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ERROR INVESTIGATION FOR THE LOCATION OF THE SOURCES OF ATMOSPHERICS BY RADIO DIRECTION FINDING

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Abstract

In order to locate the atmospheric sources accurately, the bearing errors at the fixed stations, Kagoshima, Sakushima and Moshiri, have been investigated. The results of the present investigation indicate that the bearing error curves represent a quadrantal form, having the maximum error of less than $\pm 4°$ in the daytime free from polarization errors. It may be mentioned conclusively that the bearing angles measured by loop antenna at each fixed station are hardly disturbed by the local irregularities in the terrain. By using the correction curve at the data reduction process of the computer, the accuracy of fixing atmospheric sources is likely improved in the sector of South China and North China.

1. Introduction

A new automatic direction finding network for locating the sources of atmospheric was constructed in 1968, consisting of the three direction finding stations, Moshiri, Sakushima and Kagoshima. Observations by using this new system have been made during a week every month. Each direction finder adopts a conventional twin-channel loop antenna. The observation frequency is fixed at 8.5 kHz. Since 1968, the improvements of the direction finder have been made on several points, through routine observations. At present, the location of atmospheric sources can be found more accurately by using this improved system. However, the bearing angle measured by a loop antenna is perpendicular to the incident plane of incoming atmospheric waves. In general, atmospherics in VLF range propagate for a long distance over sea and land, so that the plane of waves is deflected by various factors of the medium and the terrain. Therefore, the bearing angle measured includes various kinds of errors, such as site errors and polarization errors. These errors are unavoidable on principle in measuring the arriving direction as far as a loop antenna is used. In order to reduce these errors, it is necessary to obtain an accurate correction curve by calibrating the various errors.

At higher frequencies than LF range, the bearing errors are usually measured by a portable transmitter carrying around the antenna. But for VLF range, this method can not be applied because of long wave length, so that the error observation is made by comparing the bearing angles, simultaneously taking at a fixed station and at a mobile station operated at a short distance from a fixed station.

Horner (1954) investigated the origins of error in VLF range of atmospherics by using the same method. He reported that the error of maximum 10° had been caused by the local irregularities in the terrain and by the buried cables.

The authors investigated the bearing errors at these three fixed stations by using the mobile station which was installed at a short distance from each fixed station. The observation period was about a month for all seasons except for summer. The purpose of this paper is to obtain the bearing error and to estimate the correction curve, and thereafter to discuss the corrected distribution of the atmospheric sources in the area of Far East by using the correction curve obtained.

2. Origins of Error

The bearing errors can be divided into items as follows.

1). Instrumental errors.
2). Observer's errors and data reduction errors.
3). Errors due to adjacent obstacles.
4). Site errors.
5). Polarization errors.

Item 1) is caused by the imperfections of the instrument, for example the misalignment of the loop antenna, and the imperfect equalization of the gains, bandwidths and phases of the amplifiers. These instrumental errors are estimated to be a quadrant, and the maximum error must be kept within 1° with careful alignment. The interference errors caused by the signals which arrive almost simultaneously are regarded as the instrumental errors, but are omitted in the data reduction.

Item 2) is caused by observers and data readers. This personal errors can be neglected by analyzing statistically a great number of data.

Item 3) is caused by the buried cables. the power lines, the metallic boards, etc. It is pointed out that these errors are caused by the reradiation from currents induced in the cables and the power lines. Horner (1954) reported that a maximum error of 30° could be obtained with a portable direction finder placed directly above the buried cable. Therefore, the antenna of the mobile station must be installed at the site feee from the disturbances of cables, the power lines and the adjacent obstacles.

Item 4) is caused by the unduration of the antenna site and the terrain around the site. It was reported by Horner that when the antenna was installed on a ridge-like hill at Irvinstown, the maximum site error reached 10°, and that the site error curve was related to the local contours of the hill. Therefore, the antenna used, as a temporary standard, must be installed at a flat site from which the elevation angle of surrounding hills and mountains does not exceed 3°.

Item 5) is caused by the horizontally polarized component of the ionospheric waves, that is the relative intensity, phase angle and arrival direction of the incident wave are affected by the ionospheric variations. So, the major axis of the elliptic Lissajous' figure on the cathode-ray tube (C. R. T.) does not indicate the correct bearing angle. In general, polarization errors are considerably large at night than in the daytime. And they are smaller in the atmospherics than in the continuous weves, because the only initial part of the atmospherics signals received are reduced. From above facts, it is difficult to investigate the polarization errors quantitatively. In the present work, investigation is carried out only the data obtained in the daytime.

3. Stations, Instruments and Obsrevation Method

The three fixed stations, Kagoshima, Sakushima and Moshiri, and the mobile stations are indicated in Table 1. And the investigation period and the distance from each fixed station are indicated in Table 1 together. The present investigation

Fixed Station	Mobile Station (M.S.)	Distance	Investigation Period
Kagoshima St. 31°31′ lat. 130°46′ long.	Iwakawa M.S.	20 km	Feb. 18-23, 1970
	Chiran M.S.	36 km	Feb. 26 - Mar. 3, 1970
	Yamakawa M.S.	37 km	Mar. 3-11, 1970
Sakushima St. 34°43′ lat. 137°02′ long.	Himagashima M.S.	4.2 km	Oct. 14-23, 1970
	Isshiki M.S.	10 km	Oct. 27-Nov. 6, 1970
	Irako M.S.	11 km	Nov. 10-18, 1970
Moshiri St. 44°22′ lat. 142°16′ long.	Kembuchi M.S.	31 km	May 26-Jun. 2, 1971
	Furen M.S.	14.4 km	Jun. 4-15, 1971

Table 1. Mobile Station

was mainly carried out about the atmospheric sources at a long distance more than a few thousands kilometers so that the bearing angles taken at the fixed station can be considered to be equal to that at the mobile station. The instrument at each fixed station is the direction finder of Watson Watt type. The coded data of the arriving direction and occurrence time of an atmospheric obtained by the instrument are punched out on a paper tape with a high speed mechanical puncher.

On the other hand, the instrument at the mobile station is D-29 type direction finder made by Iwai et al. in 1956. This Brown tube is the magnetic deflection type, so that the directional figure is photographed clearly. The data of arriving direction and occurrence time were photographed on 35mm high speed film. Time coincidence between the fixed and mobile stations was carried out by means of receiving the time signal of JJY. Most of the error observations were carried out simultaneously with the routine observation for locating the sources of atmospherics, except the night time. Observation time was from 10m to 20m at 09h, 12h 15h and 18h J. S. T., respectively.

In order to eliminate the ambiguity of 180° for arriving direction, uni-directional direction finding system has been added to the D-29 type direction finder in the case of the investigation at Moshiri. The block diagram of the uni-directional direction finder (improved D-29 type) is shown in Fig. 1. The electric characteristics of the sense amplifier must be the same as that of N-S and E-W amplifiers, especially at phase characteristics. The display of C. R. T. is uni-directional indication by point blanking, as shown in Fig. 1. Sense antenna is a vertical aluminum pole of 4m long. The preamplifier, the sense amplifier and brightness modulator were made of transistors, linear and digital integrated circuits.

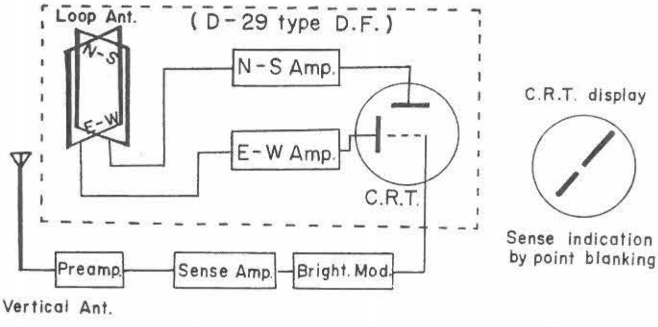

Fig. 1. Block diagram of the uni-directional direction finder and C. R. T. display.

4. Investigation Results and Discussions

At first, the differences between the bearing angles taken at Sakushima and the near mobile stations, Himagashima, Isshiki and Irako, are shown in Fig. 2, in order to analyze the mechanism generating the errors. In this figure, a spot on a certain azimuth represents the mean value of bearing errors included within $\pm 1°$ around the objective azimuth, assuming that the measuring accuracy of bearing of the insrument

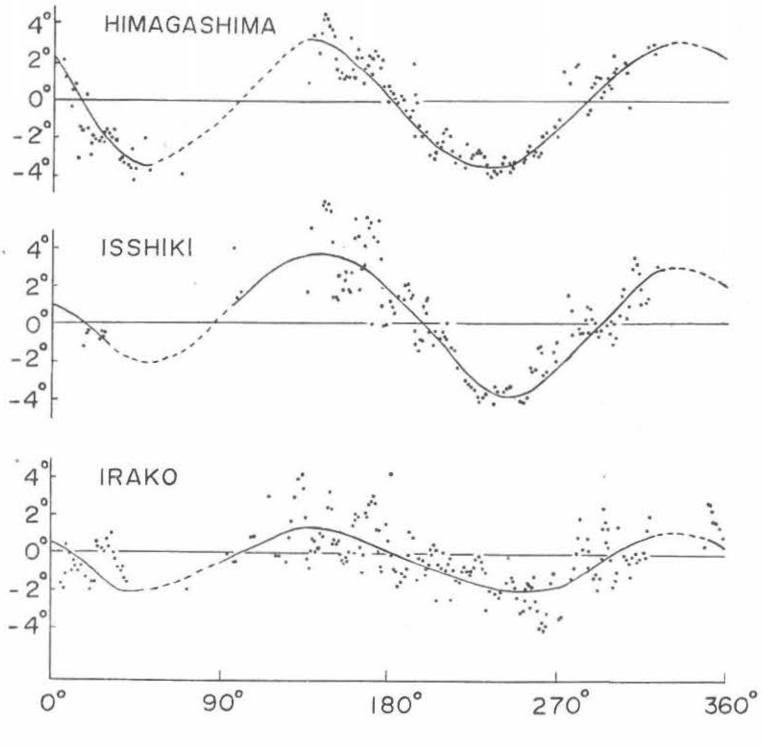

Fig. 2. Error distribution reduced from the differences between the bearing angles taken at Sakushima and the near mobile stations.

at the fixed and mobile station are within $\pm 1°$. Solid lines are supposed to be average error curves. The form of three curves indicates apparently a quadrant, but the amlitude of the curves at Isshiki and Himagashima are larger than that at Irako. The condition of the mobile station used for the purpose of the correction may not be idealistic. There are power lines and steel-skeleton buildings around the Isshiki mobile station, and also power lines at the distance of several meters in the south of the Himagashima mobile station. It was suggested that the cause originating the large quadrantal errors might be the reradiation from the power lines and other metallic disturbances. At Irako, such disturbances are not found around the antenna, so that

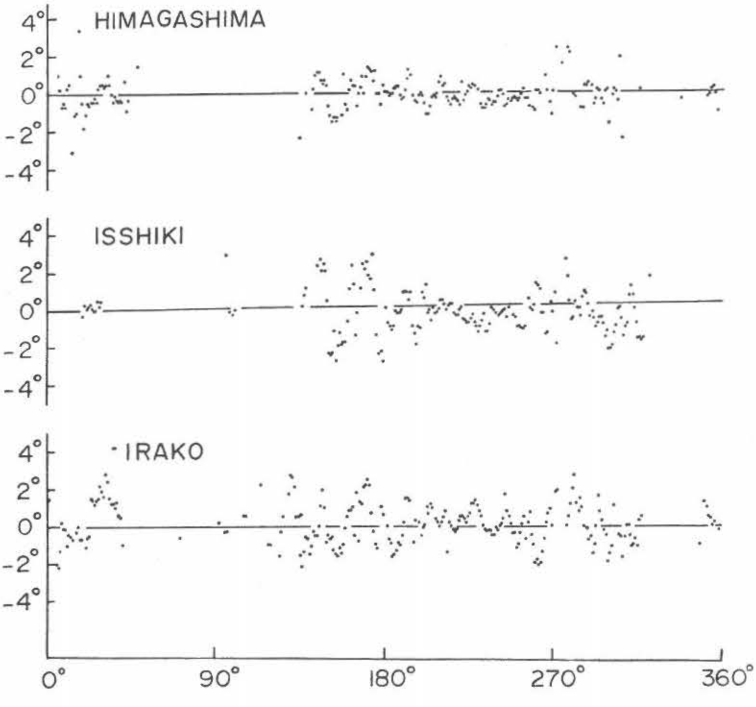

Fig. 3. Error distribution which eliminates the quadrantal component from the original error distribution.

the magnitude of the bearing errors is smaller than at the other two stations. In order to discuss in detail, the error distribution which eliminates the quadrantal component from the original error distributions is shown in Fig. 3. It is seen from this figure that both of the error distributions of Isshiki and Irako are more dispersive than that of Himagashima. Himagashima is surrounded by sea free from disturbances, so that the error distribution is estimated to be less dispersive than at the other two stations.

Although the Irako site is flat and no remarkable disturbances are found around the site, there are a large number of pine-trees of about 4m high there. So that the error distribution of Irako seems to be more dispersive than at Himagashima. As described above, the antenna itself which uses for the calibration of the site errors at the fixed station includes proper site errors, so it is necessary to investigate simultaneously the errors at an ideal mobile site. But it is, in practice, very difficult to find out such an ideal site. Therefore, in order to eliminate proper errors of a mobile site, investigations must be carried out at several different sites, and a large number of data must be analyzed statistically. From these results, correction curve for the fixed site can be obtained accurately. In this paper, the correction curve at

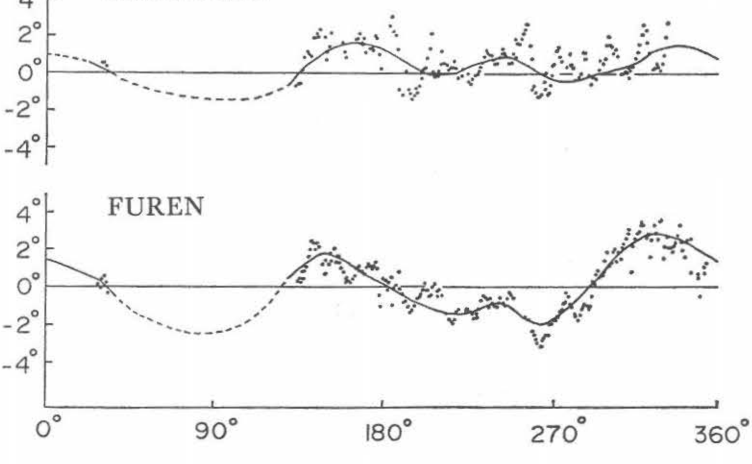

Fig. 4. Error distribution reduced from the differences between the bearing angles taken at Moshiri and the near mobile stations.

Sakushima can be estimated by combining the error distributions at Himagashima and Irako, as shown in the later figure.

Next, the differences between the bearing angles taken at Moshiri and the near mobile stations, Kembuchi and Furen, are shown in Fig. 4. The error curve at Furen represents a quadrantal form, containing some higher harmonic components. On the other hand, the error curve at Kembuchi represents an octantal form rather than a quadrantal. Any remarkable disturbances generating these errors could not be found at both of these sites. The correction curve of Moshiri can be estimated by combining the error distribution at Kembuchi and Furen, as shown in the later figure.

Furthermore, the differences between the bearing angles taken at Kagoshima and the near mobile stations, Iwakawa and Chiran, are shown in Fig. 5. Both error curves represent a quadrantal form. But the amplitude of curve at Chiran is larger than that obtained previously. This is closely related to the fact that the instrument at Kagoshima was disturbed by unknown interfering waves. The instrument had some troubles in the case of the investigation at Yamakawa, so that the errors could

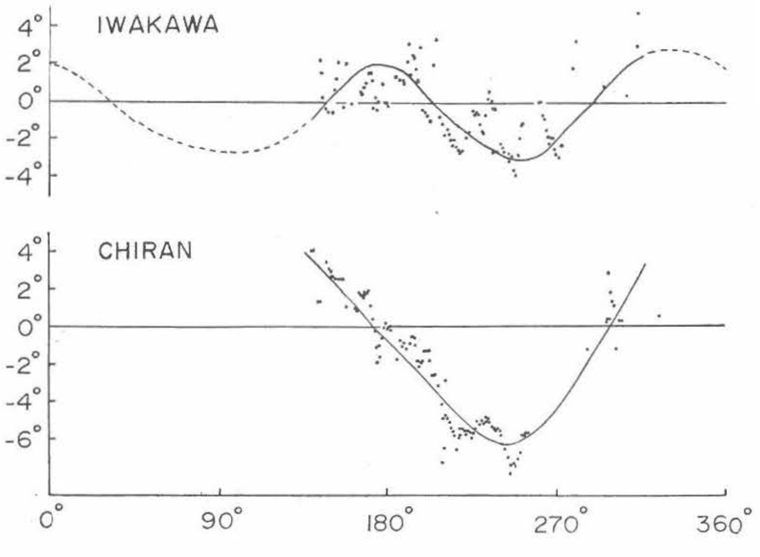

Fig. 5. Error distribution reduced from the differences between the bearing angles taken at Kagoshima and the near mobile stations.

not be reduced.

From the previous results and the discussions the correction curve of each fixed station, as a temporary standard, can be estimated as shown in Fig. 6. Each correction curve is almost a quadrantal form, and the maximum is less than $\pm 4°$, and is hardly related the undulation of the antenna site and the terrain around the site. This maximum is smaller than that expected from Horner's investigations, described above. In other words, a remarkable site error at each fixed direction finding station could not be found.

Now, the corrected location of atmospheric sources by using the correction curve of Fig. 6 can be obtained. The result reduced by the computer is shown in Fig. 7. The distribution of atmospheric sources in China were taken from the data observed

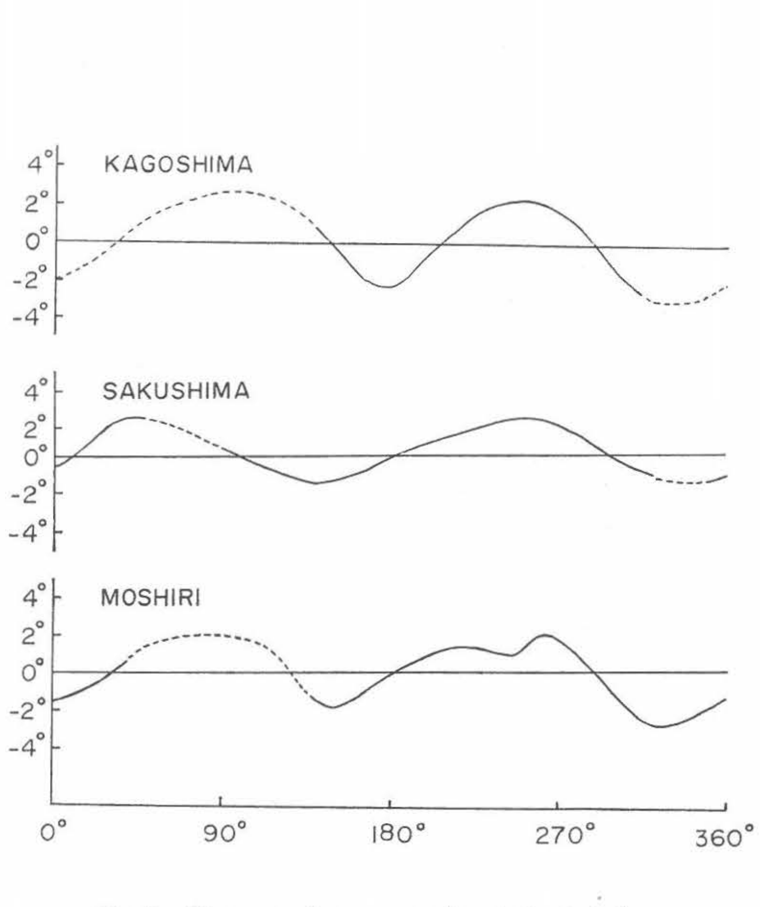

Fig. 6. The correction curves of each fixed station.

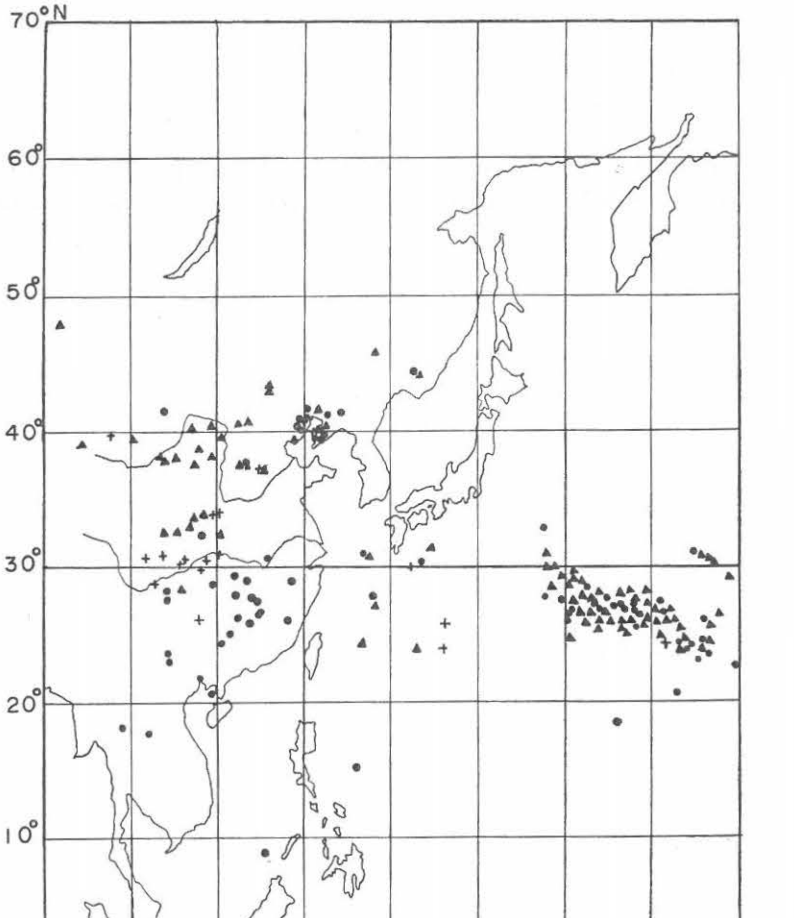

Fig. 7. The corrected distribution of atmospheric sources.

during 15:10-15:15 and 18:10-18:15, J. S. T. Sep. 16 in 1971. And also the distribution of sources in the Pacific Ocean were taken from the data observed during 9:10-9:15 and 12:10-12:15, J. S. T. Sep. 12 in 1969. In this map, symbol [●] indicates the point whose accuracy of fixing is improved, symbol [▲] indicates the point whose accuracy is aggravated, and symbol [+] the point of no change. The classification of the accuracy of fixing was carried out by comparing the values of DAN* of original fixing with that of the corrected fixing. From this figure, it may be concluded that the accuracy of fixing for the atmospheric sources in South China and North China can be improved. The fixing accuracy for atmospherics occurring in South China is aggravated for the location method of triangulation, because South China is in the worst fixing sector along the base line connecting the fixed direction finding stations. Therefore, it is attractive to improve the fixing accuracy for the atmospheric sources in this sector by using the correction curve. On the other hand, it is not evident whether the fixing accuracy is improved or not for the atmospheric sources in the Pacific Ocean. It is necessary to discuss in detail about the fixing accuracy for a large number of the atmospheric sources by using the correction curve.

5. Concluding Remarks and Future Developments

It is very difficult to discuss the error investigation because of the complex origins of various errors. In view of this investigation described above, it can be suggested that the error distributions at the three fixed stations similarly indicate the quadrantal form, and the maximum error is less than $\pm 4^\circ$. Therefore, it may be mentioned conclusively that the directivity of the loop antenna installed at each fixed station for the location of the atmospheric sources is hardly disturbed by local irregularities in the terrain, because the antenna is installed more than 21m above the ground. In future, it is necessary to analyze the various errors, including the polarization errors. Other methods for measuring the bearing errors, such as the Adcock antenna system free from the polarization errors and also phase difference method between two sites, are being studied now. Further investigations on the bearing errors of atmospherics will be carried out until it becomes possible to obtain the accurate fixing for all ranges.

* See the Fig. 11 in the paper of Proc. Res. Inst. Atmospherics, Nagoya Univ. 16 (1969).

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