# ON THE CHARACTERISTIC PHENOMENA FOR SHORT WHISTLERS OBSERVED AT TOYOKAWA IN WINTER

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*Summary*:

About 84% of short whistlers observed at Toyokawa on winter nights were recognized by analysis to be preceded by tweek type atmospherics, which made it possible to measure distances between the observation station and the sources of short whistlers.

And also at Toyokawa in winter, dispersions of short whistlers were found out to decrease regularly toward midnight. A variation of electron density in the outer ionosphere are calculated from this variation of dispersions.

## I. Introduction.

Two characteristic phenomena which had not been reported so far were found out for short whistlers observed at Toyokawa (geomag. lat. 24.5°) in winter. The first is a phenomenon of the existence of preceding atmospherics of short whistlers at night, and second is that of a regular diurnal variation of dispersions of short whistlers.

These seem to occur by the reason that the latitude of the observation station at Toyokawa was the lowest one in the world then. Because, according to the propagation theory of whistler by Storey, the distance between a station and short whistler sources in the opposite hemisphere is markedly reduced as the latitude of the station becomes lower, a possibility may arise to detect any preceding atmospheric clicks; further, case of propagation to a lower latitude station a portion of propagation path of a whistler in the ionospheric region will increase, where the diurnal variation of electron density is well known to be great. Accordingly, the effect of the variation will cause the dispersion to variate reguraly.

The preceding atmospherics detected at Toyokawa were of tweek type, which made the recognition of preceding atmospherics easy and sure and gave a means to measure the distances of short whistler sources.

Some informations about variations of electron density and dispersions in the outer ionosphere are got from analysis of diurnal variation of dispersions.

The measurement of dispersions and the recognition of tweek type preceding atmospherics are made by sona-graph.

## II. Preceding Atmospherics.

### 1. Tweek type preceding atmospherics of short whistlers.

The propagation time $t$ for a component frequency of a whistler is given by

$$t=Df^{-\frac{1}{2}} \qquad (1)$$

where $D$, the dispersion, is a constant for the whistler.

A method adopted to determine the dispersion is as follows; plotting the $t$-$f$

curves for the parameter $D$ from Eq. (1), a curve is found among them, which best fits in the curve of a whistler analysed by sona-graph, then the value of parameter $D$ of the curve is regarded as tbe dispersion of the whistler. Hereafter, this method will be called the proper "fit-method". In practice, dispersions are measured as small as $5/4\sqrt{s}$, but an error of $5/2\sqrt{s}$ will be probable in bad conditions.

Though the time origin of Eq. (1) is the instant of a lightning flash, it might be taken to be the instant of the arrival of a preceding atmospherics to a point of reception, for the propagation time of atmospherics is generally very small compared with that of a whistler. Accordingly, the time difference between a whistler and its preceding atmospherics is almost equal to that given by Eq. (1). This is a criterion to recognize the preceding atmospherics, *i. e.* whether an atmospherics is a preceding one of a whistler or not is guessed from studying whether the dispersion of a whistler determined by fit-method agrees with the dispersion determined from the time difference between them. But in general atmospherics occur so frequently, that there will be enough chances for an atmospherics to have such a time difference without any preceding atmospherics. Consequently, it is considerably difficult in practice to detect a preceding atmospherics. As for this point, the preceding atmospherics observed at Toyokawa on winter night were tweek type atmospherics which, as seen in Figs. 1 and 2,

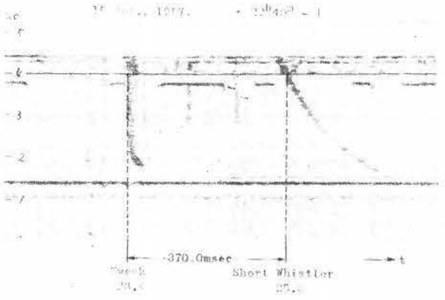


Fig. 1 Sona-gram of a short whistler accompanying a tweek type preceding atmospherics. 15 Feb. 1957, 2240 J. S. T.
Dispersions $25\sqrt{s}$ by fit-method
$23.4\sqrt{s}$ by time difference

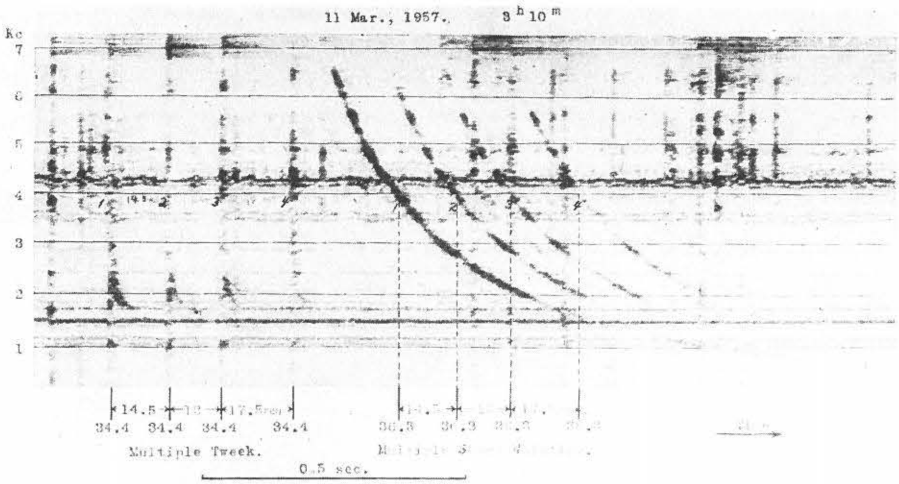


Fig. 2 Sona-gram of short whistlers accompanying tweek type preceding atmospherics in a multiple flash type group. 11 Mar. 1957, 0310 J. S. T.

Dispersions $36.3\sqrt{s}$ by fit-method
$34.4\sqrt{s}$ by time difference

were clearly distinguishable from normal atmospherics, so the recognition of preceding atmospherics were sure and easy. The error in time difference measurement is smaller than 7.55 m sec, which corresponds to a length of 1 mm on sona-gram. So the error in dispersion measurement by time difference method is only $0.48\sqrt{s}$, which is much smaller than the smallest value of dispersions determined by fit-method.

Fig. 1 is a sona-gram of a preceding atmospheric click followed by a short whistler observed on 15th Feb. 1957, 22 h 40 m-1. The dispersion of the whistler is $25\sqrt{s}$, while the dispersion determined from the time difference 370.0 m sec at frequency 4 kc/s is $23.4\sqrt{s}$. Fig. 2 is also a sona-gram of short whistlers and their tweek type preceding atmospherics in a multiple flash type group, observed on 11th Mar. 1957, 3 h 10 m. The dispersions decided by fit-method are all the same, $36.3\sqrt{s}$ and the dispersions obtained by time difference method are also all the same, $34.4\sqrt{s}$. Some results analysed from whistlers observed during several nights in Mar. 1957 are shown in Table 1, where the dispersion determined by fit-method and from time difference are shown in column A and column B respectively, and a mark $*$ means a multiple flash type group as shown in Fig. 2. In these illustrations, the values of dispersions got by both methods prove to agree good within the error of measurement, but it may be seen that values obtained by fit-method is generally greater than those culculated from time difference. This seems to be caused from the negligence of propagation time of tweeks, because the propagation time given by eq. (2) (derived in the next section) is about 16.6 m sec, assuming the values of $d$, $h$, and $f$ in Eq. (2) being 4,000 km, 88 km and 4 kc/s respectively, which corresponds to $1.1\sqrt{s}$ of dispersion.

Table 1 Short whistlers and their tweek type preceding atmospherics in Mar., 1957.

| | Date | | | | Disper. A | Disper. B |
|---|---|---|---|---|---|---|
| | 1 d | 1 h | 10 m | | 26.3 | 24.4 |
| * | 2 | 0 | 40 | −1 | 30.0 | 29.6 |
| | | 1 | 40 | | 26.3 | 25.8 |
| * | 3 | 20 | 40 | −2 | 30.0 | 28.2 |
| * | | 21 | 40 | −2 | 26.3 | 25.3 |
| | | 22 | 10 | −2 | 26.3 | 24.9 |
| * | | 23 | 40 | −1 | 26.3 | 24.9 |
| * | 4 | 1 | 40 | −2 | 26.3 | 24.4 |
| * | | 2 | 40 | −1 | 25.0 | 23.6 |
| * | | 3 | 40 | −2 | 23.8 | 22.5 |
| * | | 4 | 10 | −3 | 23.8 | 22.0 |
| * | 5 | 2 | 40 | −1 | 28.8 | 26.4 |
| | 6 | 4 | 10 | | 22.5 | 21.5 |
| | 8 | 1 | 40 | | 27.5 | 26.8 |
| * | 11 | 0 | 40 | −2 | 40.0 | 36.7 |
| * | | 2 | 10 | −1 | 33.8 | 32.9 |
| * | | 3 | 10 | −1 | 36.3 | 34.4 |
| | 12 | 22 | 10 | −1 | 30.0 | 30.8 |
| | 23 | 3 | 10 | | 33.8 | 32.8 |
| | 28 | 4 | 40 | | 22.5 | 21.6 |

A: Dispersion by fit-method
B: Dispersion by time difference
*: Multiple flash type group

The tweek type preceding atmospheric clicks are found in about 84% of short whistlers analysed, which were observed on the nights between 21 o'clock and 6 from Dec. 1956 to April 1957. These results are sufficient to verify the existence of the preceding atmospherics of short whistlers at Toyokawa on winter nights. Considering the distances from an observation station to short whistler sources, this may be a characteristic phenomenon for stations in lower geomagnetic latitudes as Toyokawa.

## 2. Measurement of distances of short whistler sources by tweek type preceding atmospherics.

As the short whistlers detected at Toyokawa have been proved to be preceded by tweek type atmospherics, it becomes possible to measure the distances of short whistler sources by making use of the propapgation characteristics of the tweeks.

It is a well known fact that a tweek type atmospherics is produced from the propagation of a wave radiated from a distant lightning discharge through a wave guide constructed by the earth and ionosphere. Assuming that the earth and ionosphere are parallel plane conductors, the cut-off frequency $f_c$ for $TM_{0m}$ mode is $f_c = \mathrm{m}c/2h$, where $c$ is the light velocity, $h$ is the height of ionosphere above the ground, the $y$ axis is vertically upward, the $z$ axis indicates the direction of wave propagation as shown in Fig. 3 and m is a positive integer. Then, the group velocity $v_c$ of frequency $f$ is given by, $v_c = c\{1-(f_c/f)^2\}^{\frac{1}{2}}$, consequently, the time for a wave component of frequncy $f$ to propagate a distance $d$ is determined by

$$t = d/v_c = d/c\{1-(mc/2hf)^2\}^{\frac{1}{2}}$$
$$= d/c\{1-(c/2hf)^2\}^{\frac{1}{2}} \quad \text{for } m=1 \qquad (2)$$

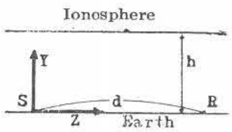


Fig. 3

$h$=height of the ionosphere above the ground

$d$=distance between source (S) and point of reception (R)

The Eq. (2) is the relation between frequency and propagation time of tweeks, which are used to measure the distance in practice. As in the case of whistlers, the fit-method is applied here, but now the precision of determination is less, because the time rate of change of frequency is so rapid, that the time duration of tweek is very short and furthermore Eq. (2) involves two parameters $d$ and $h$, which make the fit-method considerably ambiguous.

Six examples of distances measured by tweeks, which were intense and fine,

Table 2 Distances of short whistler sources measured by their tweek type preceding atmospherics.

| Date | 14.— 3h40m—1 | | | | | | 14.— 3h40m—2 | | | | | | 14.— 5h10m | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| d \ h | 90 | 89 | 88 | 87 | 86 | 85 | 90 | 89 | 88 | 87 | 86 | 85 | 90 | 89 | 88 | 87 | 86 | 85 |
| 3,000 | | | | | | | | | | | | | | | | | | |
| 3,500 | | | | | | | × | × | × | × | × | | | × | | × | × | × |
| 4,000 | | × | × | | × | | * | * | * | * | | | × | * | * | * | × | × |
| 4,500 | × | × | × | × | * | × | × | × | × | * | | × | * | × | × | × | × | × |
| 5,000 | × | * | * | * | × | | | | | | | | × | | | | | |
| 5,500 | * | × | × | | | | | | | | | | | | | | | |
| 6,000 | × | | | | | | | | | | | | | | | | | |
| Date | 15.—22h10m | | | | | | 15.—22h40m—1 | | | | | | 15.—22h40m—2 | | | | | |
| 3,000 | | × | × | | × | × | × | × | * | × | × | × | × | × | × | × | × | × |
| 3,500 | × | * | * | * | × | | * | * | × | × | | | * | × | * | * | × | |
| 4,000 | * | × | × | × | × | | × | | | | | | × | | × | × | | |
| 4,500 | × | × | | × | | | | | | | | | | | | | | |
| 5,000 | | | | | | | | | | | | | | | | | | |

* generally good fit × comparatively good fit

are shown in Table 2, where marks * and × mean a generally good fit and a comparatively good fit respectively. These results show the distances of short whistler sources ranging about 3,500 km to 5,000 km, which seem fairly short compared with the distance, about 6,000 km, of the geomagnetic conjugate point of Toyokawa which is expected to be the location of source under the propagation of whistlers quite along the geomagnetic line of force. This looks to support the asymmetric propagation theory of whistlers[2] with respect to the geomagnetic equator, but further examinations will be necessary to conclude, for analysed data are very few and there may be a considerable ambiguity in the determination of the distances.

Thus, being imperfect, a way to determine the distances of sources of short whistlers observed at Toyokawa are found by using propagation characteristics of tweek type preceding atmospherics.

## III. Dispersions.

### 1. Diurnal variations.

Table 3 Examples of diurnal variation of dispersions of short whistlers.

| Date | Feb./Mar., 1957. | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 8 | | | | | | | | | | 41.3 | 40.0 | 37.5 | | 30.0 | 27.5 | |
| 9 | | | | 23.8 | | | | | 42.5 | 42.5 | 40.0 | 36.3 | 34.4 | 30.0 | 28.8 | |
| 11 | | | | | | | | 45.0 | 43.8 | 43.5 | 42.5 | | | | | |
| 12 | | | | | | | | 46.3 | 45.4 | 44.3 | 41.3 | | | | | |
| 14 | | | 28.7 | 29.1 | 27.3 | 25.0 | | | | 38.8 | | | | | | |
| 15 | | | | | | | | | 41.3 | 40.0 | | | | | 25.0 | |
| 16 | 22.5 | 22.5 | 21.3 | 21.3 | | | | | | | | | | | | |
| 2 | 30.0 | 27.5 | 25.0 | | | | | | | | | | | | | 35.0 |
| 3 | 31.3 | | | | 33.8 | | | 41.3 | 40.0 | 38.1 | 36.3 | 33.3 | 29.8 | 26.9 | 27.5 | 26.7 |
| 4 | 25.8 | 26.3 | 25.0 | 24.2 | 24.0 | 25.5 | 29.4 | | | | | | | | | |
| Time | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
| | ( J. S. T. ) | | | | | | | | | | | | | | | |

So far as we know, nothing has been reported about diurnal variations of whistler dispersions except a report by Storey[1], in which he described that the dispersion showed remarkably little systematic variation with time of day. But, at Toyokawa, a regular tendency was clearly seen, as shown in Table 3, that the dipersions of short whistlers decrease gradually with the lapse of time, when short whistlers were observed from the evening till near sunrise. Fig. 4 is sona-grams which show a decrement of dispersions from value $41.3\sqrt{s}$ at 16th on 15th to value $21.3\sqrt{s}$ at 2 and 3 hrs. on 16th of Feb. 1957. In Fig. 5, the monthly mean of dispersions at each hour of day in Feb. and Mar. of 1957 are plotted against time. These curves indicate, in general, though differing in details, that dispersions are the greatest at the beginning of appearance of whistlers, then they continue to decrease till near sunrise, but the rate of decrement is small till 1 or 2 hours after sunset, after which time it rises up for 2 or 3 hours, and then it again slightly falls off till near sunrise, when the dispersions seem to increase. This

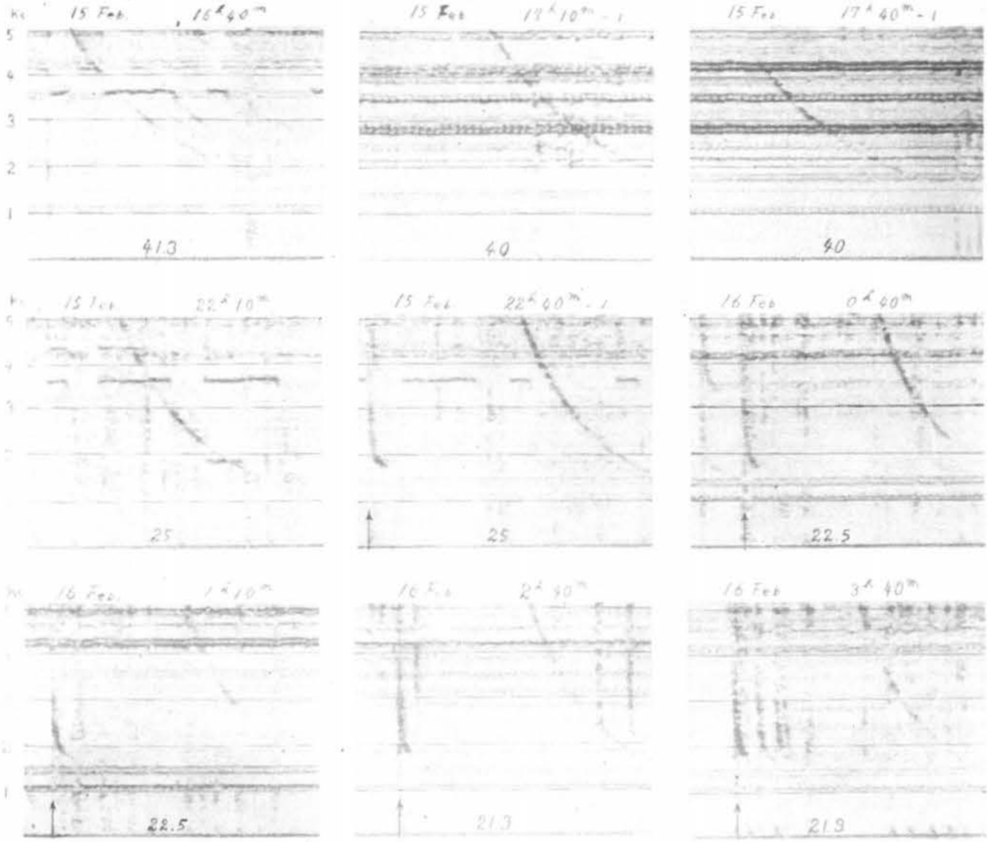

Fig. 4 An Example of the diurnal variation of dispersions analysed by sona-gram.

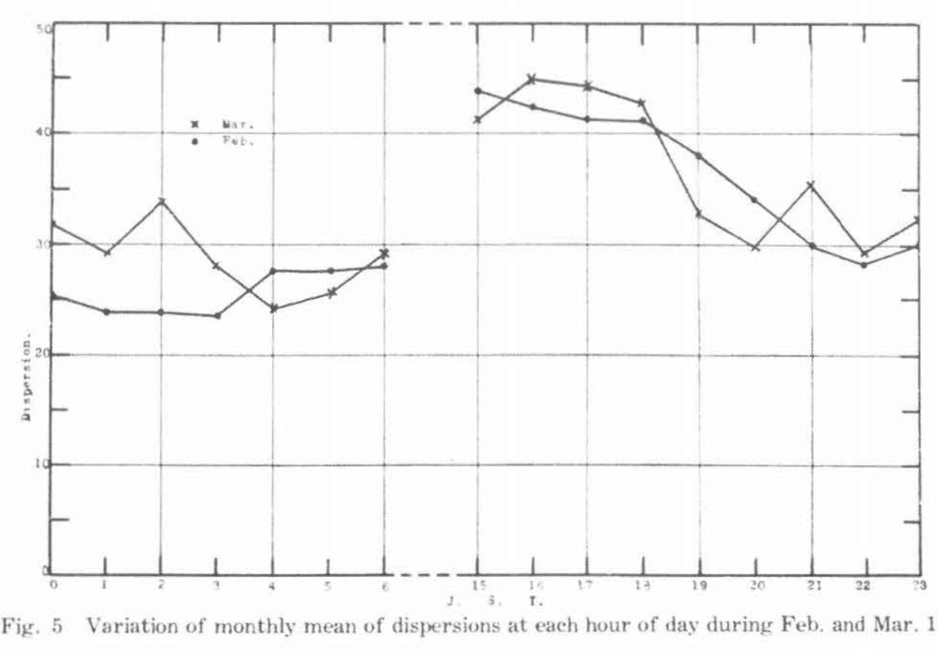


Fig. 5 Variation of monthly mean of dispersions at each hour of day during Feb. and Mar. 1957.

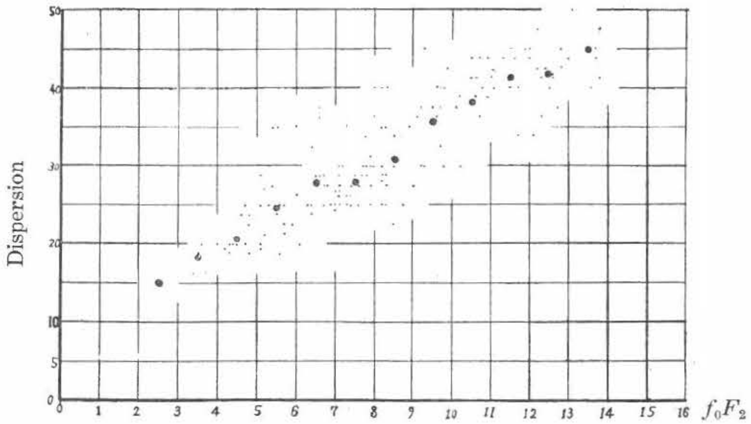


Fig. 6 Relation between $f_0F_2$ and dispersions of short whistlers
$f_0F_2$ (Mc/s): Averaged value of Kokubunji and Yamagawa.
Data of dispersions are obtained during from Dec. 1955 to Feb. 1957.

tendency of variation of dispersions looks to correspond to the height of the sun, *i. e.* to the diurnal variation of electron density of ionosphere. From this point of view, a relation between dispersions and $f_0F_2$, the critical frequency of $F_2$ layer of ionosphere, was examined and the result is plotted in Fig. 6, in which the data of dispersions were obtained from short whistlers observed during a period from Dec. 1955 to Mar. 1957 and the values of $f_0F_2$ are taken, averaging values observed at Kokubunji and Yamagawa. Individuals being scattered, in average, a linear relation between them is seen. This means that the electron density averaged along a whistler path is nearly proportional to the maximum electron density of $F_2$ layer, since a dispersion is approximately proportional to square root of a electron density averaged along a whistler path, while $f_0F_2$ is also proportional to square root of a maximum electron density of $F_2$ layer.

**2. Dispersions in the ionosphere and in the outer ionosphere:**

According to the propagation theory of whistlers and assuming a propagation to take place along a geomagnetic line of force, the dispersion $D$ is given by the next eq.,

$$D=1/2c\int(f_0/f_H^{\frac{1}{2}})\,ds \quad \text{(integration is done along propagation path)}$$

$$=(eb^5/2ca^3H_0)^{\frac{1}{2}}\int_{-\theta_0}^{\theta_0}\sqrt{N}\cos^4\theta(1+3\sin^2\theta)^{\frac{1}{4}}d\theta$$

$$\doteqdot 1.26(eb^5/2ca^3H_0)\int_0^{\theta_0}\sqrt{N}\cos^4\theta\,(1-0.15\cos 2\theta)\,d\theta\,.$$

$f_0$ is a critical frequency, $f_H$ is a gyro-frequency of electron, $c$ is the light velocity, $e$ is the electron charge, $a$ is the radius of the earth, $H_0$ is the horizontal component of geomagnetic field at the geomagnetic equator, $b$ is a distance from the center of the earth to the summit of a geomagnetic line of force going through a point of reception (geomag. lat. $\theta_0$), $\theta$ is a geomag. lat. at any point on the propagation path, and $N$ is an electron density. The last of the above eqs. is derived from an approximation $(1+3\sin\theta)^{\frac{1}{4}}\doteqdot 1.26(1-0.15\cos 2\theta)$.

In order to calculate the magnitudes of dipersions of short whistlers in the ionosphere and in the outer ionosphere respectively, the space for whistlers to propagate is divided into two regions, the first of which is called region I being between 100 km and 500 km above the ground, the second of which is called region $U$ being from 500 km above the ground to the summit of the propagation path. The dispersions in the region $I$ and $U$ are expressed by $D_i$ and $D_u$ respectively, then

$$D = D_i + D_u. \quad \cdots\cdots(4)$$

Though the electron density depends on height and latitude, for convenience, it is regarded as a constant $N_i$ in the region $I$ and a constant $N_u$ in the region $U$, so that from Eq. (3),

$$D_i = 1.26(2eb^5/ca^3H_0)^{\frac{1}{2}} \cdot N_i^{\frac{1}{2}} \int_{\theta_{500}}^{\theta_{100}} \cos^4\theta(1-0.15\cos 2\theta)\,d\theta$$

$$D_u = 1.26(2eb^5/ca^3H_0)^{\frac{1}{2}} \cdot N_u^{\frac{1}{2}} \int_{0^\circ}^{\theta_{500}} \cos^4\theta(1-0.15\cos 2\theta)\,d\theta$$

where $\theta_{100}$ and $\theta_{500}$ are geomag. lats. of the points at 100 km and 500 km above the ground on the propagation path passing through the observation station of geomag. lat. $\theta_0$, respectively.

Taking $\theta_0 = 24^\circ$, being nearly geomag. lat. of Toyokawa, $a = 6{,}370$ km and $H_0 = 0.29$ gauss, b, $\theta_{100}$ and $\theta_{500}$ become 7,634 km, 22°59′ and 18°27′ respectively.

Consequently,

$$\left.\begin{aligned} D_i &= 5.237\times10^{-2}\times N_i^{\frac{1}{2}} \int_{18^\circ27'}^{22^\circ59'} \cos^4\theta(1-0.15\cos 2\theta)\,d\theta \\ D_u &= 5.237\times10^{-2}\times N_u^{\frac{1}{2}} \int_{0^\circ}^{18^\circ27'} \cos^4\theta(1-0.15\cos 2\theta)\,d\theta \end{aligned}\right\}. \quad (5)$$

Calculating from Eq. (5), $D_i$ and $D_u$ are plotted against $N_i$ and $N_u$ in Fig. 7.

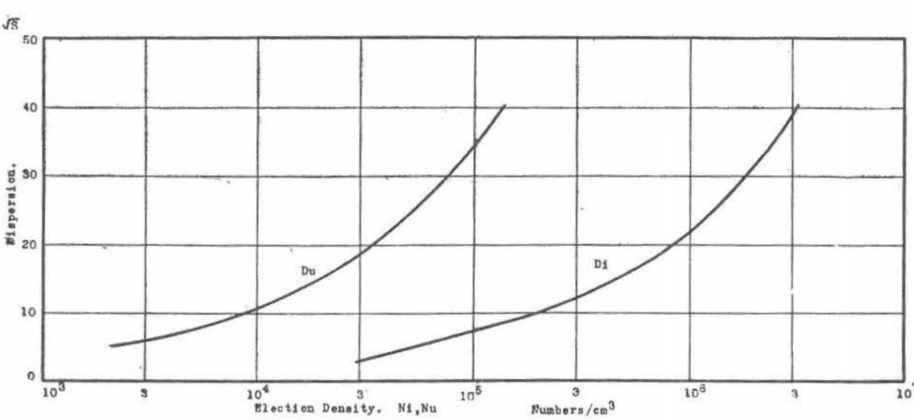


Fig. 7 Dependence of magnitude of dispersions on average electron density.
$N_i$: Dispersion caused by an average electron density $N_i$ between 100 km and 500 km.
$D_u$: Dispersion caused by an average electron density $D_u$ between 500 km and 1,263 km, the height of summit of the line of geomagnetic force starting from geomag. lat. 24°.

For the value of $N_i$, it seems reasonable to take an electron density which has some relation with the maximum electron density of $F_2$ layer, for dispersions are proportional to $f_0F_2$ as described in §3.1. Considering this point, a parabolic distribution of electron density in region I is adopted and an average electron density $N_{av}$ computed from this distribution is regarded as $N_i$ in Eq. (5). The parabolic distribution is

$$N=N_m\frac{2}{z_m}\left(z-\frac{z^2}{3z_m}\right),$$

where $z_m$ and $z$ are the heights of the point of maximum electron density $N_m$ and of any point, measured from the lower boundary of the ionosphere respectively. The average electron density $N_{av}$ in the region I is given by

$$N_{av}=\frac{1}{400}\int_0^{400}N\cdot dz=N_m\cdot\frac{400}{z_m}\left(1-\frac{400}{3z_m}\right)\cdots\cdots\cdots\cdots\cdots\cdots(6)$$

Here, the value of $z_m$ is given by $h_pF_2$ in the ionospheric data and $N_m=1.24\times10^{-8}f_0F_2$. Now, $D_i$, $D_u$ and $N_u$ may be evaluated from Eq. (4), (5) and (6), using values of dipersion, $f_0F_2$ and $h_pF_2$ observed in practice. The process is as follows; first, $D_i$ is calculated by Eq. (5) for the value of $N_i$ given by Eq. (6), then $N_u$ is obtained by Eq. (5) for the value of $D_u$ equaling to $D-D_i$. $D_i$, $D_u$ and $N_u$ obtained by the calculation are tablated with $N_i$ in Table 4, using the data of five nights of Feb. and Mar. in 1957. Though these results are not discussed here in detail, it will be generally seen that the dispersions caused in the ionosphere are comparable with those in the outer ionosphere and that the electron density varies diurnally in the outer ionosphere as in the ionosphere, but the rate of variation in the outer ionosphere is about 1/4 of that in the ionosphere.

## IV. Conclusions.

At Toyokawa, on winter nights, tweek type atmospherics have been found to satisfy the conditions of a preceding atmospherics in about 84% of the short whistlers. And such a phenomenon has been seen even in a case of multiple flash type group of short whistlers and tweeks. Consequently, we may take with a fair degree of certainty that these tweeks are really preceding atmospherics of short whistlers. The distances from Toyokawa to the short whistler sources measured by the propagation characteristics of tweeks are ranging from about 3,500 km to 5,000 km which seems to support the asymmetric propagation theory of whistlers with respect to the geomagnetic equator, but for conclusion it is necessary to analyse more tweeks and to increase the precision of measurement. Since a distance between a observatory and a short whistler source increases rapidly as the geomag. lat. of point of observation becomes heigher, the existence of the preceding atmospherics of short whistlers will be a characteristic phenomenon in lower latitudes.

A regular diurnal variation of dispersions of short whistlers observed at Toyokawa in winter will be also a characteristic phenomenon in lower latitudes for the reason that in the lower latitudes the dispersion caused in the ionosphere is comparable with that in the outer ionosphere and the electron density changes diurnally even in the outer ionosphere.

Another reason being capable of detection of these phenomena is perhaps that

Table 4 Results of calculation of $D_i$, $D_u$ and $N_u$

| Time | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 15 | 16 | 17 | 18 | 19 | 20 | 21 | 22 | 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1957 Feb. 8 | $N_i \times 10^{-5}$ | | | | | | | | | | 9.4 | 7.3 | 4.9 | | 3.2 | 2.75 | |
| | $D_i$ | | | | | | | | | | 21.2 | 18.8 | 15.5 | | 12.5 | 11.1 | |
| | $D_u$ | | | | | | | | | | 20.1 | 21.1 | 22.0 | | 17.5 | 16.4 | |
| | $N_u \times 10^{-4}$ | | | | | | | | | | 3.4 | 3.8 | 4.1 | | 2.6 | 2.3 | |
| 9 | $N_i \times 1.^{-5}$ | | | | 1.3 | | | | | 11.0 | 10.0 | 6.4 | 4.8 | 3.9 | 3.6 | 2.5 | |
| | $D_i$ | | | | 8.4 | | | | | 23.0 | 22.0 | 17.8 | 15.3 | 13.6 | 13.2 | 11.1 | |
| | $D_u$ | | | | 15.4 | | | | | 19.5 | 20.5 | 22.2 | 21.0 | 20.8 | 16.8 | 17.7 | |
| | $N_u \times 10^{-4}$ | | | | 2.05 | | | | | 3.2 | 3.6 | 4.2 | 3.8 | 3.7 | 2.5 | 2.7 | |
| 15 | $N_i \times 10^{-5}$ | | | | | | | | | 8.3 | 6.8 | | | | | 2.85 | |
| | $D_i$ | | | | | | | | | 20.0 | 17.2 | | | | | 11.8 | |
| | $D_u$ | | | | | | | | | 21.3 | 22.8 | | | | | 13.2 | |
| | $N_u \times 10^{-4}$ | | | | | | | | | 3.8 | 4.4 | | | | | 1.5 | |
| 16 | $N_i \times 10^{-5}$ | 1.4 | 1.35 | 1.2 | 1.23 | | | | | | | | | | | | |
| | $D_i$ | 8.6 | 8.5 | 8.2 | 8.2 | | | | | | | | | | | | |
| | $D_u$ | 13.9 | 14.0 | 13.1 | 13.1 | | | | | | | | | | | | |
| | $N_u \times 10^{-4}$ | 1.6 | 1.67 | 1.45 | 1.45 | | | | | | | | | | | | |
| Mar. 3 | $N_i \times 10^{-5}$ | | | | | | | | 12.1 | 12.5 | 11.5 | 9.0 | 6.8 | 5.4 | 4.2 | 3.6 | 3.7 |
| | $D_i$ | | | | | | | | 24.5 | 25.0 | 23.5 | 21.0 | 18.2 | 16.5 | 14.3 | 13.2 | 13.4 |
| | $D_u$ | | | | | | | | 16.8 | 15.0 | 14.6 | 15.3 | 15.1 | 13.3 | 12.6 | 14.3 | 13.3 |
| | $N_u \times 10^{-4}$ | | | | | | | | 2.45 | 1.92 | 1.80 | 2.02 | 1.93 | 1.50 | 1.32 | 1.72 | 1.50 |
| 4 | $N_i \times 10^{-5}$ | 2.65 | 2.9 | 3.0 | 3.1 | 1.3 | 1.1 | 1.95 | | | | | | | | | |
| | $D_i$ | 11.4 | 12.0 | 12.3 | 12.4 | 8.5 | 8.0 | 10.0 | | | | | | | | | |
| | $D_u$ | 14.4 | 14.3 | 12.7 | 11.8 | 15.5 | 17.5 | 18.4 | | | | | | | | | |
| | $N_u \times 10^{-4}$ | 1.75 | 1.72 | 1.35 | 1.15 | 2.10 | 2.61 | 3.00 | | | | | | | | | |

most of the short whistlers observed at Toyokawa have been pure tone type, which makes the measurement of dispersions easy and exact.

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