SOME CHARACTERISTICS OF THE DISPERSION OF WHISTLERS

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Abstract.

The author studied some characteristics of dispersion (D) of whistlers for 4 years since the beginning of IGY, and found that in diurnal variation D decreases in general from sunset to sunrise and increases thereafter. This tendency is observed very clearly in winter but not in summer, and it becomes ambiguous in accordance with the decrease of solar activity. At Toyokawa D is minimum in winter and maximum in summer, while at Wakkanai it is minimum in winter and summer and maximum in spring and autumn, contradictory to Helliwell's report, suggesting a geomagnetic latitude dependence. As to solar activity, D correlates with the sunspot number with time lag of 1 to 2 months. Investigating D individually, the author also found that on storm days the diurnal variation of D is exaggerated.

1. Introduction

As is generally known, the dispersion of whistlers is given by

$$D = \frac{1}{2c}\int_{path}\frac{f_p}{\sqrt{f_H}}ds$$

where

f_p = plasma frequency $= 9\sqrt{N}$ kc

f_H = electronic gyro-frequency $= 2800B$ kc

B = flux density of earth magnetic field in gauss

Therefore, if the path of propagation and gyrofrequency variation are known and a form for the electron distribution is assumed, the electron density can be determined. It should be noted that the effect of a given electron density on the time delay becomes greater as the gyrofrequency is reduced. Thus the dispersion of a whistler is most sensitive to regions near the top of the path.(9)

The investigation of characteristics of the dispersion (D) at calm and disturbed periods will be very useful to the study of geophysical phenomena such as geomagnetic storm, aurora, cosmic rays, etc. as well as to the applications to radio communications in the exosphere.

At XIIIth General Assembly of URSI at London (1960)(2) the resolution was adopted, for effective latitude coverage, to observe dispersion at every 5° or 10° in geomagnetic latitude all over the world, and our Toyokawa and Wakkanai observatories were recommended as responsible stations at 25° and 35°.

2. Diurnal variation of disersion (D)

Investigating "dispersion" observed at Toyokawa and at Wakkanai for 4 years since the beginning of IGY in July 1957, we found that the monthly average of its diurnal variation can be classified in 3 types, i.e. the summer type, the spring-autumn type and the winter type, and its characteristics vary slowly in accordance with the solar activity from 1957 to 1961 as shown in Figs. 1−4 (Toyokawa) and Figs. 5−15 (Wakkanai).

The dispersion (D) in general decreases slowly from sunset to sunrise and increases again thereafter. We can find this tendency very clearly in winter, fairly well in spring and autumn and rather poorly in winter, and in accordance with the decay of solar activity this tendency becomes ambiguous. In average, D at 18−24 in JST (9−15 UT) is larger than that at 0—6 in JST (15—21 UT), and that at 6—12 in JST (21—3 UT) is much larger.

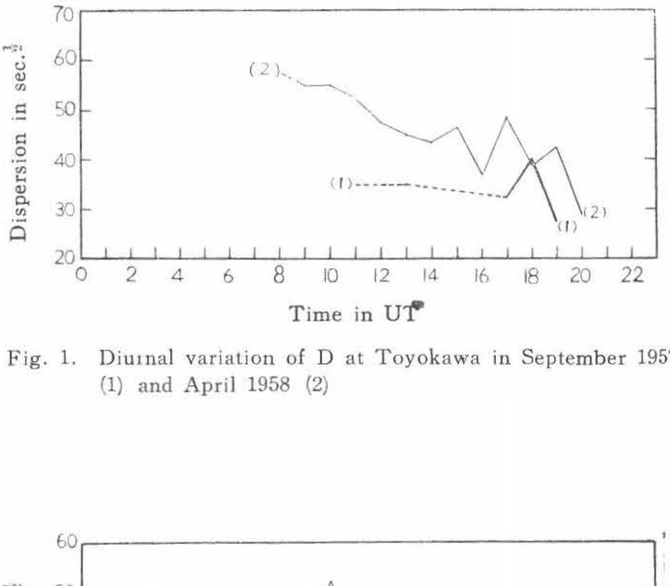

Fig. 1. Diurnal variation of D at Toyokawa in September 1957 (1) and April 1958 (2)

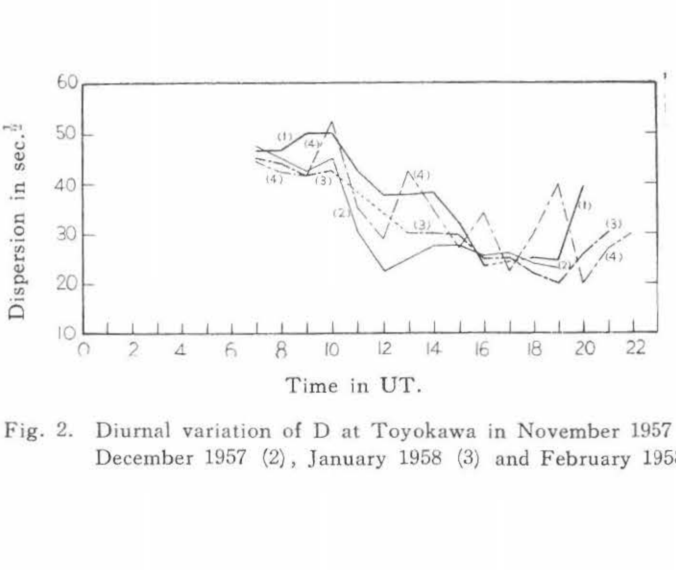

Fig. 2. Diurnal variation of D at Toyokawa in November 1957 (1), December 1957 (2), January 1958 (3) and February 1958 (4)

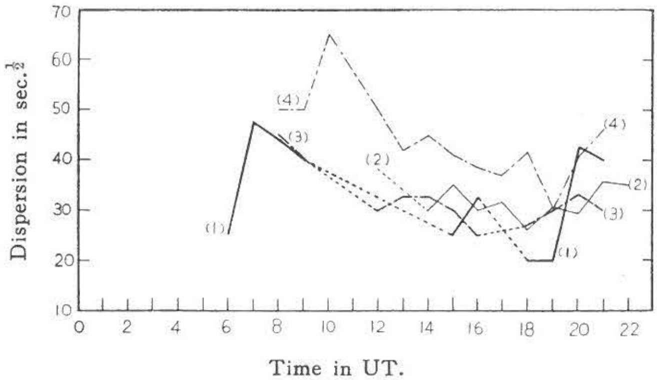

Fig. 3. Diurnal variation of D at Toyokawa in November 1958 (1), January 1959 (2), February 1959 (3) and March 1959 (4)

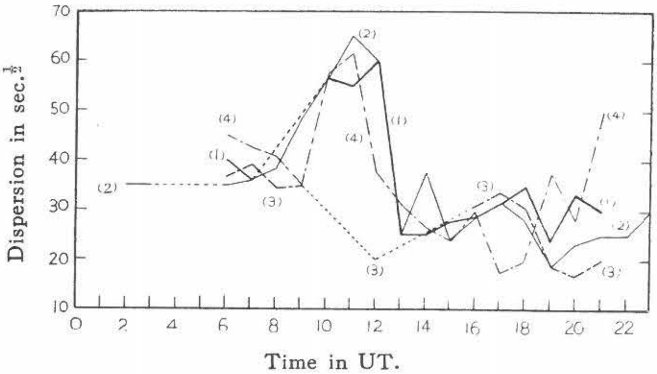

Fig. 4. Diurnal variation of D at Toyokawa in November 1959 (1), December 1959 (2), January 1960 (3) and February 1960 (4)

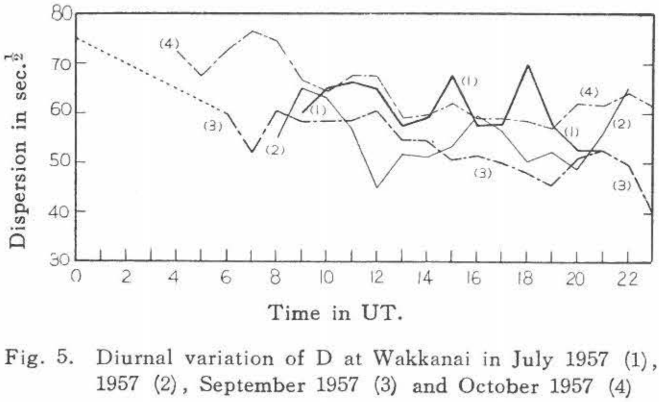

Fig. 5. Diurnal variation of D at Wakkanai in July 1957 (1), August 1957 (2), September 1957 (3) and October 1957 (4)

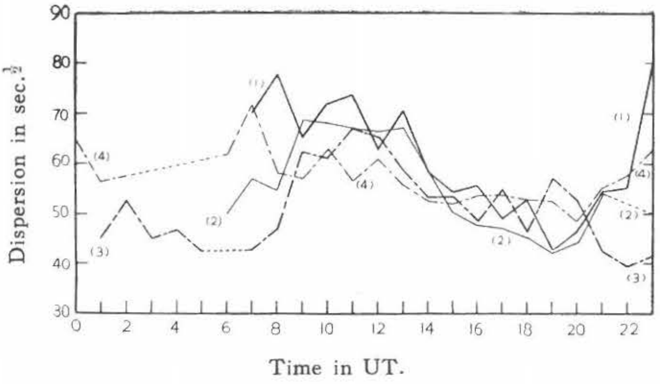

Fig. 6. Diurnal variation of D at Wakkanai in November 1957 (1), December 1957 (2), January 1958 (3) and February 1958 (4)

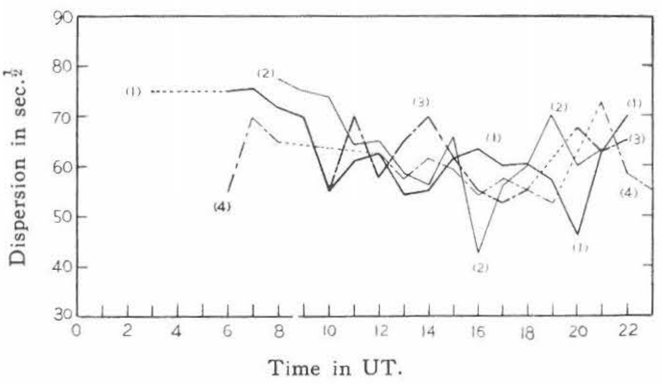

Fig. 7. Diurnal variation of D at Wakkanai in April 1958 (1), May 1958 (2), July 1958 (3) and August 1958 (4)

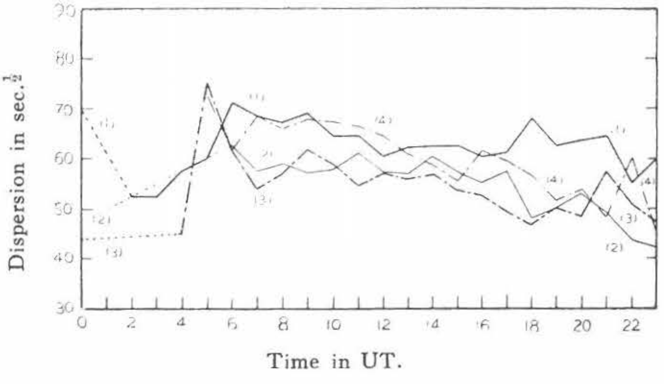

Fig. 8. Diurnal variation of D at Wakkanai in November 1958 (1), December 1958 (2), January 1959 (3) and February 1959 (4)

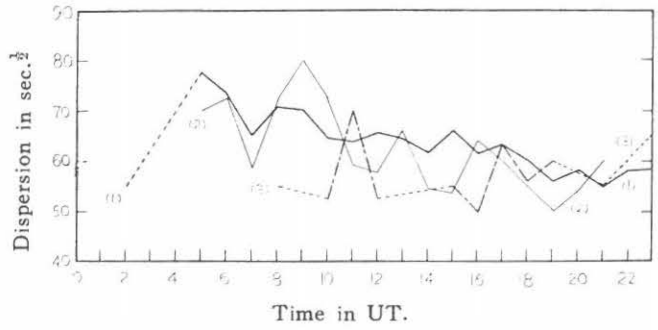

Fig. 9. Diurnal variation of D at Wakkanai in March 1959 (1), April 1959 (2) and May 1959 (3)

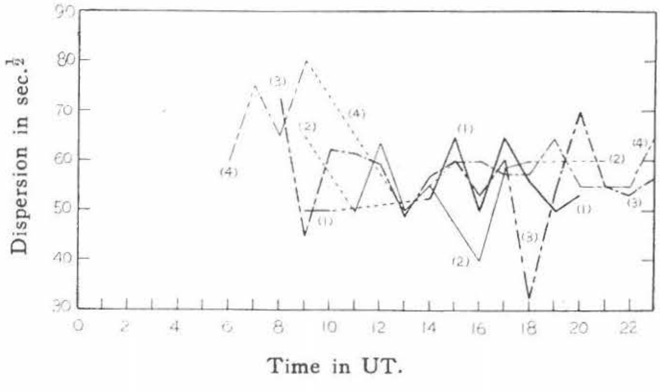

Fig. 10. Diurnal variation of D at Wakkanai in June 1959 (1), July 1959 (2), August 1959 (3) and September (4)

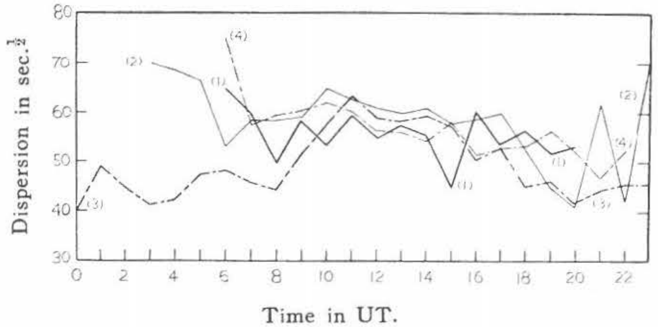

Fig. 11. Diurnal variation of D at Wakkanai in November 1959 (1), December 1959 (2), January 1960 (3) and February 1960 (4)

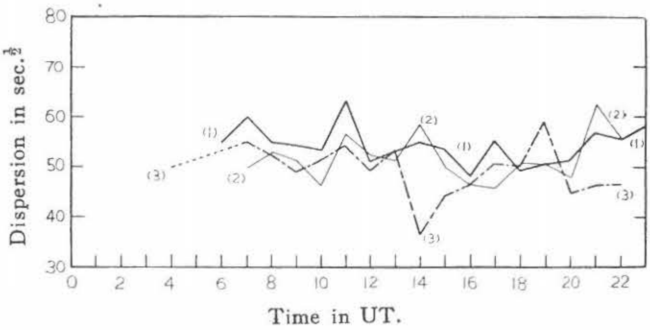

Fig. 12. Diurnal variation of D at Wakkanai in March 1960 (1), April 1960 (2) and May 1960 (3)

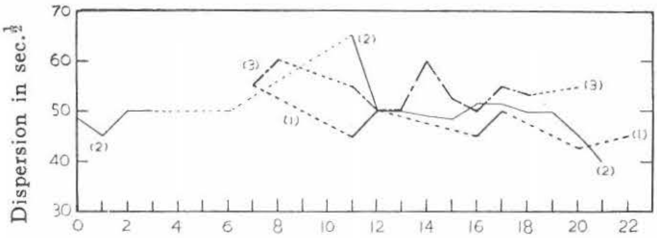

Fig. 13. Diurnal variation of D at Wakkanai in June 1960 (1), July 1960 (2) and August 1960 (3)

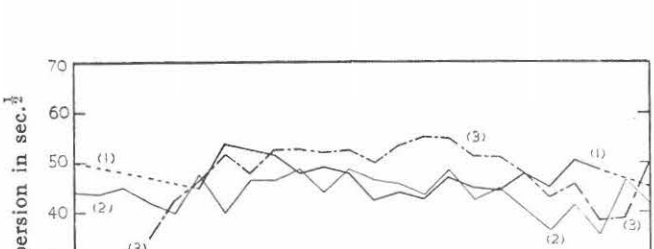

Fig. 14. Diurnal variation of D at Wakkanai in October 1960 (1), November 1960 (2), and December 1960 (3)

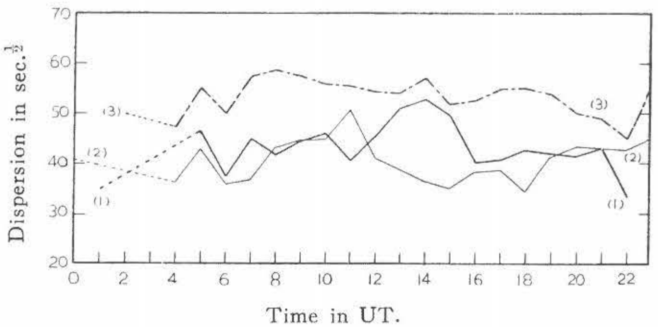

Fig. 15. Diurnal variation of D at Wakkanai in January 1961 (1), February 1961 (2) and March 1961 (3)

3. Seasonal variation of dispersion

According to Helliwell, dispersion is minimum at the June solstice and maximum at the December solstice, and shows the same variation in both hemispheres. The explanation of this remarkable circumbstance is not clear, but may be related to the eccentricity of the earth's orbit about the sun or to the seasonal asymmetry in the relation between the sun-earth line and the geomagnetic equator.[1]

In our observation at Toyokawa dispersion is minimum in winter (Nov.—Dec., sometimes from Oct. or to March) and maximum in summer (June—July, sometimes from May or to Aug. and Sep.), showing the inverse results with those of Helliwell, and at Wakkanai minimum in winter and summer and maximum in spring and autumn (Fig. 16, a. b., Fig. 17, a. b.). Therefore, it seems that the seasonal variation of dispersion depends on geomagnetic latitude; the conclusion should, however, be postponed to the future study.

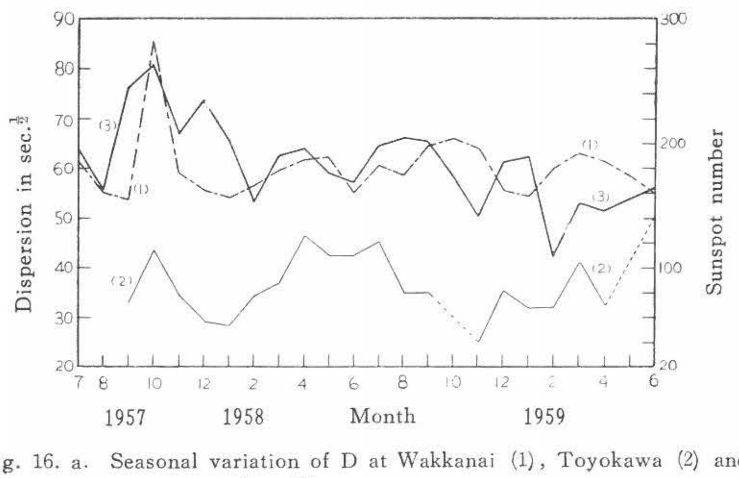

Fig. 16. a. Seasonal variation of D at Wakkanai (1), Toyokawa (2) and sunspot number (3)

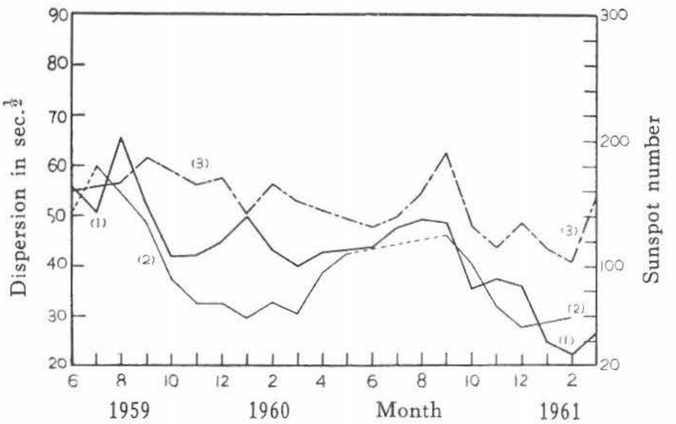

Fig. 16. b. Seasonal variation of D at Wakkanai (1), Toyokawa (2) and sunspot number (3)

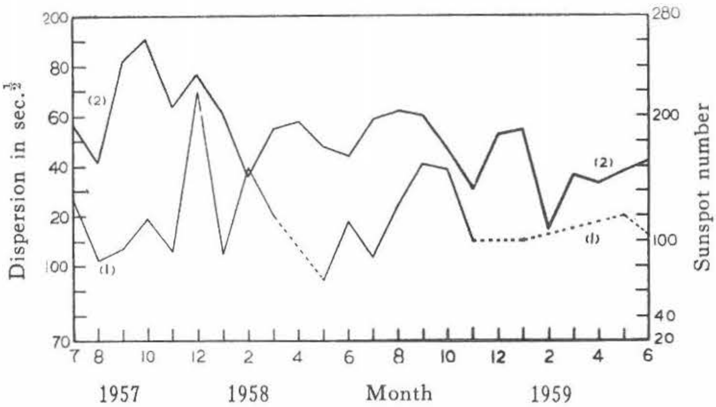

Fig. 17. a. Seasonal variation of D of long whistlers at Wakkanai (1) and sunspot number (2)

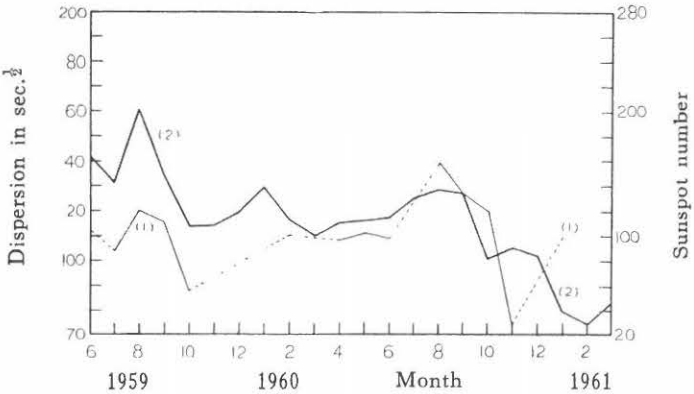

Fig. 17. b. Seasonal variation of D of long whistlers at Wakkanai (1) and sunspot number (2)

4. Geomagnetic activity and dispersion

Outsu[3] investigated statistically the correlation of dispersion with geomagnetic storms and found that the average dispersions on storm days are smaller than those on the days before and after, both in daytime and at night. We investigated in detail the characteristics of geomagnetic storms individually and compared them with the variation of dispersion, in every phase of storms. Although there are many data of storms and dispersions, rather few data are found to be observed simultaneously.

No. 1. 4 September 1957. According to data at Kakioka Geomagnetic Observatory, the storm began at 13.0 UT with SSC and the horizontal component (H) increased $+48\gamma$, at 14.4 UT it entered the main phase and at 18.0 UT the last phase. The dispersion decreased gradually from the beginning to the end. On 7 September, 3 days afterwards, the diurnal variation of D indicated a very small variation, i.e. the summer type variation (Fig. 18).

No. 2. 21 September 1957. According to Kakioka, the storm began at 10.05 UT with SSC* and H increased $+79\gamma$, at 10.5 UT it entered its main phase (K-index 7) and at 01.0 UT on 22 September its last phase. D decreased gradually, too, from beginning to the end. On 26 September, 5 days later, D indicated a very small variation, returning to the ordinary tendency in summer (Fig. 19).

No. 3. 14 February 1959. According to Kakioka, the storm began at 11.43 UT with SSC and H increased $+12\gamma/2\text{m}$. Though it is not clear when the main and the last phases began, the storm ended at 21.0 UT, and the maximum range was 99γ. D decreased suddenly at the beginning, but afterwards it indicated small variations, sometimes showing little increases. Observation of D on days near the storm are lacking, but we find that it indicates about the similar tendency with the monthly mean of February 1959 and it is characterized by a sudden decrease at the beginning (Fig. 20).

No. 4. 5 December 1959. According to Kakioka the storm began at 06.59 UT with SSC and H increased $+29\gamma$. At 10.5 UT it entered the main phase, at 17.0 UT the last

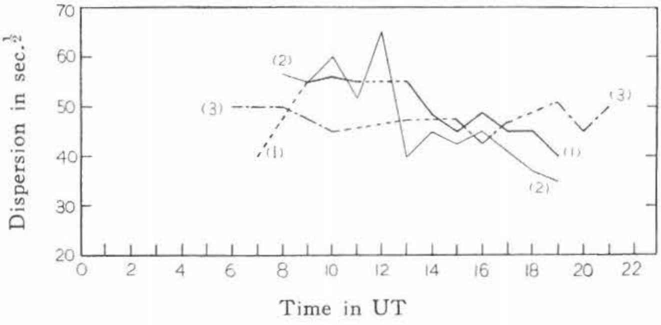

Fig. 18. Variation of D on storm day and on the days before and after: D on storm day (1) on 4th September 1957, 6th (2) and 7th (3) September 1957.

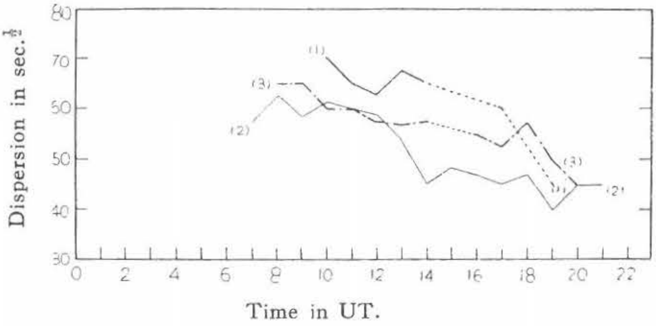

Fig. 19. Variation of D on storm day and on the days before and after: D on storm day (1) on 21th September 1957, 25th (2) and 26th (3) September 1957.

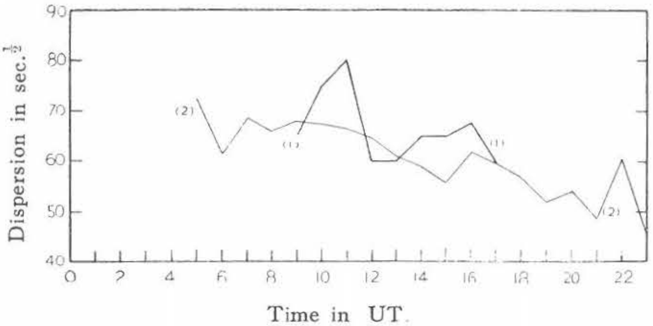

Fig. 20. Variation of D on storm day and on the days before and after: D on storm day (1) on 14th February 1959, mean variation of D in February 1959 (2)

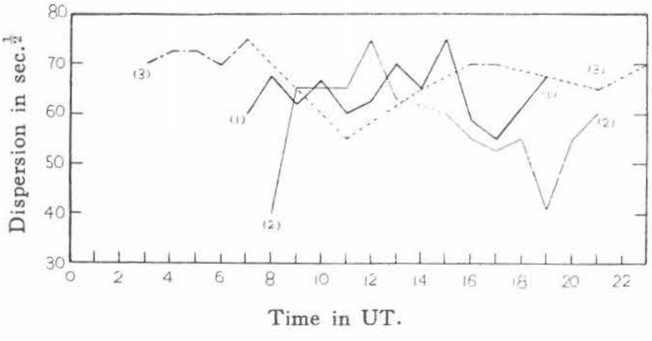

Fig. 21. Variation of D on storm day and on the days before and after: D on storm day (1) on 5th December 1959, 12th (2) and 13th (3) December 1959.

phase and at 22.0 UT ended, indicating the maximum range of 156γ. D oscillates remarkably and after the last phase it increases, showing a difference with those on calm days (Fig. 21).

No. 5. 15 November 1960. According to Kakioka, the storm began at 13.03 UT with SSC and H increased +31γ/3m. At 16.8 UT it entered the main phase and at 02.9 UT on 16 November the last phase, ending at 03.0 UT on 18 November. The maximum range of H is 225γ. D decreases at the main and the last phases respectively and indicates oscillatory characteristics as a whole. This tendency can also be seen on 14 and 16 November, latter, however, showing no oscillations (Fig. 22).

No. 6. 15 March 1960. According to Kakioka, the storm began at about 12.00 UT with Sg and it is not clear when it entered the main and the last phases, but it ended at 17.0 UT and the maximum range of H is 138γ. D decreased gradually, but it has no peculiality in comparison with the monthly mean of March 1960 (Fig. 23).

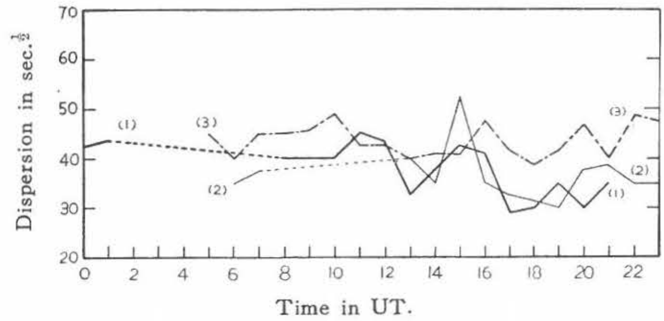

Fig. 22. Variation of D on storm day and on the days before and after: D on storm day (1) on 15th November 1960, 14th (2) and 16th (3) November 1960.

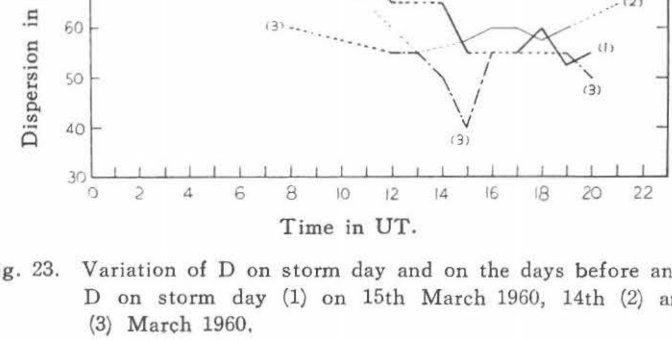

Fig. 23. Variation of D on storm day and on the days before and after: D on storm day (1) on 15th March 1960, 14th (2) and 16th (3) March 1960.

These examples show that, when a storm begins with SSC or SSC*, the tendency of D to decrease from sunset to sunrise is exaggerated during the storm in comparison with calm days around storm days. It seems that there is some correlation between a geomagnetic storm and the decrease of D observed at lower geomagnetic latitude, and accordingly the variation of H in the exosphere, but it is not yet conclusive.

5. Solar activity and dispersion

Allcock, Morgan(6) and Kimpara(4)(5) investigated independently the dispersion in detail and found that the dispersion correlates with the sunspot number with a time-lag of one to 2 months. Here I examined again the dispersion for 4 years from the beginning of IGY and found that the correlation of dispersion with the sunspot number indicates also about the same tendency as shown in the following table — the correlation coefficient is +63.0% for dispersion one month later.

D	Correlation coefficient of D with sunspot number
Same month	55.5 %
1 month later	63.0 %
2 months later	52.0 %

6. Conclusion

Since the beginning of IGY 1957 we have observed whistlers for 4 years and obtained many data on the dispersion of whistlers, which is considered to be very useful to the study of geophysics and to the application to communications in the exosphere. We studied, first of all, the diurnal and the seasonal variations of dispersion and found that the dispersion decreases, in general, gradually from sunset to sunrise and increases again thereafter. This tendency is very definite in winter and not so very in summer, while in spring and autumn it lies between the tendensies in summer and winter.

As to the seasonal variation we have found that at Toyokawa the dispersion is minimum in winter and maximum in summer contradictory to Helliwell's report, while at Wakkanai it is minimum in winter and summer and maximum in spring and autumn. This tendency suggests us the existence of geomagnetic latitude dependence.

We have long had deep interests in the correlation of geomagnetic activity with whistlers, especially with dispersion, and have reported on it elsewhere.(4)(5)(7)(8) This time we studied whistlers not statistically but individually in detail and found that, when a storm begins with SSC or SSC*, the tendency of D to decrease from sunset to sunrise is exaggerated during the storm when compared with calm days around storm days.

The correlation of solar activity with dispersion about which we reported[4][5] recently was confirmed by the 4 years' data of IGY, i. e. the dispersion correlates with the sunspot number with a time lag of one to 2 months.

7. Acknowledgements

The work described above was carried out as part of the Japanese IGY and IGC programme in the Research Institute of Atmospherics, Nagoya University. I wish gratefully to acknowledge incessant encouragements and advices by Dr. M. Shibusawa, ex-President, Dr. S. Matsusaka, President, Dr. Hasegawa and Dr. Hagihara. I should like also to acknowledge the assistance of my colleagues, Messrs. Iwai and Outsu, in discussion and observation. Finally I appreciate very much the faithful assistance of Miss Yabuta in preparation of this paper.

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