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INITIAL RESULTS OF IMAGING RIOMETER OBSERVATIONS AT POLAR CAP CONJUGATE STATIONS

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Abstract: Geomagnetically conjugate observations using a newly installed imaging riometer at Zhongshan (74.7°S geomag. lat.), Antarctica and the existing imaging riometers at Ny-Ålesund/Longyearbyen (~76°N, geomag. lat.), Svalbard, started in January 1997 for studying conjugate characteristics of cosmic radio noise absorption (CNA) in the high-latitude ionosphere. Examples of nighttime ionospheric absorptions observed at the conjugate stations are presented for strong and weak geomagnetic disturbances in the polar region. Conjugate characteristics of total 30 nighttime absorption events during initial two-week observations are investigated in relation to the ground geomagnetic activities, and also discussed about the effect of the interplanetary magnetic field (IMF), in comparison with the conjugate points calculated by Tsyganenko-96 magnetic field model. The following characteristics are described: (1) Simultaneous absorptions are observed between the conjugate stations more preferentially on the strong geomagnetic disturbances. (2) The shape and movement of small-scale absorption (50–100 km) are considerably different, even if large-scale absorption (>100 km) shows a similar aspect between the conjugate stations. (3) On weak geomagnetic disturbances, absorptions are mostly observed at a station in one hemisphere only; they may be conjugate or non-conjugate.

1. Introduction

Geomagnetically conjugate observations between the northern and southern high-latitude regions have been carried out for checking symmetry or asymmetry of the Earth's magnetosphere. Conjugate optical observations of auroral phenomena were initiated during the IGY period (*e.g.*, DEWITT, 1962; WESCOTT, 1966), and were followed by the experiment using the aircraft by University of Alaska (BELON *et al.*, 1969; STENBAEK-NIELSEN and DAVIS, 1972; STENBAEK-NIELSEN *et al.*, 1973). The National Institute of Polar Research (NIPR) in Japan started Syowa (Antarctica)-Iceland conjugate observations during the IMS period, and SATO and SAEMUNDSSON (1987) reported that auroral breakups occurred almost simultaneously in the northern and southern hemispheres, and east-west aligned auroral arcs appeared at almost the same geomagnetically conjugate latitude with the IGRF model. For conjugate optical observations, however, it is an inevitable problem that a possible observation period is very short in a year when dark sky appears simultaneously in the both hemispheres, resulting in case studies only during equinoxes.

Cosmic radio noise absorption (CNA) in the polar ionosphere occurs mainly in the *D*- or lower *E*-region where electron density is enhanced by precipitating energetic electrons with several to several tens of keV energies from the magnetosphere, associated with auroral disturbances. CNA is usually measured by a riometer (Relative Ionospheric Opacity Meter) radio wave receiver in a frequency range of 20–50 MHz. The radio wave measurement has an excellent merit which enables us to carry out observations at all the time. In earlier years, conjugate riometer observations were carried out at Longyearbyen (74.4° N geomag. lat.) in Spitzbergen and Mirny (77.0° S geomag. lat.) in Antarctica by using the conventional type of 30 MHz broad-beam riometers for studying symmetric and asymmetric configurations of the magnetosphere between sunlit and dark ionosphere conditions (ERICKSEN *et al*., 1964). It was found that some CNA events appeared at both northern and southern hemisphere stations, but others appeared in one hemisphere station only. The conjugate riometer observations at Frobisher Bay ($L=15.0$), Canada and South Pole ($L=13.3$) demonstrated that the conjugate CNA events showed a tendency of greater intensities in local winter with some significant differences in their maximum times (HARGREAVES and CHIVERS, 1965). From the conjugate riometer observations at Frobisher Bay ($L=15.0$) and South Pole ($L=13.3$), ROSENBERG (1987) found that the ionospheric absorption and intense electrojet current in the dusk ionosphere occurred preferentially in one hemisphere. He suggested that this was a piece of evidence for non-conjugate electron precipitation or for a severe distortion of the magnetic field-line topology in the nighttime sector.

The recent development of the imaging riometer for ionospheric study (IRIS) (*e.g*., DETRICK and ROSENBERG, 1990) has enabled us to discover new interesting observations for complex dynamics of ionospheric absorptions in the auroral and polar-cap regions (STAUNING, 1996a). The imaging riometer is a powerful tool to measure spatial-scale, shape and movement of absorption features as well as all-sky measurements of auroras. At present, as far as we know, eight imaging riometers with two-dimensional 49 or 64 narrow-beams are operated in the arctic region, and five imaging riometers with the similar type are operated in Antarctica. Among them, a pair of the imaging riometers at Tjornes ($L=6.5$), Iceland and Syowa ($L=6.2$), Antarctica has a conjugate relation in the auroral region. From the conjugate absorption observations, YAMAGISHI *et al*. (1998) demonstrated that the conjugate point of Syowa mapped to the northern hemisphere was located at the lower-latitude side of Tjornes by several tens of km, in accordance with the model conjugate points calculated by Tsyganenko-1987 magnetic field model for quiet condition ($Kp=0$). In the higher latitude, a pair of the imaging riometers at Iqualuit ($L=12.2$), Canada and South Pole ($L=13.3$) has a geomagnetically conjugate relation along the America-Canada meridian, but, as far as we know, conjugate characteristics of absorption events have not been presented.

An imaging riometer was recently installed at Chinese Antarctic station (Zhongshan) in January 1997 by NIPR and collaborating scientists. This installation is intended to study conjugate characteristics of dynamic behaviors of ionospheric absorptions caused by auroral particle precipitations in the higher latitude, in combination with the existing two imaging riometers (Ny-Ålesund and Longyearbyen in Svalbard) in the European arctic region. In this paper, we first demonstrate the calculation of geomagnetically conjugate points of Zhongshan mapped to the northern hemisphere, according

Table 1. Geographic and corrected geomagnetic coordinates, approximate local times of magnetic midnight and intensities of the magnetic fields at Ny-Ålesund, Longyearbyen and Zhongshan with T-96 IGRF model.

Stations	Geographic		Corrected geomag.		MLT in midnight	T-96 IGRF magnetic fields
	Lat.	Long.	Lat.	Long.		
Ny-Ålesund (NYA)	78.92	11.92	76.08	112.42	2047 UT	53484 nT
Longyearbyen (LYB)	78.20	15.80	75.13	113.15	2043 UT	53406 nT
Zhongshan (ZHS)	−69.37	76.38	−74.52	96.00	2215 UT	51006 nT

to Tsyganenko-1996 magnetic field model (T-96) (TSYGANENKO and STERN, 1996). Next, from initial IRIS data during about two weeks in January-February 1997, we show two examples of nighttime absorption events observed at the conjugate stations on severe and weak geomagnetic disturbances. Furthermore we present a brief statistical relationship between conjugate characteristics of the absorption events and ground geomagnetic activities, and discuss about a possible effect of the interplanetary magnetic field (IMF) on the conjugate characteristics.

Table 1 shows geographic coordinates of Ny-Ålesund (NYA), Longyearbyen (LYB) and Zhongshan (ZHS) stations, and their corrected geomagnetic coordinates, approximate local times of magnetic midnight and total magnetic fields, according to the T-96 model (TSYGANENKO and STERN, 1996).

2. Imaging Riometer Installed at Zhongshan

Technical detail of the imaging riometer system (IRIS) was already described in other reports (*e.g.* DETRICK and ROSENBERG, 1990; YAMAGISHI *et al.*, 1992). Here we

Fig. 1. A picture showing a part of two-dimensional phased-array antenna composed of 8 by 8 half-wavelength dipoles, the imaging riometer, installed at Zhongshan station in January 1997.

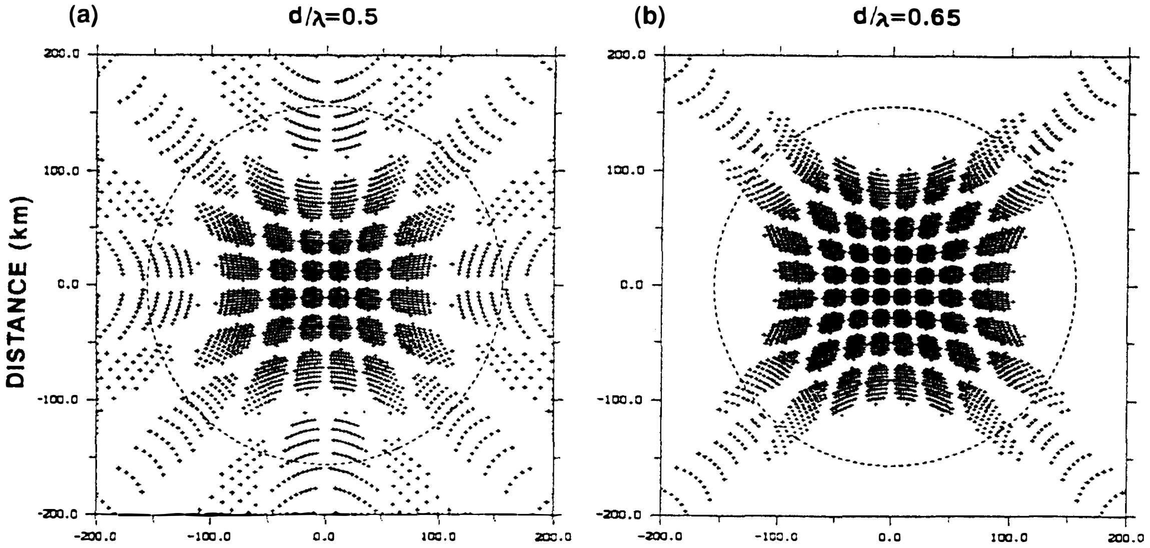

Fig. 2. Projection of 64 antenna-beams produced from 8 by 8 half-wavelength dipoles to the ionospheric absorption altitude of 90 km. The patterns are shown for the half-wavelength spacing (a) and 0.65-wavelength (b) between the individual dipoles (after Yamagishi *et al., 1992).*

present a brief description about the performance of the IRIS installed at Zhongshan station, Antarctica.

Figure 1 is a picture showing a part of two-dimensional phased array antenna composed of 8 by 8 half-wavelength dipoles on the operating frequency of 38.2 MHz. The antenna arrays are aligned along the geomagnetic north-south and east-west directions, while the 64 dipoles are inclined by 45° inclination from these arrays. A spacing between individual dipoles is a half-wavelength. A horizontal plane containing the dipoles is declined downward by 2.8° from the west to the east directions. Figure 2 shows a projection of 64 beams to the absorption altitude of 90 km in the ionosphere for the half-wavelength spacing, comparing with another beam-pattern produced by the 0.65-wavelength spacing on the IRIS antenna (30 MHz) installed at Ny-Ålesund (Yamagishi *et al.*, 1992; Nishino *et al.*, 1993). The phased-array of the IRIS antenna (38.2 MHz) installed at Longyearbyen has almost the same performance as the one at Zhongshan (Stauning and Yamagishi, 1995).

3. Model Calculation for Geomagnetically Conjugate Points of Zhongshan

The Earth's magnetic field lines are generally thought to be open in the polar-cap magnetosphere, where the field lines are connected to the interplanetary magnetic field (IMF). According to this definition, it seems difficult to obtain geomagnetically conjugate points in the higher latitude. However, the field-line tracing using the recent T-96 model enables us to calculate geomagnetically conjugate points up to invariant latitude of ~77° (Yamagishi *et al.*, 1998). Figure 3 shows a daily variation of geomagnetically conjugate points of Zhongshan mapped to the northern hemisphere, which is calculated by the field-line tracing with the T-96 model under the solar wind dynamic pressure $P_{\mathrm{dyn}}=4$ nPa, IMF $B_y=B_z=0$ and $D_{\mathrm{st}}=0$ conditions. The conjugate points can be calculated for 04–19h UT on January 25, 1997, which is very near to our

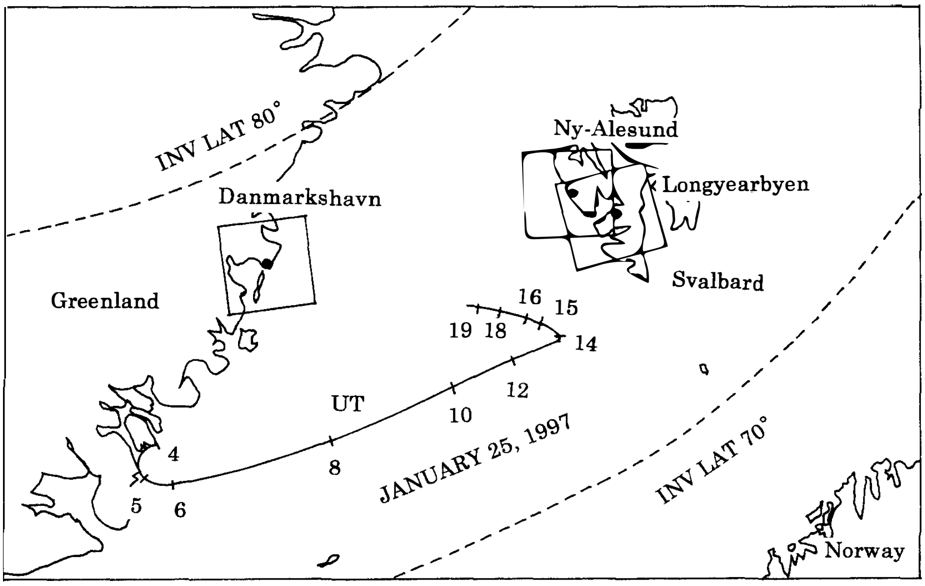

Fig. 3. Daily variation of conjugate points of Zhongshan mapped to the northern hemisphere by the magnetic field-line tracing with Tsyganenko-96 model for winter solstices (January 25, 1997). The IRIS fields of view at Ny-Ålesund, Longyearbyen and Danmarkshavn are drawn by solid squares on the map of European arctic region.

initial IRIS observations at Zhongshan station. It is found that the excursion of the conjugate points extended by about 30° in longitude, in which the conjugate points are comparatively close to the LYB/NYA stations during 14–18h UT in the evening to nighttime sectors. This suggests that it is more appropriate to investigate conjugate characteristics of nighttime ionospheric absorptions associated with substorms. The IRIS fields of view at NYA, LYB and at Danmarkshavn in Greenland are displayed by solid squares on the arctic map (STAUNING *et al.*, 1992). The IRIS data from Danmarkshavn (DMH) are available for future investigation of conjugate characteristics in summer solstice.

According to the model calculation using the Tsyganenko-1987 model, the conjugate points of Syowa ($L=6.2$) mapped to the northern hemisphere are mostly situated in and around the IRIS field of view of Tjornes, Iceland in equinoxes on quiet geomagnetic conditions ($Kp=0$) (YAMAGISHI *et al.*, 1998; FUJITA *et al.*, 1998). Even in solstices, the excursion of the conjugate points is within 6° in longitude, almost situated in Iceland. Therefore the conjugate characteristics of the absorptions between Syowa and Tjornes were discussed with regards to their similar shapes. However, as shown by Fig. 3, the excursion of conjugate points extends by 30° in longitude, which is much larger than the IRIS field of view. This requires an alternative definition of conjugate relation between the absorptions observed at NYA/LYB and at ZHS. Here we define the conjugate relation as follows: (a) Absorptions are simultaneously observed at the both northern and southern hemisphere stations, and they show similar time variations. This is identified as conjugate absorptions. (b) Absorptions are observed at the station(s) in only one hemisphere. This may be conjugate or non-conjugate. Because conjugate absorptions occur at the both hemispheres, and the absorption region is close to the station(s) in one hemisphere, but the counterpart absorption region is apart from the station(s) in another hemisphere. On the contrary, absorption occurs at only one hemisphere (non-conjugate), and the absorption region is close to the corresponding station. In the case (b), it is difficult to distinguish conjugate or non-conjugate relationship with the present IRIS stations. In this paper, we investigate conjugate characteristics of the absorptions, referring to the ground geomagnetic data from the magnetometers at and around the IRIS stations in the northern and southern hemispheres.

4. Observational Results

4.1. Absorption event during strong geomagnetic disturbances

Figure 4 shows the time variation of the absorptions observed in a time-period from 1710 to 1810 UT on January 30, 1997 at NYA (upper panel) and LYB (middle) in the northern hemisphere, and ZHS (bottom) in the southern hemisphere. The absorptions are displayed in the north-south cross-section at the second westernmost beam at NYA,

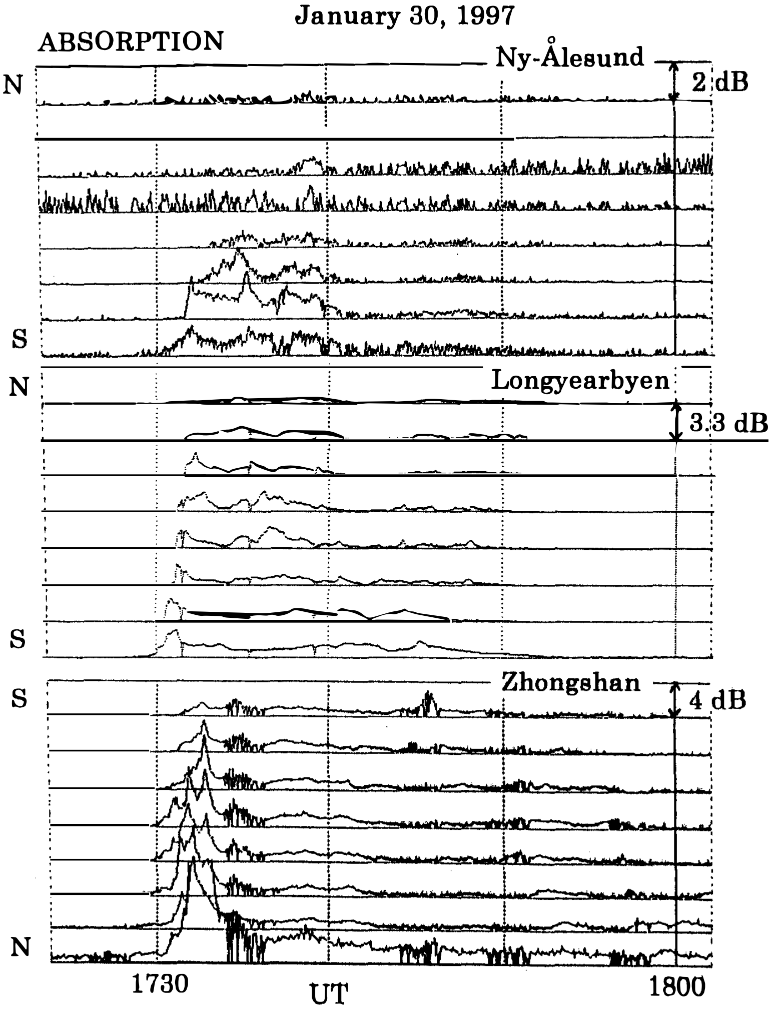

Fig. 4. Time variations of ionospheric absorptions observed during about 1730 to 1800 UT on January 30, 1997 at Ny-Ålesund (NYA), Longyearbyen (LYB) and Zhongshan (ZHS). The absorption scales are 2.0 dB/div., 3.3 dB/div. and 4 dB/div. for NYA, LYB and ZHS, respectively.

and near the zenith at LYB and ZHS. Each stack point display averaged absorption values every 4 s. Note that the northern beams direct to poleward of NYA and LYB, while the southern beams direct to poleward of ZHS.

The absorptions showed similar aspects with sharp onset and short duration ($\leqq 30$ min) in approximately 19–21h MLT at the three stations, and they were most enhanced during about 1730–1740 UT. Such absorptions were frequently observed in the evening

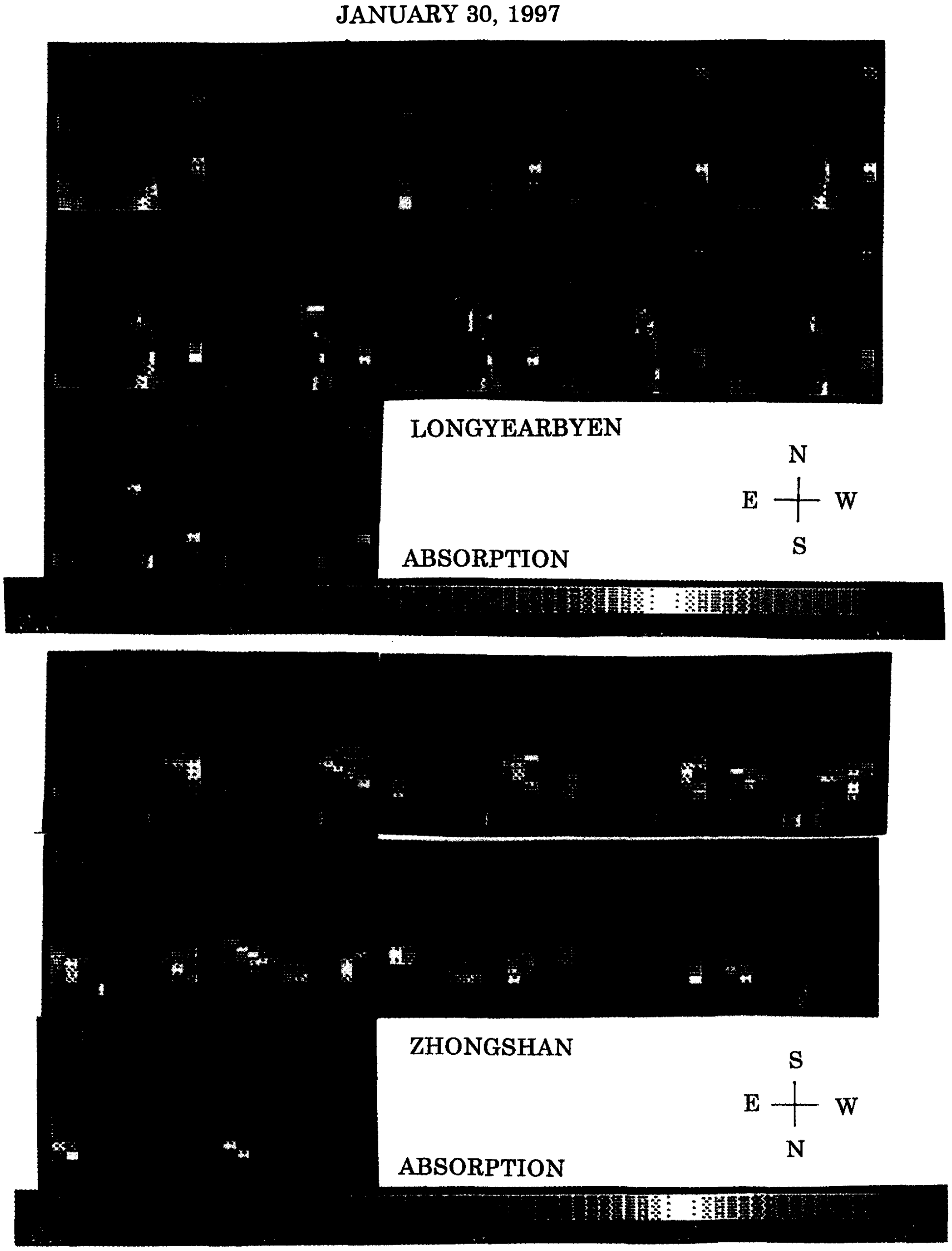

Fig. 5. A time-series of absorption images at every 8 s during 1731:22 to 1732:50 UT for LYB and during 1731:23 to 1732:51 UT for ZHS on January 30, 1997. North directs approximately to the geomagnetic poleward, and West to the right for LYB, while South directs to the geomagnetic poleward, West to the right for ZHS. Absorption values are displayed by color bars for the respective station.

during about three years at NYA (OTA, 1996). Although some beams in NYA and ZHS were interfered by radio noise, it is evident from almost simultaneous occurrences that the absorptions are identified as the conjugate characteristic between the northern and southern hemispheres.

It is remarked that the absorption features at ZHS show a poleward progression entirely with multiple spikes of very strong intensities more than 6 dB near the zenith. The simultaneous poleward progression is seen at LYB, and also at NYA by a few minutes delay, indicating that poleward progression of the absorption continues to the NYA field of view. Thus, in this example, the pair of LYB and ZHS indicates more preferable conjugate relationship, in comparison with the pair of NYA and ZHS. However we notice that the variation of the spikes is considerably different between LYB and ZHS.

Figure 5 shows a time series of the absorption images obtained at every 8 s from 1731:22 UT to 1732:50 UT on January 30 for LYB (upper panel) and during 1731:23 UT to 1732:51 UT for ZHS (lower panel). The images are produced by computer-aided data processing from the IRIS 64 beam-outputs (SATO *et al.*, 1992). Absorption values are displayed by color bar for the respective station. It is found from the absorption images for LYB that a pronounced, shin arc-like absorption is extended from the southeast corner to the zenith, and is followed by a localized enhancement (~3 dB) near the zenith at 1732:10 UT. On the contrary, for ZHS, the absorption extends in longitude as an arc-shape, showing a change of strong enhancement (~12 dB) from the western to the eastern parts at 1731:31 UT, and is followed by a torch shape in the

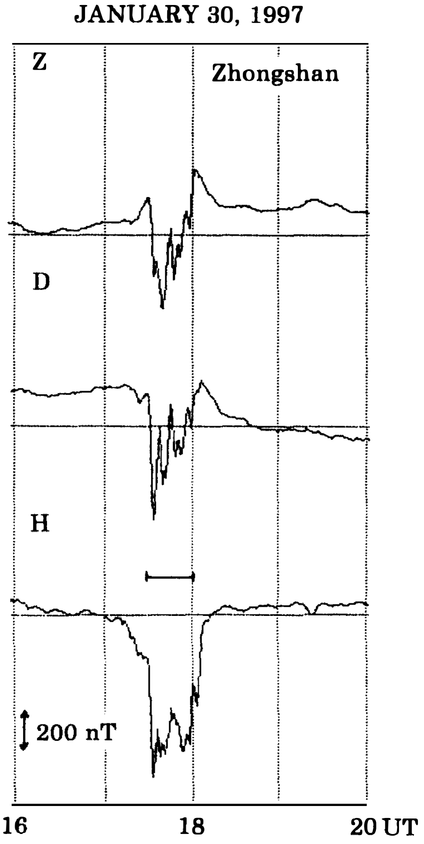

Fig. 6. Time variations of the geomagnetic H, D and Z-components at Zhongshan on January 30, 1997.

southeast part at 1732:51 UT. Thus the shape and the movement of the small-scale (50–100 km) absorption features exhibit a considerably different aspect between the both hemisphere stations.

Figure 6 shows the time variations of the geomagnetic H, D and Z-components at ZHS during 16–20h UT, in which the H-component shows a sharp and extremely large negative excursion to ~800 nT at about 1730 UT. The duration of the absorptions observed at LYB/ZHS is displayed by a horizontal bar in the figure. It is evident from the coincidence between the absorptions and the H-deflection that the strong absorption is related to enhanced ionospheric currents caused by precipitating auroral particles. From the IMAGE magnetometer network in Scandinavia and Svalbard, the H-deflections at some stations in Svalbard show similar variations to the H-deflection at ZHS, and the H-deflection is largest at LYB. Thus, during strong geomagnetic disturbances, it is considered that the counterpart absorptions of ZHS are located near LYB, displacing northeastward from the model conjugate points in nighttime (see Fig. 3).

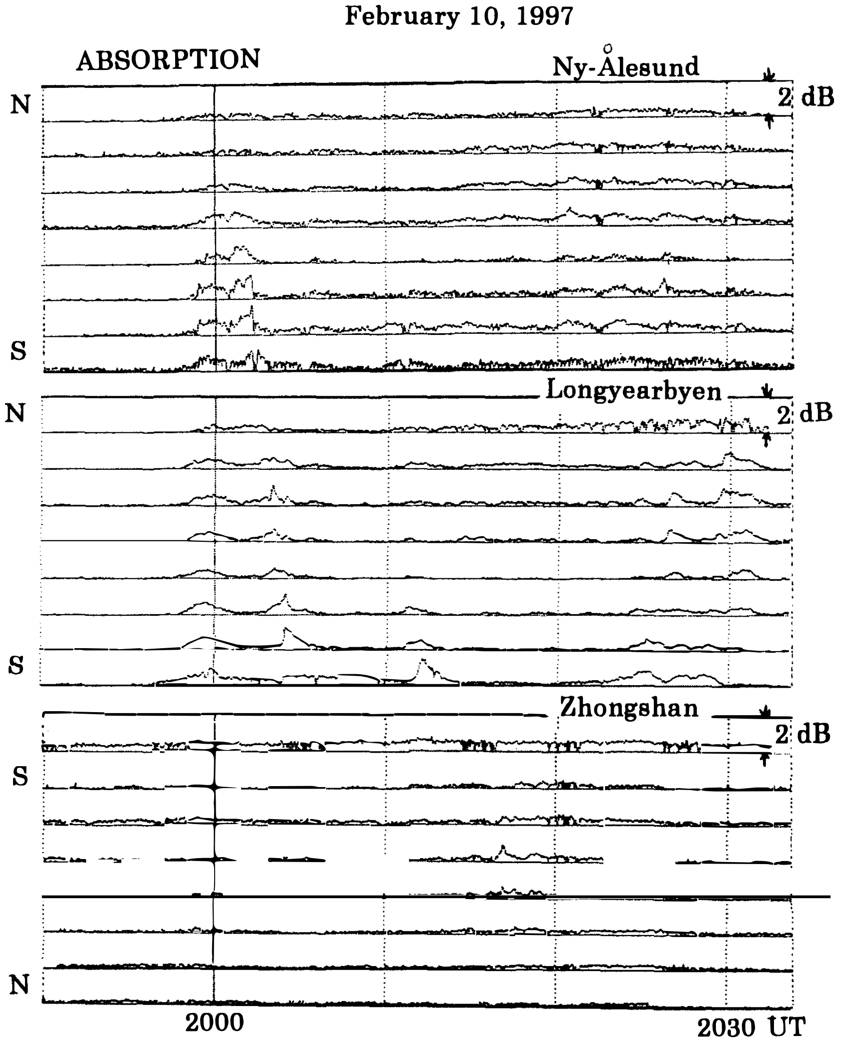

Fig. 7. Time variations of ionospheric absorptions observed during about 1955 to 2042 UT on February 10, 1997 at NYA, LYB and ZHS. The absorption scales are 2 dB/div. for all the three stations.

4.2. *Absorption event during weak geomagnetic disturbances*

Figure 7 shows the time variation of the absorptions observed from 1950 to 2040 UT (approximately 22–23h MLT) on February 10, 1997 at the three IRIS stations. It is found that relatively weak absorptions ($\leqq 1$ dB) progress poleward from LYB to NYA at about 2000 UT, and thereafter retreat equatorward from NYA to LYB near 2005 UT. This is a typical behavior of the nighttime absorption associated with substorms, as presented by STAUNING *et al.* (1995) and STAUNING (1996b). On the contrary, no absorption was observed at ZHS at about 2000 UT. Thereafter, at ZHS, a localized and short-duration absorption of ~1 dB was observed near the zenith at about 2017 UT, while no corresponding absorption was observed at NYA/LYB. Subsequently, weak absorptions ($\leqq 1$ dB) were observed at NYA/LYB during about 2020–2033 UT which are expanded over the both fields of view, showing partly small-scale (of 50–100 km) enhancements, and poleward motions at LYB, while no corresponding absorption was observed at ZHS during about 2020–2032 UT.

Figure 8 shows the time variations of the geomagnetic H, D and Z-components at ZHS. The duration of the absorption at LYB is displayed by horizontal bars in the figure. The H-component shows small negative (~100 nT) bay at about 2000 UT, and thereafter larger negative(~250 nT) one at about 2020 UT. On the other hand, the H-deflections at the geomagnetic stations in Svalbard show similar negative bays (200–250 nT), and they progress poleward around 2000 UT, followed by equatorward retreats (not shown), which correspond to the behavior of the absorptions at LYB/NYA. That is, the geomagnetic variations induced by ionospheric currents are simultaneously

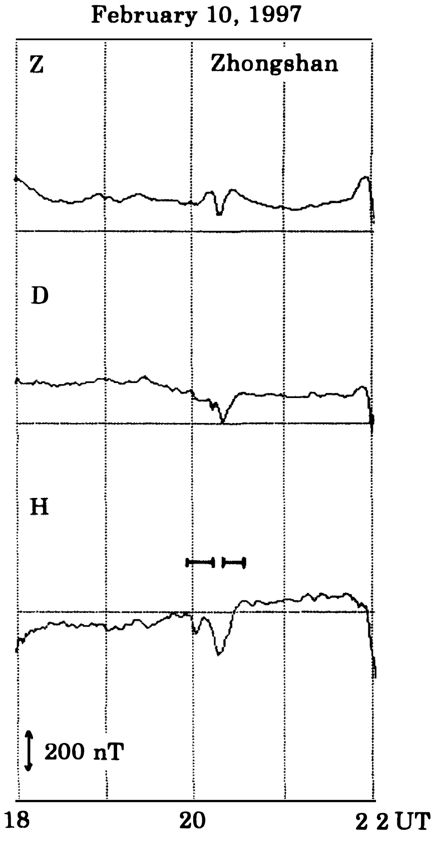

Fig. 8. Time variations of the geomagnetic H, D and Z-components at ZHS on February 10, 1997.

observed in the both hemispheres, while the absorptions caused by auroral particle precipitation are observed only at LYB/NYA in the northern hemisphere. These results indicate that the counterpart absorption at about 2000 UT and 2030 UT at LYB/NYA might occur outside (probably poleward) of the ZHS field of view in the southern hemisphere. On the other hand, the counterpart absorption at about 2017 UT at ZHS might occur outside (probably equatorward) of the LYB field of view.

4.3. Relationship between the absorptions and geomagnetic activities

We have presented the examples of the absorptions showing simultaneous and non-simultaneous occurrences between the conjugate stations in the northern and southern hemispheres, associated with geomagnetic disturbances. Here we further investigate a statistical relationship between the conjugate characteristics of absorptions and geomagnetic activities. The investigation connects to a prediction how the conjugate points of ZHS shown in Fig. 3 are affected by geomagnetic activities. The geomagnetic data at ZHS are used for our analysis. Total 30 absorption events are picked up in the time-period of 16–24h UT from January 27 to February 10, 1997. As the result, the relationship is summarized below: 14 absorption events were observed simultaneously between the inter-hemispherical stations, and 13 events among them were associated with H-deflections greater than 200 nT. The remaining 16 events were observed non-simultaneously between the inter-hemispherical stations (7 events at only LYB, while 9 events at only ZHS), and 15 events among them were associated with weak H-deflections less than 200 nT. The event number is not necessarily sufficient, but the simultaneous absorption events during strong geomagnetic disturbances tell us that the conjugate points of ZHS mapped to the northern hemisphere are displaced north-eastward from the model points in Fig. 3, closing to LYB. On the other hand, non-simultaneous absorption events during weak geomagnetic disturbances tell us that if the absorptions are observed at only ZHS, the conjugate points mapped to the northern hemisphere may be close to the model points.

5. Summary and Discussion

Summarizing the initial results of the nighttime absorption events observed at the higher-latitude conjugate IRIS stations, we can conclude, as follows.

1) Simultaneous absorptions were observed between the northern and southern hemisphere stations more preferentially during severe geomagnetic disturbances, indicating an excellent conjugate relationship.
2) The form and movement of small-scale absorption (50–100 km) are considerably different, even if large-scale absorption features show similar aspects between the conjugate stations.
3) During weak geomagnetic disturbances, absorptions are mostly observed at the station in only one hemisphere; they may be conjugate or non-conjugate.

FUJITA *et al.* (1998) have recently investigated the seasonal variation of the conjugate points of ionospheric absorptions between the Syowa-Tjornes pair in the auroral region. They exhibited that the conjugate point of Syowa mapped to the northern hemisphere was displaced most poleward (~100 km) at midnight hour in

December for moderately disturbed conditions ($Kp=4$), in consistent with the conjugate points calculated by the combination of IGRF 1995 and Tsyganenko 1989 models. The characteristics obtained by the higher-latitude conjugate stations in winter solstice described in this paper show a similar tendency to the ones by FUJITA *et al.* (1998). Since the present initial results are limited in time-period in the day and only winter solstice, further analyses are required for absorption events throughout the year in order to investigate the local time dependence and seasonal variations of the conjugate points. The seasonal variation of the absorption intensities between the inter-hemispherical stations will be useful for studying symmetric and asymmetric configurations of the magnetosphere.

From Husafell (Iceland)-Syowa conjugate auroral observations in September, SATO and SAEMUNDSSON (1987) reported that east-west aligned aurora arcs appeared at almost the same geomagnetically conjugate latitude in the pre-midnight sector, but the arcs show different movements and fine-structures. FUJII *et al.* (1987) revealed that the vortex-like structures such as folds on the discrete auroras in the pre-midnight sector were not always simultaneously observed between Husafell-Syowa conjugate stations, and have suggested that the small-scale structure (50–100 km) is due to local acceleration processes between the magnetosphere and ionosphere. In Fig. 5, we show different small-scale features of the absorption images between LYB and ZHS, associated with severe geomagnetic disturbances. And also, we show that the intensities of the spike-type absorptions at ZHS are extremely stronger than that at LYB/NYA. These results indicate that the asymmetry of local acceleration processes between the magnetosphere and ionosphere and of a severe distortion of magnetic field lines may give a significant influence for precipitation of auroral particles into the higher-latitude ionosphere. Discrete auroral emissions are caused dominantly by precipitating electrons of several keV energies, while ionospheric absorptions are caused by precipitating electrons of higher energies. Therefore simultaneous observations by the IRIS and aurora all-sky TV may contribute to the solution of the asymmetry of acceleration processes relating to inter-hemispherical field aligned currents.

WING *et al.* (1995) has shown, for the magnetospheric topology, that the IMF would penetrate deep into the magnetosphere. STENBAEK-NIELSEN and OTTO (1997) recently inferred that the observed hemispherical differences in discrete auroras may be caused by an inter-hemispherical field-aligned current component driven by the penetration of the IMF from the magnetopause to the nightside plasma sheet, primarily depending on the sign of IMF B_y-component. They illustrated a net effect on the evening auroral field-aligned currents and inter-hemispherical currents for $B_y<0$ bounding the dipolarization region from the inner magnetosphere (equatorward edge) and the lobes (outer magnetosphere, poleward edge) (see Fig. 7 in their paper). Thus the presence of the north-south inter-hemispherical field-aligned current system in the evening sector, that is, the enhancement of auroral particle precipitation would generate brighter discrete auroras displacing farther poleward in the northern hemisphere for IMF $B_y<0$. Therefore it is significant to investigate the IMF-B_y effect on the conjugate characteristics of absorptions between the inter-hemispherical stations.

During the absorption event on January 30 shown in Fig. 4, the IMF from IMP-8 satellite was negative $B_y(-2\sim-4$ nT) and negative $B_z(-2$ nT). The absorptions were

Table 2. IMF dependence of simultaneous and non-simultaneous occurrences of absorption events between Ny-Ålesund/Longyearbyen and Zhongshan from January 27 to February 10, 1997. The number of the events are noted in the table.

	$B_z<0$		$B_z>0$	
	$B_y<0$	$B_y>0$	$B_y<0$	$B_y>0$
Simultaneity	6	3	0	1
Non-simultaneity	3	8	2	1

identified as the conjugate characteristics during severe geomagnetic disturbances, and the conjugate point of ZHS mapped to the northern hemisphere was displaced to higher latitude in the northern hemisphere. This result is consistent with the inference by Stenbaek-Nielsen and Otto (1997). However, the absorption intensities at ZHS were distinctly stronger than that at LYB against their inference.

Table 2 shows a brief summary of the IMF effect on the simultaneous and non-simultaneous absorptions between the inter-hemispherical stations during two weeks, being classified by the signs of B_y- and B_z-components. It is found that the absorptions entirely occur more frequently with $B_z<0$ than $B_z>0$. A significant result is that the simultaneous absorptions are more preferable for $B_y<0$ (on $B_z<0$), which indicates that the conjugate point of ZHS is displaced poleward for $B_y<0$. This summary is also consistent with the inference by Stenbaek-Nielsen and Otto (1997). However, the absorption intensities did not show any definite difference between $B_y>0$ and $B_y<0$. The difference (~2500 nT) between the total magnetic field strengths at the inter-hemispherical stations (see Table 1), which is larger at the north than at the south may affect the absorption intensity difference between LYB and ZHS. On the conjugate observations using the pair of Tjornes-Syowa in the auroral region, Yamagishi *et al.* (1998) showed that interhemispherical difference of CNA intensity is mostly controlled by a seasonal effect (winter hemisphere is stronger), and they could not confirm the IMF B_y effect proposed by Stenbaek-Nielsen and Otto (1997). Further analysis will be investigated for the IMF effect.

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References

BELON, A. E., MAGGS, J. E., DAVIS, T. N., MATHER, K. B, GLASS, N. W. and HAUGHES, G. F. (1969): Conjugacy of visual auroras during magnetically quiet periods. J. Geophys. Res., **74**, 1–28.

DETRICK, D. L. and ROSENBERG, T. J. (1990): A phased-array radio wave imager for studies of cosmic noise absorption. Radio Sci., **25**, 325–338.

DEWITT, R. N. (1962): The occurrence of aurora in geomagnetically conjugate areas. J. Geophys. Res., **68**, 1347–1352.

ERIKSEN, K. W., GILLMOR, C. S. and HARGREAVES, J. K. (1964): Some observations of short-duration cosmic noise absorption events in nearly conjugate regions at high magnetic latitude. J. Atmos. Terr. Phys., **26**, 77–90.

FUJII, R., SATO, N., ONO, T., FUKUNISHI, H., HIRASAWA, T., KOKUBUN, S., ARAKI, T. and SAEMUNDSSON, T. (1987): Conjugacy of rapid motions and small-scale deformations of discrete auroras by all-sky TV observations. Mem. Natl Inst. Polar Res., Spec. Issue, **48**, 72–80.

FUJITA, Y., YAMAGISHI, H. and SATO, N.(1998): Seasonal variation of the latitude of geomagnetically conjugate points observed by conjugate pair of imaging riometers in the auroral zone. Nankyoku Shiryô (Antarct. Rec.), **42**, 1–19.

HARGREAVES, J. K. and Chivers, H. J. A. (1965): A study of auroral absorption events at the South Pole, 2. Conjugate properties. J. Geophys. Res., **70**, 1093–1102.

NISHINO, M., TANAKA, Y., OGUTI, T., YAMAGISHI, H. and HOLTET, J. A. (1993): Initial observation results with imaging riometer at Ny-Ålesund (*L*= 16). Proc. NIPR Symp. Upper Atmos. Phys., **6**, 47–61.

OTA, H. (1996): Statistical characteristics of ionospheric absorptions in the polar ionosphere associated with geomagnetic disturbances. Master's thesis of Electric Engineering Course, Nagoya University, 54–55 (in Japanese).

ROSENBERG, T. J. (1987): Cosmic noise absorption at South Pole and Frobisher Bay: Initial results. Mem. Natl Inst. Polar Res., Spec. Issue, **48**, 161–170.

SATO, N. and SAEMUNDSSON, T. H. (1987): Conjugacy of electron auroras. Mem. Natl Inst. Polar Res., Spec. Issue, **31**, 169–179.

SATO, M., YAMAGISHI, H., KATO, Y. and NISHINO, M. (1992): Quick-look system of auroral absorption images by imaging riometer. Nankyoku Shiryô (Antarct. Rec.), **36**, 251–267 (in Japanese with English abstract).

STAUNING, P. (1996a): Investigations of ionospheric radio wave absorption processes using imaging riometer techniques. J. Atmos. Terr. Phys., **58**, 753–764.

STAUNING, P. (1996b): High-latitude *D*- and *E*-region investigations using imaging riometer observations. J. Atmos. Terr. Phys., **58**, 765–783.

STAUNING, P. and YAMAGISHI, H. (1995): Imaging riometer installation, Longyearbyen, Svalbard. DMI Tech. Rep., **95-X**, 1–27.

STAUNING, P., HENRIKSEN, K. and YAMAGISHI, H. (1992): Imaging riometer installation in Danmarkshavn, Greenland. DMI Tech. Rep., **92-4**, 1–25.

STAUNING, P., YAMAGISHI, H., NISHINO, M. and ROSENBERG, T. J. (1995): Dynamics of cusp-latitude absorption events observed by imaging riometers. J. Geomagn. Geoelectr., **47**, 823–846.

STENBAEK-NIELSEN, H. C. and DAVIS, T. N. (1972): Relative motion of auroral conjugate points during substorms. J. Geophys. Res., **77**, 1844–1858.

STENBAEK-NIELSEN, H. C. and OTTO, A. (1997): Conjugate auroras and the interplanetary magnetic field. J. Geophys. Res., **102**, 2223–2232.

STENBAEK-NIELSEN, H. C., WESCOTT, E. M. and DAVIS, T. N. (1973): Differences in auroral intensity at conjugate points. J. Geophys. Res., **78**, 659–671.

TSYGANENKO, N. A. and. STERN, D. P. (1996): Modeling the global magnetic field of the large-scale Birkeland current systems. J. Geophys. Res., **101**, 27187–27198.

WESCOTT, E. M. (1966): Magnetoconjugate phenomena. Space Sci. Rev., **5**, 507–561.

WING, S., NEWELL P. T., Sibeck, D. G. and Baker, K. B. (1995): A large statistical study of the entry of interplanetary magnetic field Y-component into the magnetosphere. Geophys. Res. Lett., **22**, 2083–2086.

YAMAGISHI, H., NISHINO, M., SATO, M., KATO, Y., KOJIMA, M., SATO, N. and KIKUCHI, T. (1992): Development of imaging riometers. Nankyoku Shiryô (Antarct. Rec.), **36**, 227–250 (in Japanese with English abstract).

YAMAGISHI, H., FUJITA, Y., SATO, N., STAUNING, P., NISHINO, M. and MAKITA, K.(1998): Conjugate features of auroras observed by TV cameras and imaging riometers at auroral zone and polar cap conjugate-pair stations. Polar Cap Boundary Phenomena, ed. by J. MOEN *et al*. Dordrecht, Kluwer Academic Publ., 289–300.

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