from the data of the arrival time difference and the location of atmospherics by the DF network in the daytime from Sep. 28 to Oct. 15, 1979, and 54 pairs in the nighttime, on the following bases: the area of the cocked-hat was less than $1 \times 10^4 km^2$ (equivalent to the area of a circle with its radius of about 56km and the average distance among the vertexes of the cocked-hat was less than 85km) and these sources were distributed in Central China and around the Yangtze River for the daytime (1,500km - 3,500km from Sakushima), and the area less than $5 \times 10^3 km^2$ (the area of the corresponding circle with its radius of about 40km and the average distance among the vertexes of the cocked-hat was less than 60km) and the source distribution around Yellow Sea, North-East China for the nighttime (1,000km - 2,000km from Sakushima). The region for these sources is represented by "A" in Fig. 3 shown later.

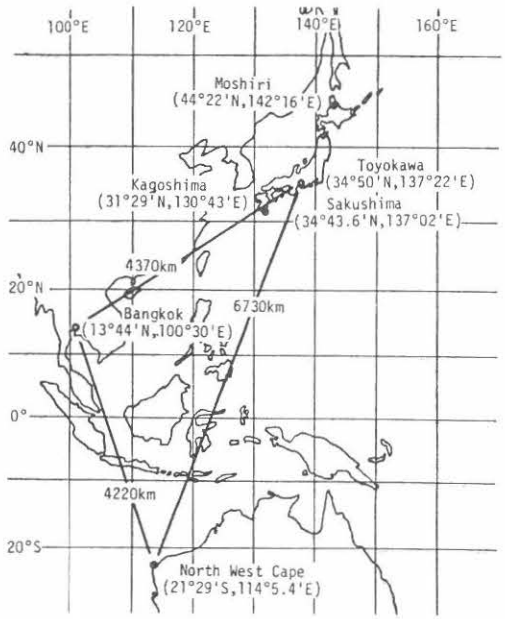

Fig. 1 Configuration of the three DF stations (Moshiri, Sakushima, Kagoshima), Toyokawa, Bangkok and NWC transmitting station.

Fig. 2 shows the histograms of the propagation velocities estimated from these extracted data in the daytime and in the nighttime. From this figure, the average propagation velocities of ELF atmospherics are estimated to be 2.74×10^5 km/sec. in the daytime and 2.91×10^5 km/sec. in the nighttime. The estimated values are distributed around the average ones, the deviation of which may be due to the measuring error of arrival time difference between Toyokawa and Bangkok and the observations being on different days (i. e., the variation of the ionospheric parameters, then that of the propagation constants).

The maxima in the fixing error of the TD method are calculated under conditions that the propagation velocities are distributed around their average values by less than 4% deviation deduced from the standard deviations in Fig. 2 and that the measuring accuracy of the DF at Sakushima is 1 degree. The calculated results in the daytime (0740-0745 UT) are shown on equi-error curves in Fig. 3. In the region "B" (i.e. South-East Asia) discussed below, the deviation of the propagation velocity of atmospherics scarcely affects on the location of a fixed point by the TD method, so that the comparison between the accuracy of the fixing by the DF network and that by the TD method can be also made in the nighttime by referring to the equi-

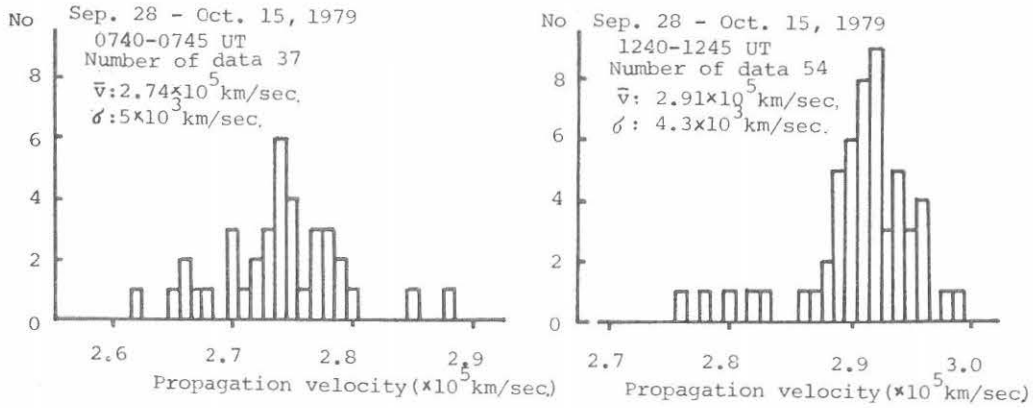

Fig. 2 Histograms of the estimated propagation velocities of ELF atmospherics calculated from the data of the arrival time difference and the location of atmospheric sources by the DF network from Sep. 28 to Oct. 15, 1979, extracted on the bases; the area of the cocked-hat is 1×10^4 km^2 in the daytime (0740-0745 UT), 5×10^3 km^2 in the nighttime (1240-1245 UT), and the sources are located in the region "A" shown in the next figure.

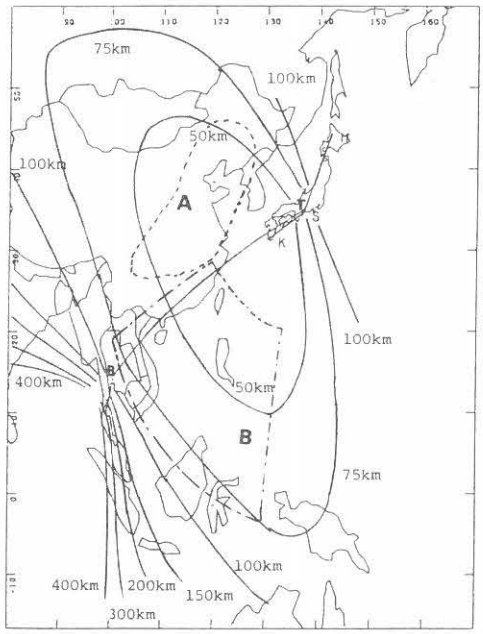

Fig. 3 The contour of equi-error curves in the daytime (0740-0745 UT) for the TD method estimated in the conditions; 4% deviation of the propagation velocities centred the average one, and the measuring accuracy of 1 degree of DF at Sakushima.
"A", where propagation velocities of ELF atmospherics are estimated from the triangulation DF data.
"B", where the evaluation of the fixing accuracy of the triangulation and the two station's DFs is made.

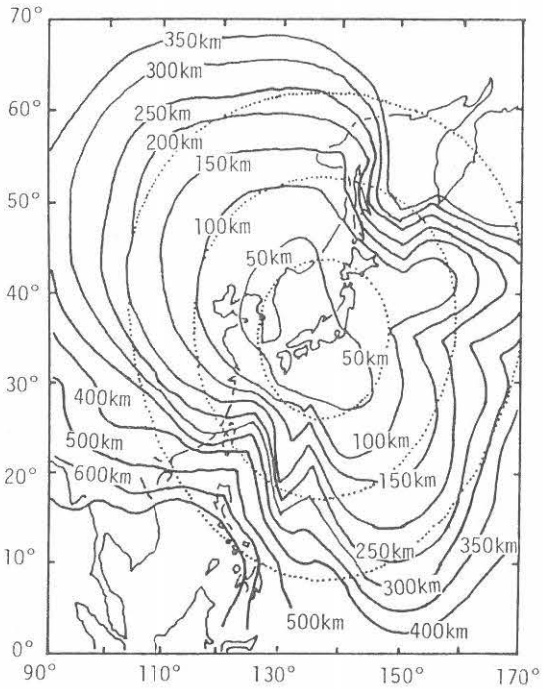

Fig. 4 The contour of equi-error curves for the triangulation DF. (Fig. 6 after Nishino et al., 1979)

error curves shown in Fig. 3. Fig. 4 shows the equi-error curves for the fixed sources by the DF network, which have been calculated under the condition of a measuring accuracy of 1 degree for the DF at each of the three DF stations (Nishino et al., 1979). The measuring accuracy is attributed to only the resolution of bearing angle, and the polarization error and the site error are not included. Note that the fixing error of the TD method is remarkably smaller than that of the DF in locating atmospheric sources in South-East Asia. Therefore, the fixing error of the triangulation DF can be evaluated by the TD method.

3. The evaluation of the accuracy of the DF method

Fig. 5 shows the distribution of atmospheric sources fixed by means of the DF network and that obtained by the TD method in the daytime (0740-0745 UT) from Sep. 28 to Oct. 15, 1979. Fig. 6 shows the distributions obtained by both methods in the nighttime (1240-1245 UT).

3-1. The fixing accuracy of the triangulation DF

The shape of the cocked-hat formed by the direction lines at the three DF stations is extended in South-East Asia along the baselines of the DF stations. Therefore, the fixing accuracy in South-East Asia is lower than that in other regions, as shown in Fig. 4.

For the evaluation of fixing accuracy of the triangulation DF in South-East Asia ("B" region in Fig. 3), in the case when the area of the cocked-hat obtained by the DF was less than $5 \times 10^5 km^2$, the data were extracted as follows; the arrival direction of atmospherics at Sakushima ranged from 185° to 260°, with a distance of 1,700km - 3,700km from Sakushima to the atmospheric sources fixed by the TD method.

In order to evaluate the fixing accuracy of the triangulation DF in the "B" region, the ratio of the difference between the distance (dis.TD) from Sakushima to the atmospheric source fixed by the TD

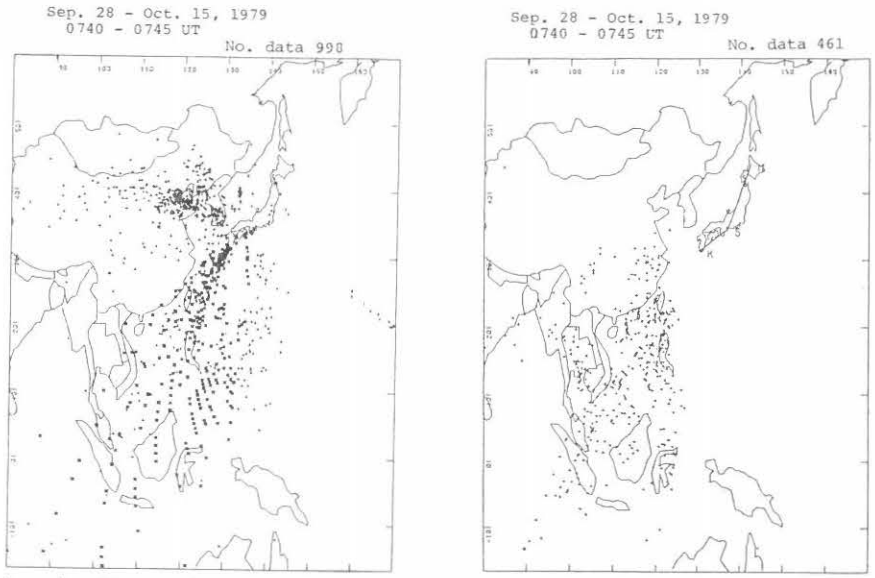

Fig. 5 Distributions of atmospheric sources fixed by the DF network and those by the TD method, in the daytime (0740-0745 UT) from Sep. 28 to Oct. 15, 1979.

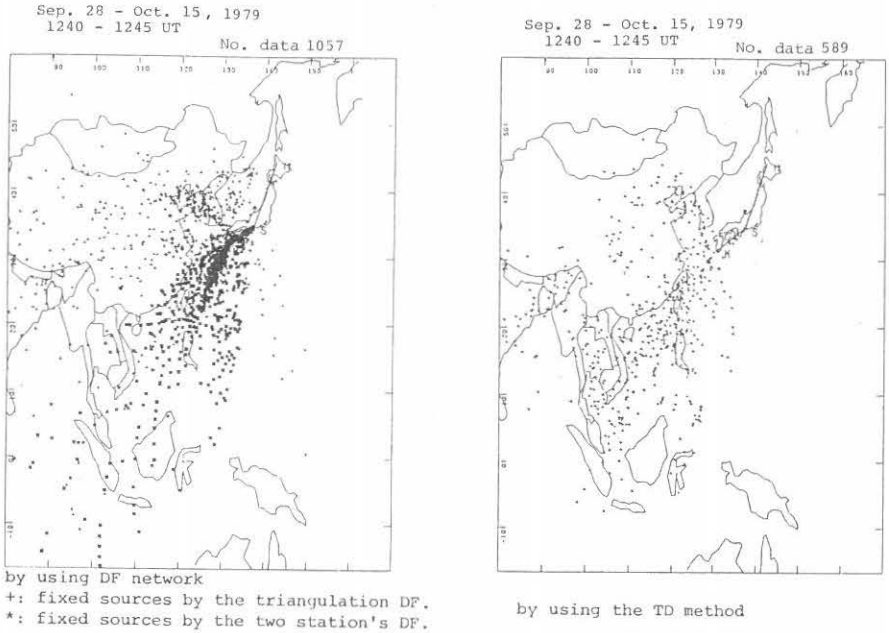

Fig. 6 Distributions of atmospheric sources fixed by the DF network and those by the TD method, in the nighttime (1240-1245 UT) from Sep. 28 to Oct. 15, 1979.

method and that(dis.DF) from Sakushima to the source fixed by the DF network, to the corresponding distance (dis.TD) by the TD method was examined. The histograms of the ratio[(dis.TD-dis.DF)/dis.TD] are shown in Fig. 7 with respect to the bearing angles measured at Sakushima. The ratio is within $\pm$0.13 for the area of the cocked-hat less than 5×10^3km^2, except in one case. And, it is within $\pm$0.13 for the area of less than 1×10^4km^2, except in one case in the daytime and three cases in the nighttime. The ratio of about 0.5 in the two exceptional cases may be attributed to erroneous fixing of different atmospherics at the DF stations.

As regards the distance from Sakushima by the triangulation DF, the ratio ranging $\pm$0.13 corresponds to the fixing accuracy of the distance within $\pm$0.15. For 82% of the data used, the sources are determined with the ratio in the range of $\pm$0.17, corresponding to the determination of the distance from Sakushima by the triangulation DF with an accuracy within $\pm$0.20.

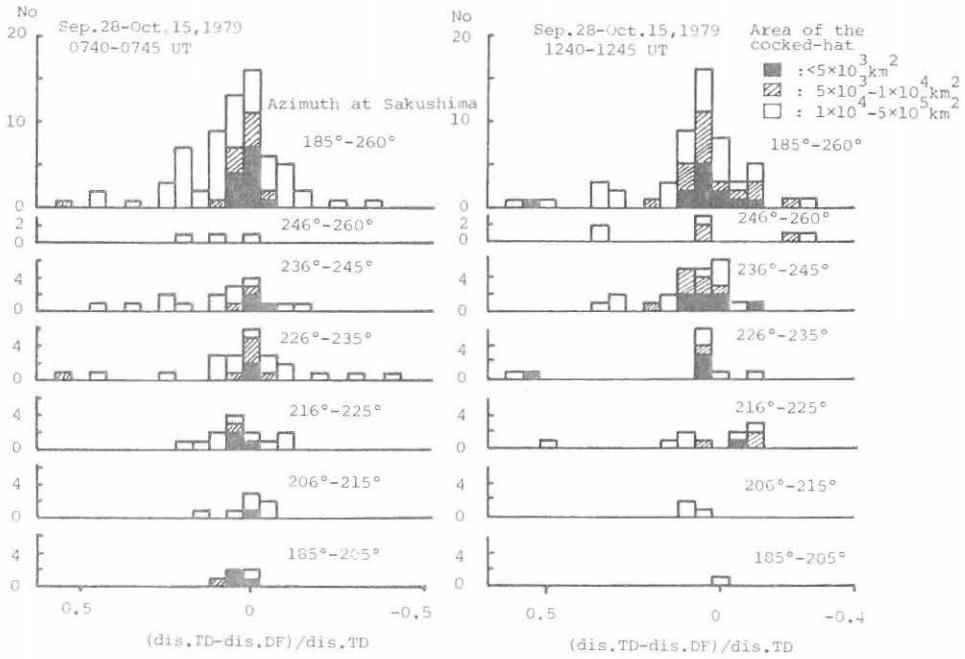

Fig. 7 Variation in the ratio of the difference between the distance (dis.TD) from Sakushima to the atmospheric sources fixed by the TD method and that (dis.DF) from Sakushima to the source fixed by the triangulation DF to the corresponding distance (dis.TD) , with respect to the bearing angles measured at Sakushima, in the daytime (0740-0745 UT) and in the nighttime (1240-1245 UT) from Sep. 28 to Oct. 15, 1979.

3-2. The fixing accuracy of the two station's DF

In order to increase the fixing rate of atmospheric sources in South-East Asia and survey high thunderstorm activities there, DFs at only two stations among the three stations have been complementarily operated, but nevertheless no attempt has ever been made to examine the fixing accuracy of the two station's DF. Now let us examine this fixing accuracy, comparing the points fixed independently by the two station's DF and the TD method in the region "B" labelled in Fig. 3.

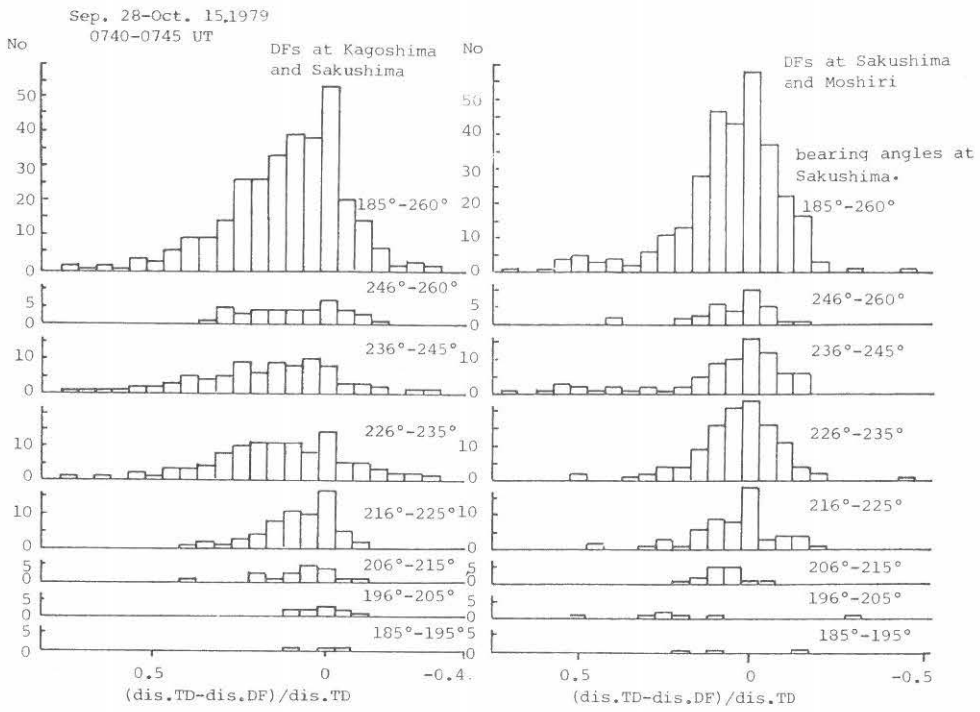

Fig. 8 Variation in the ratio of the difference between the distance (dis.TD) from Sakushima to the atmospheric source fixed by the TD method and that (dis.DF) to the source fixed by the two station's DF to the corresponding distance (dis.TD), with respect to the bearing angles measured at Sakushima in the daytime (0740-0745 UT) from Sep. 28 to Oct. 15, 1979.

Fig. 8 shows the histograms of the ratio [(dis.TD-dis.DF)/dis.TD] with respect to the bearing angles measured at Sakushima in the daytime (0740-0745 UT) from Sep. 28 to Oct. 15, 1979, where the distance from Sakushima to a point fixed by the two station's DF ranges 1,700km-3,700km.

The ratios represented on the top frames are for the points fixed by the DF using two stations of Kagoshima and Sakushima (on left frame), and using Sakushima and Moshiri(right), with respect to the bearing angles measured at Sakushima in the range of 185° - 260° . As is found in the frames, most of the fixed data are distributed over a wide range with the ratio of +0.4 - -0.2. The variation of the ratio distribution with bearing angles is shown in the lower frames.

As for the DF at Kagoshima and Sakushima, the ratios are widely distributed in the range of the bearing angles of 260°-226°, while the ratios for the angle of 225°-185° are rather concentrated, ranging ±0.18. In contrast, most of the ratios are concentrated within

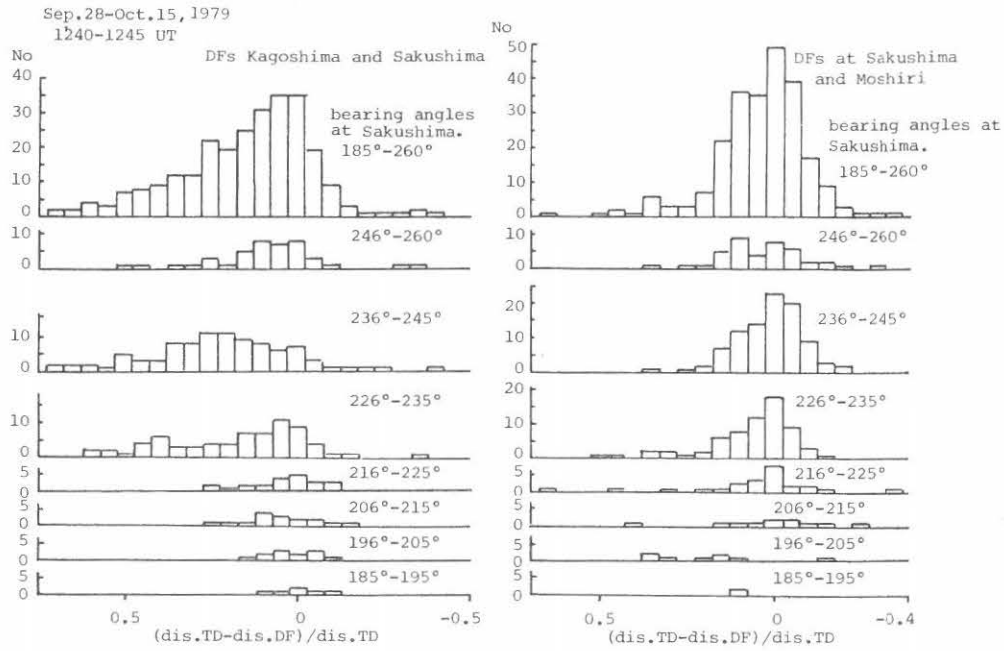

Fig. 9 Variation in the ratio of the difference between the distance (dis.TD) from Sakushima to an atmospheric source fixed by the TD method and that (dis.DF) from Sakushima to the atmospheric source fixed by the two station's DF to the distance (dis. TD), with respect to the bearing angles measured at Sakushima in the nighttime (1240-1245 UT) from Sep. 28 to Oct. 15, 1979.

±0.18 for the DF at Sakushima and Moshiri in the range of the bearing angles of 260°-226°. For 75% of the fixed data, atmospheric sources can be located with an accuracy in the ratio +0.18 - -0.18, when the two station's DF is made at Kagoshima and Sakushima for the bearing angles of 185° - 225°, and at Sakushima and Moshiri for the angles of 226°-260°. Accuracy in the ratio +0.18 - -0.18 corresponds to the accuracy of ±22% in measuring the distance from Sakushima to a fixed point.

Fig. 9 also shows the histograms in the nighttime (1240-1245 UT) for the same observing period as in Fig. 8. It can be seen from the figure that the general trend in the distribution of the ratio is similar to that in Fig. 8, and that the dependence of the ratio distribution on the bearing angles is also similar. It is found that for 78% of the fixed data in the nighttime, the fixing of atmospheric sources can be made with an accuracy in the same ratio of +0.18 - -0.18 as for the daytime.

4. Conclusion

The fixing accuracy of atmospheric sources in South-East Asia by means of the triangulation DF network had been inferred from the shape and the area of the cocked-hat, and that by the two station's DF had been much less inferable.

Now, we have demonstrated that the use of the TD method has enabled us to estimate the fixing accuracy of atmospheric sources in South-East Asia by means of not only on the triangulation DF but also on the two station's DF.

83% of all data fixed by the triangulation DF are extracted. The fixing error of the DF is within ±15% with respect to the distance from the Sakushima to a fixed source, where the distance ranges 1,500km - 4,100km and the area of the cocked-hat is less than $1 \times 10^4 km^2$. This case corresponds to 32% and 49% of the extracted data in the daytime and in the nighttime, respectively. For 82% of the extracted data, the area of their cocked-hats is less than $5 \times 10^5 km^2$ and the location of atmospheric sources is determined within an accuracy of ±20% for the distance from Sakushima.

As for the two station's DF, 75% of the sources are, in the daytime, fixed within an error of ±22% with respect to the distance

from Sakushima, and 78% are fixed in the nighttime with the same accuracy.

Acknowledgment

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