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PRELIMINARY STUDIES ON THE WHISTLER OBSERVATION AT GREAT WALL STATION OF CHINA, ANTARCTICA

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Abstract: During the First Chinese National Antarctic Research Expedition 1984/85, observation on whistler and VLF emission was carried out by using GM type VLF broadband direction-finding receiver. The morphology of whistlers received shows two peaks of their activity at 17–20 LT around sunset and at 03–06 LT of the early morning. Whistler dispersion is greater during sunset and less after midnight.

Detailed analysis of whistler data of Januray 23 and 26 at Great Wall Station reveals that the dispersions of whistlers propagating in different shells markedly decrease on the day of geomagnetic storm commencement (January 23). It implies a rapid depletion of the electron density in the shells. There is a downward flux of electron of 1×10^9 el/cm^2 s. A steady refilling process occurs in shells of $L\sim$ 2.8–2.9 three days after the storm on January 26.

Whistler direction-finding data obtained on January 20 show that the exit points of the whistlers are situated in a strip of about 80 km wide in longitudes whith an azimuthal direction 20°–40°E of N between 48°–52° geomagnetic latitude, and there are no obvious cross L or longitudinal drifts. Whistler data at Great Wall Station are very useful for deducing temporal and spatial variations of electron density in $L\sim$ 2–3 shells and investigating particle interchange processes between the ionosphere and the plasmasphere.

1. Introduction

From the standpoint of spacial geographic and geomagnetic location and aeronomic environment the Antarctica is the most ideal region to receive and investigate whistlers and VLF emission. Since 1950's a lot of whistler data obtained from Antarctic stations such as Siple, Byrd, Eights, Halley Bay, etc., have made outstanding contributions to the study of space physics (HELLIWELL *et al.*, 1956; CARPENTER, 1963).

By means of whistlers and VLF waves observed in Antarctica to diagnose the wide region of the plasmasphere and the magnetosphere, many phenomena had been discovered which were proved later by *in situ* measurements by satellites.

PARK (1974) deduced some characteristics of plasma distribution in the plasmasphere by using Antarctic whistlers data. He studied the processes of the electron density depletion of the plasmasphere during magnetospheric substorms and found the frequent interchange of ionization between the ionosphere and the inner plasmasphere.

SAGREDO and BULLOUGH (1973) used the goniometer technique for a detailed study of the magnetospheric structure associated with the whistler ducts near Halley Bay. LESTER and SMITH (1980) investigated the evolution of whistler duct structure; CARPEN-

TER (1979) made similar observations in Palmer Station, too.

During the First Chinese National Antarctic Expedition, the observations of whistler and VLF emission were carried out by using our GM type VLF broadband direction-finding receiver from January 17 to February 22, 1985. The data were automatically recorded two minutes per hour from 20th and 50th min. The observation site was in an open field to the south of Great Wall Station (geographic coordinates 62°13′S, 58°57′W; geomagnetic latitude 50°36′, $L=2.5$).

This paper presents preliminary results of the whistler observation at Great Wall Station. Section 2 of this paper shows the morphology on the observed whistler activity. In Section 3 whistler data during a magnetic storm are analyzed in detail. Exit points of whistlers and duct structure are studied in Section 4 by using direction-finding data. In Section 5 some preliminary conclusions are summarized.

2. Characteristics of Whistler Activity

Because the thunder storm activity is very high in the lower latitude area of the northern hemisphere in the same longitude region as that of western Antarctica, a lot of whistler have been received in Great Wall Station even in Austral summer. Observations are automatically done with the aid of a time-controller. Two mutually perpendicular aerials (NS and EW) are triangle-shaped and have twin-turn loops of 350 m^2 area. The antenna is 14 m high, and is linked by cable to a work tent which is 30 m apart. Received whistler signals are registered by a recorder using FeCo tape. The range of bandwidth is from 500 Hz to 16 kHz. Whistler data are analyzed later by using Kay Electric Sonagraph.

The analysis of data of 32 days from Januray 19 to February 20 showed that most of whistlers were one-hop whistler and hybrid whistler. Because the conjugated point of King George Island is in the ocean off northeast America, a region of more thunder activity, location of whistler sources is estimated to be there. A part of lightning energy propagates directly to Antarctica along geomagnetic field line to form one-hop short whistler, but another part of its energy propagates first to the southern hemisphere in the earth-ionosphere guide and then enters into a whistler duct through the ionosphere and propagates to the northern hemisphere and returns again to the southern hemisphere, forming a hybrid whistler. One of the main features of the observation is that a lot of hybrid whistler were received. Their dispersion is about two times of the preceding short-whistler. At the same time, whistlers of many other types were also received, *e.g.* multipath-whistler, multiflash-whistler, diffused whistler, VLF emission associated with whistler, etc. Upper cut-off frequency of some whistlers was higher and often spread to 16 kHz. There were some whistlers with lower cut-off frequency of 1 kHz. Tweak activity was not rich (see Fig. 1).

The whistler activity level was not very high. Occurrence rate was 2 per minute on average, with two peaks a day at 17–20 LT around sunset and at 03–06 LT of the early morning. This fact coincides with the observation results at other middle-low latitude stations. It is worth noting that the whistler propagation condition becomes better during sunset hours. It remains to be discussed whether or not sunset whistlers are related with duskside bulge of the plasmasphere.

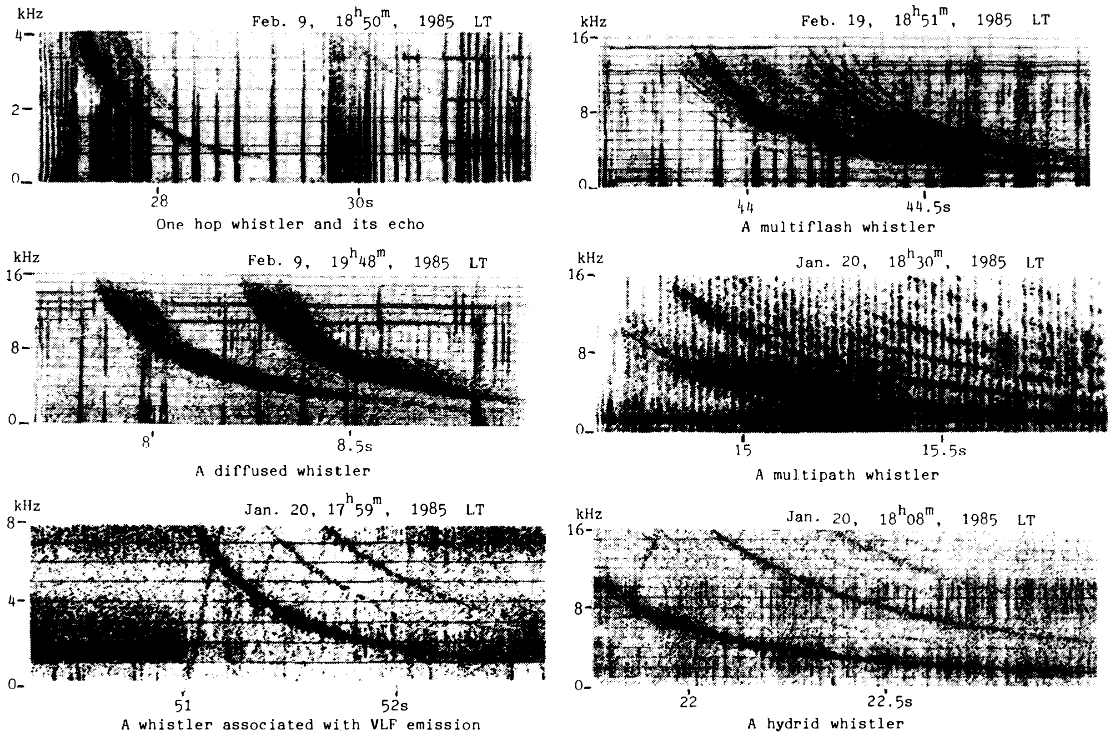

Fig. 1. Various types of spectrograms of whistlers received at Great Wall Station of China, Antarctica.

At Great Wall Station the mean dispersion of whistlers was 65 $s^{1/2}$, but greater during sunset and less after midnight. Day to Day variability of occurrence and dispersion was notable.

Except for the polar regions (where whistler activity is negatively correlated with geomagnetic activity), the whistler activity is almost enhanced with increasing *Kp* index and becomes highest a few days after storm commencement. After examinating whistler data of Wellington (φ_m=47°S) and Laude (φ_m=52°S), Andrews (1975) found that whistler activity has a delay effect when geomagnetic storm is not strong enough; this effect is associated with the formation mechanism of whistler duct.

At Great Wall Station whistler activity reached maximum 1–3 days after geomagnetic disturbance and at the same time whistler dispersion tend to decrease (10–20 $s^{1/2}$).

3. Electron Density Variation of L=2–3 Shells During Storm

Whistler observation (Park, 1970, 1973) shows that the plasmasphere often shrinks or expands several earth radii responding to geomagnet activity. Especially, during magnetic storms electron interchange between the ionosphere and the plasmasphere becomes more frequent. Besides the interchange between day and night the electron density in the plasmasphere is depleted rapidly due to effects of the magnetospheric electric field. After storm activity the plasmasphere is replenished by an upward flux from the underlying ionosphere. This recovery process will take a period of many days. But there are yet many unclarified questions, *e.g.* how the plasmasphere is depleted? How much plasma is 'lost' from the plasmasphere during storm? etc.

The space of $L=2$–3 shells is a very important region for electron interchange between the plasmasphere and the ionosphere. Whistler recorded at Great Wall Station has been used to monitor the electron density variation in the plasmasphere during storm activity.

3.1. Method of observation

A detailed analysis has been carried out with the whistler data of January 23 and subsequent January 26 at Great Wall Station. January 23 was a geomagnetic disturbed day with $\Sigma\ Kp=35_{-}$; a moderate storm with sudden commencement occurred at 0808 universal time. For Great Wall Station UT=LT+4 h, that is, the storm started at 04 LT, with maximum $Kp=6_{-}$ and ended at 20 LT. January 26 was a geomagnetic quiet day. There were more whistler activity at 16–21 LT of the afternoon. It may be found that whistler dispersions show a trend to decrease during storm and to increase after storm, after comparing the variation in geomagnetic activity Kp index with that of mean dispersion of whistlers during the period of observation.

Since propagating paths of observed whistler are almost below $L=3$ shell even for some whistlers with a higher upper cut-off frequency, it is not yet evident whether the nose frequency appears on frequency-time spectrograms. It is necessary to use a method of nose extension. There are many nose extension methods applied to the whistler data in middle latitudes. Here we used TARCSAI's method (1975). The model adopted is a diffusive equilibrium model. The critical parameters, whistler dispersion D, nose frequency f_n, nose delay t_n, the equatorial radius of whistler path L, electron tube content N_T and electron density in equator n_0 were calculated by using this method. The earth's magnetic field was approximated by a dipole field. Here N_T is defined as the total number of electrons in a tube of magnetic flux having 1 cm^2 cross-section at 1000 km altitude and extending to the magnetic equator. Meanwhile it was assumed that the effects of electron moving across field lines above 1000 km are small compared with effects of diffusion along the field lines and hence the time rate of change of tube content is interpreted in term of flux along the field lines across the 1000 km level. L values deduced by using the above method show errors less than 5%. Whistler data of January 23 and 26, 1985 have been analyzed.

3.2. Electron depletion processes during the storm of January 23, 1985

A moderate magnetic storm commenced at 0408 LT of January 23. Then whistler dispersion showed a trend to decrease on the whole. Two groups (A and B) of whistler appeared firstly at 0150. Dispersion of A group whistler was about 80 s$^{1/2}$. In the noon the third (C) group whistler with 63 s$^{1/2}$ was getting strong. Dispersion of A group whistler had decreased to 72 s$^{1/2}$ and B group with 35 s$^{1/2}$ in the afternoon. Analysis indicated that the three groups of whistler ducts remained basically on the same magnetic shells of $L=2$, 2.4 and 3 respectively during the period of observation. In this case we can investigate the electron density variation in every shell in the light of whistler dispersion variations. It may be said that there is a depleting process of electron density in $L=2$–3 during storm. Especially during 1650–2150, the variation was very obvious.

Since whistler dispersion is a reliable indicator of the total electron content in the flux tube along which the whistler travels, a study of the variation of dispersion during geomagnetic storm gives us an insight into the change of electron density in the plasmasphere.

From the variation rates of electron tube content N_T and equatorial electron density n_e in different ducts it was found that downward velocity fluxes in different time and shells were not the same. The average value between $L=2$ and 3 was 1.0×10^9 el/cm^2 s. That is, electrons will pass with this velocity through the section at 1000 km height towards the underlying ionosphere.

3.3. Recovery process after storm on January 26

The whistler characteristics on a geomagnetic quiet day of January 26 is quite different from the complicated depletion process during the storm on January 23. After undergoing the depletion stages, the compressed plasmasphere started to recover, *i.e.*, electrons were refilled upward into the plasmasphere along magnetic field line from the underlying ionosphere. In the afternoon there was a strong whistler activity. Analysis shows that propagating paths of the whistlers are between $L=2.8$ and 2.9, and it remained basically at the same place during the period of monitoring. But the dispersion of whistlers had a trend to increase. From the variation of N_T and n_e with time during this period, it may be stated that a steady increase of N_T in $L=2.8$ reflects the recovery process of the plasmasphere. Since N_T increased 1×10^{13} el in 5 hours, the upward flux velocity is 5×10^8 el/cm^2 s. The recovering process occurred 3 days after storm. Electron flowed upward from the ionosphere into the plasmasphere by the effects of the diffusive barrier. The transmission events were confirmed by whistler observation results.

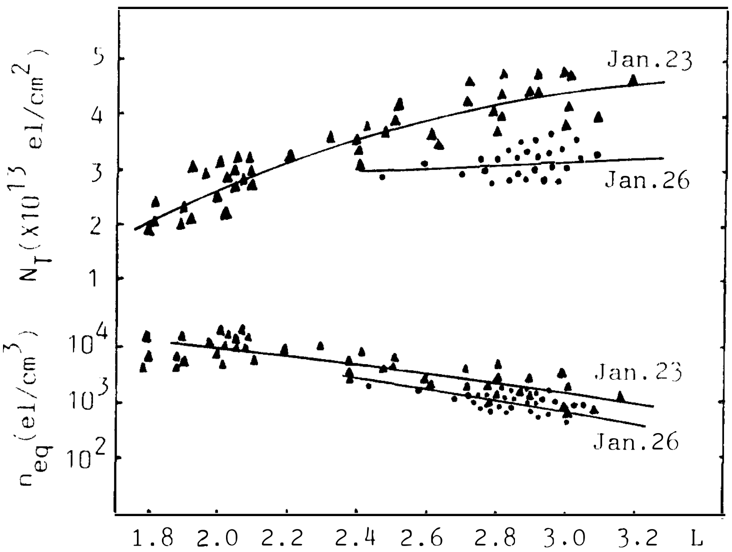

Fig. 2. Plot of electron tube content N_T and equatorial electron density n_e versus L on January 23 and 26, 1985.

Figure 2 shows the tube content N_T and equatorial electron density n_e versus L deduced from whistlers received on January 23 and 26, 1985. The solid curve represents their profile. It reveals the state of the plasmasphere during and after storm.

The wider distribution of data points reflects the variation of electron density with time in different L shells.

4. Results from Direction-Finding Whistler Data of January 20

The GM type direction finder at Great Wall Station can provide information on the bearing of signals arriving from the intersection points of the downcoming whistler paths with the lower ionosphere. The position of such an exit point can be determined by combining the arrival bearing information with the L value estimated from the dispersion characteristics.

On January 20, a geomagnetic quiet day, there was a high whistler activity in Great Wall Station and valuable data was obtained. It enables us to study in detail the plasmasphere structure associated with the whistler ducts by using direction-finding data.

4.1. Method of observation

The bearings of exit points of the local whistlers were continually monitored by a GM type whistler direction-finding receiver from 1720 to 1850. Arrival azimuths for each duct were averaged to reduce the random errors. We calculate the L value of the duct from a nose-extending method and assume that this is equal to the L value of the exit point of the whistler signal into the earth-ionosphere wave guide at approximately 100 km altitude. This means that the whistler continues to propagate along the magnetic field direction through the ionosphere between the bottom of the duct and the top of the wave guide region.

The signals induced in two loops are modulated by a signal of 25 Hz from an oscillator in the receiver. The modulation of the signal amplitude is used to determine the azimuth of the source. In each calibration interval two maxima and two minima are measured in the modulation envelope for each whistler signal. Then a weighted mean bearing is obtained. The deviation in the azimuth is usually in $\pm 10^\circ$–20°. The ambiguity of 180° in the azimuth may be resolved from the calculated invariant latitude of the exit point.

Since the frequency range of the sonagram we used is limited to 0–16 kHz, some whistler trace may have spread to higher frequencies. While a sonagram with a narrow bandwidth was used for determining the whistler nose-effecting and dispersion, the wide bandwidth has the temporal resolution necessary for the bearing determination. A lot of best-defined whistler traces were used to raise the precision of f_n. The error of f_n may be only within 5% and the invariant latitude of whistler exit point $\varphi = \cos^{-1} L^{-1/2}$ is also determined with a small error, normally within $\pm 0.5^\circ$.

4.2. Results of observation

A very strong whistler activity started at 0820 LT of the morning and reached the peak at 1730 LT of the evening. The occurrence of whistlers was 20 per min. Most of them were local whistlers and hybrid whistlers. Local whistlers had a lower cut-off frequency about 1 kHz, and the mean dispersion was 77 $s^{1/2}$. After a detailed analysis it was found that these local whistlers consisted of many very close multipath

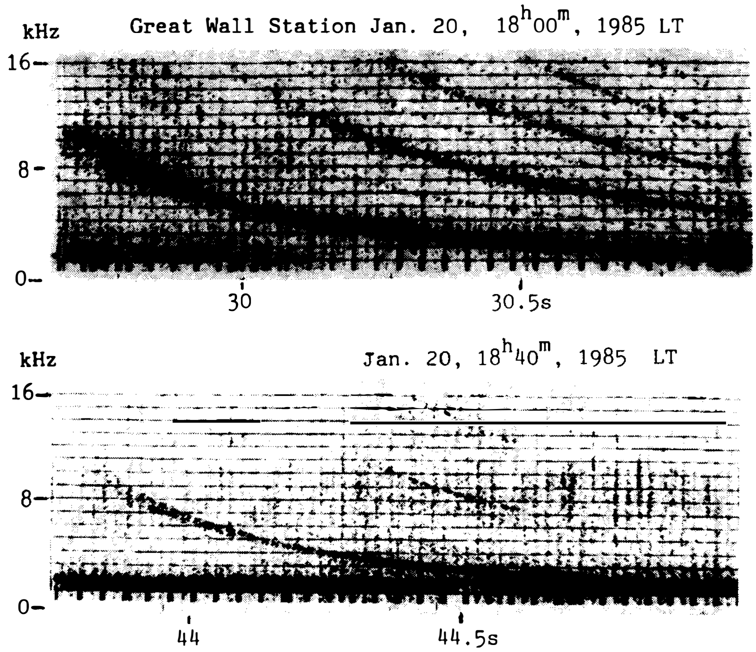

Fig. 3. Spectrograms showing a typical local whistler observed 1730–2020 on January 20, 1985.

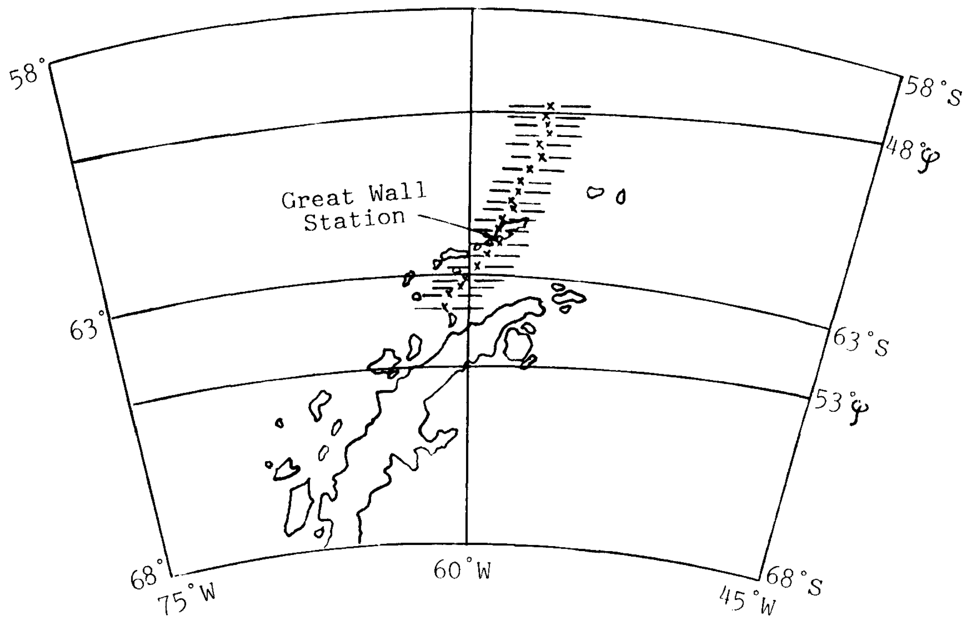

Fig. 4. Map showing the location of the whistler exit points with r.m.s. deviation.

whistlers. A multi-component whistlers cluster with a main duct was formed at 1800 LT (see Fig. 3).

The continuous observation from 1720 to 1850 showed that the whistler exit points were situated in a strip of about 80 km wide in longitudes with an azimuthal direction 20°–40°E of N between 48°–52° geomagnetic latitude (see Fig. 4).

The mean value of N_T on this day was 25% greater than on other days, indicating an enhancement of electron density in duct along magnetic field lines in comparison with the background electron density. This may be resulted from a full recovery of electron density in the plasmasphere during a long period of geomagnetic quietness (about 10 days).

The whistler dispersion in the cluster changed from 68 $s^{1/2}$ to 78 $s^{1/2}$, whereas the tube electron content N_T changed from 4.7 to 5.4×10^{13} el/cm^2 with deviation from -6 to $+8\%$ from the mean value of 5×10^{13} el/cm^2. The locations of the whistler exit points were basically the same, with a slight difference within 0.2 L in the L value.

Our observation indicated that the ducts were all in the same strip regions and there was no strong cross L or longitudinal drifts. Therefore it is concluded that the observed change in whistler characteristics on a geomagnetic quiet day is attributable to a process of the duct formation, its growth, evolution into cluster and decay rather than to the drifting of ducts into the "viewing window" of the station.

The appropriateness of a single duct shows that the lifetime of the duct is not less than 12 h. The dimensions of the duct in cluster have the order of 30–40 km in latitude direction.

5. Some Preliminary Conclusion

Through an analysis of one month whistler data we obtained some preliminary conclusions as follows.

(1) Most of whistlers received at Great Wall Station in summer are one hop whistlers. There are two peaks of whistler activity each day, one is around sunset, another in the early morning.

(2) Mean dispersion of whistlers is greater during sunset and less after midnight. Whistler activity usually reaches maximum 1–3 days after geomagnetic storm and whistler dispersions show a trend to decrease during this interval.

(3) It has been found that the plasmasphere will show an electron depletion phenomenon during magnetic storm. There is a downward flux with its velocity of the order of 10^9 el/cm^2 s in $L=2$–3 shells.

(4) A recovery process in the plasmasphere appears 3 days after magnetic storm. Electrons move upward to refill the plasmasphere from the underlying ionosphere with a flux of the order of 5×10^8 el/cm^2 s.

(5) Direction finding observations show that the exit points of whistler are all in the same strip region on a geomagnetic quiet day, without any obvious drift of the locations. Duct lifetimes are the order of 10 h. Existence of tube with a greater electron content reflects the plasmaspheric condition when the quiet period lasts for a long time.

It can be seen that the whistler data at Great Wall Station are very useful for deducing temporal and spatial variation of electron density in $L=2$–3 shells and investigating particle interchange processes between the ionosphere and the plasmasphere. But because of a limit number of data the results described in this paper are only preliminary. Further studies are required.

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