ULF waves simultaneously observed by SuperDARN and GEOTAIL around LLBL

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Abstract

We have carried out coordinated observations of GEOTAIL, SuperDARN, and ground magnetometers in order to investigate energy flow of ULF waves from the outer magnetosphere to the ground through the ionosphere. During GEOTAIL was skimming the dayside magnetopause, the ionosphere near the magnetic footprints of the satellite was searched by SuperDARN radars with high time resolution mode. This kind of special operation of SuperDARN has been carried out several times since 1998. In general, GEOTAIL observes transverse Pc 5 waves mainly in the morning sector, and compressional Pc 5 waves in the dusk side LLBL. The transverse Pc 5 waves are also detected in a wide region of the ionosphere and on the ground. On the other hand, the compressional waves are not observed on the ground.

Interesting two events in which transverse and compressional Pc 5 waves were successively excited in the dusk side LLBL were observed by GEOTAIL on January 25 and 30, 1999. In both cases, transverse waves were observed simultaneously on the ground. Latitudinal polarization characteristics shown in the IMAGE magnetometers suggests that the transverse waves are propagating eastward and resonating with the field line around the magnetic latitude of 70°. On the other hand, the compressional waves were simultaneously observed only in the ionosphere, not on the ground. This result suggests a screening effect by the ionosphere for the compressional waves, so that the spatial scale of the waves is to be small. However, the phase analysis of a longitudinal radar beam shows that the m number of the compressional waves is about 13. Therefore, we need another explanation why the compressional waves were not observed on the ground.

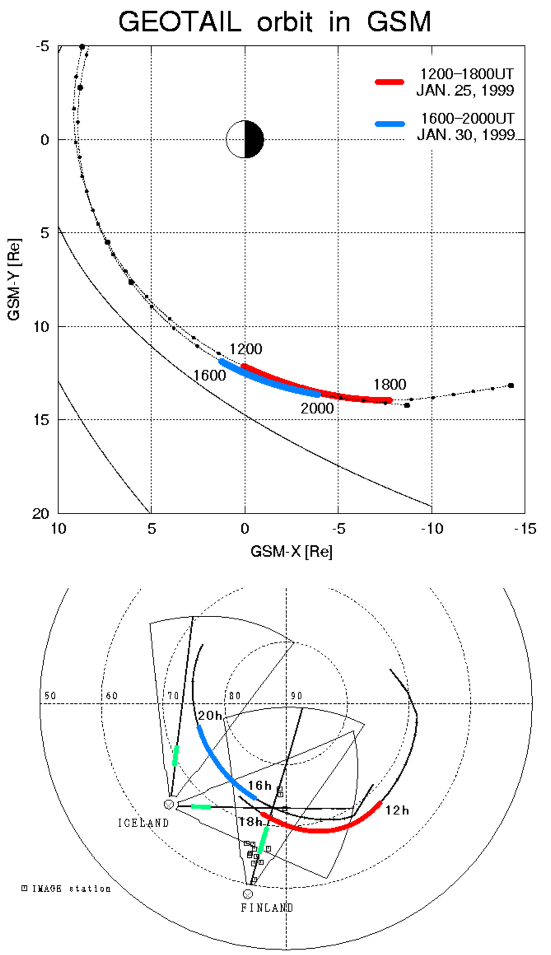

Fig.1

DATA

The GEOTAIL satellite was skimming the dusk side magnetopause on January 25 and 30, 1999, and the footprints of the satellite passed over field of views of SuperDARN radars and the IMAGE stations as shown in Fig. 1. On these days, the radars were operated as a special mode, in which the Beam #4 of Stokkseyri (Iceland West), #8 of Cutlass/Iceland (Iceland East), and #8 of Cutlass/Finland were scanned with a high time resolution mode of $\Delta t \sim 7$ s. In this study, all data set, electric and magnetic fields observed by GEOTAIL and IMAGE, and the line of sight velocity data observed by the special beams, have been rearranged with the sampling time of 10 s for spectral analyses.

The upper panel of Fig. 2 shows the total magnetic field and the east-west component of the electric field observed by GEOTAIL in the interval of 1400-1800 UT on January 25, 1999. Periodic oscillations of T ~ 6 minutes in the electric field started at ~ 1440 UT are lasted around 1700 UT without any magnetic field oscillations. On the other hand, an oscillation of the compressional component of the magnetic filed started at 1645 UT in the decay-phase of the former transverse wave. A similar event, i.e. successive excitation of transverse and compressional waves, was also observed in the next revolution of GEOTAIL on January 30 in the same region.

Transverse Wave

Although we have not plotted each component of the magnetic field observed by GEOTAIL in Fig. 2, there was no obvious magnetic oscillation until the compressional wave started at 1645 UT. On the other hand, the radial component of the electric field was well oscillated as same as the azimuthal component. Since the orbit of the satellite is almost equatorial one, this oscillation of the electric field are explained as a symmetric oscillation of the magnetic field line passing GEOTAIL, i.e. an odd mode transverse wave.

The X component of magnetometer data observed at IMAGE chain stations are plotted in the lower panel of Fig. 2. Pc 5 waves are clearly seen in the magnetogram and they are well correlated with the transverse wave observed in the space.

We have calculated power spectra of the electric fields and the ground magnetic fields for the time interval of 1515–1600 UT by using the maximum entropy method with order of 30. The peak frequencies of power spectra are plotted versus magnetic latitude in the left panel of Fig. 3. Peak frequencies are different between azimuthal (Ed) and radial (Ev) components of the electric field, and they are1.7 mHz and 2.7 mHz, respectively. It should be noted that the spectral peaks of the ground magnetic field well coincide with that of the radial electric field. This means the electric field of a toroidal mode wave is penetrating to the ionosphere, and cause Pc 5 pulsations in the wide region on the

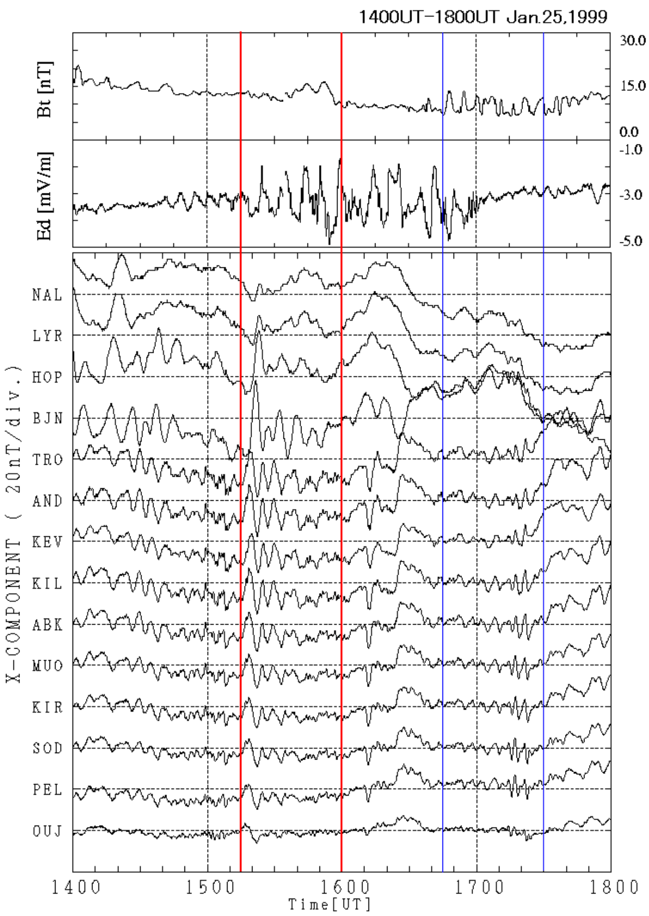

Fig.2

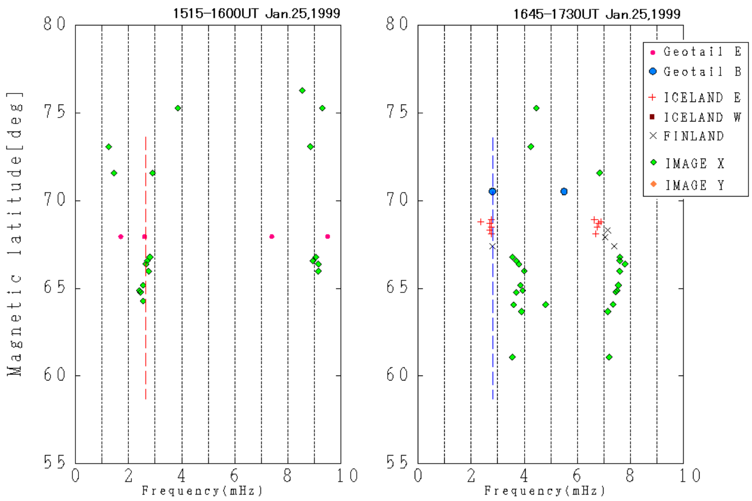

Fig.3

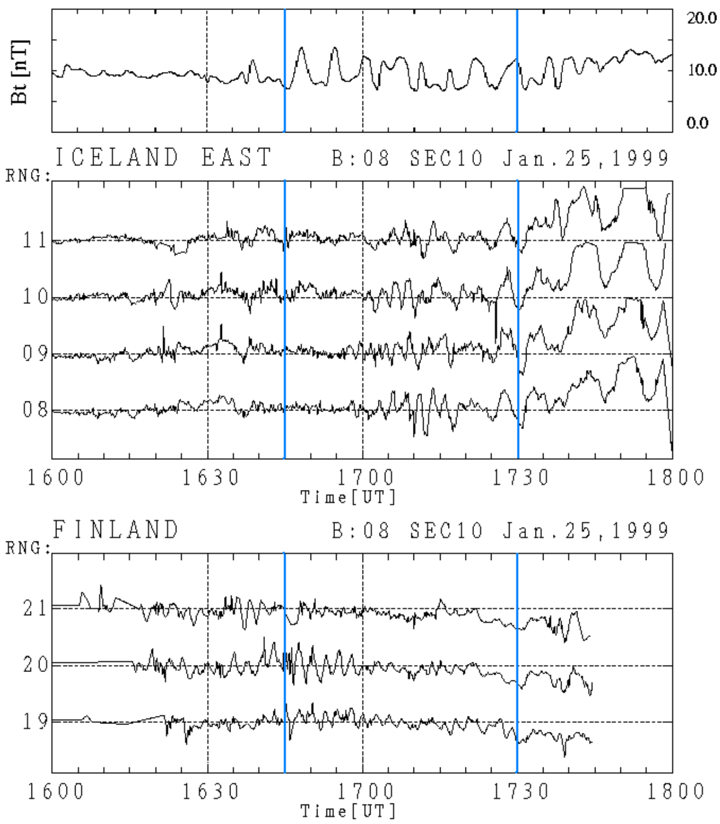

Fig. 4

ground. Unfortunately, the radar echo was not available in this period.

We did also polarization analysis for the ground magnetometer data, and it shows clearly the ellipticity reversal around the magnetic latitude of 70° where the spectral power is maximum, that is left-handed in higher latitudes and right-handed polarization in lower latitudes. This result represents that a source wave is propagating eastward and is exciting the field line resonance around 70°.

Compressional Wave

An expanded plot of the total magnetic field observed by GEOTAIL during 1600-1800 UT is shown in the top panel of Fig. 4. The waveform is not sinusoidal, and spectral analysis shows that this compressional wave has two dominant spectral peaks at 2.8 mHz and 5.5 mHz. Middle and bottom panels in the figure shows the line of sight velocity plots of the high time resolution beams of the Cutlass radars. There is some wave activity of plasma motion in the ionosphere. Portions colored with light blue in Fig. 1 indicate the ranges where ionospheric waves were observed.

Spectral peak frequencies of the total magnetic field in the space and plasma velocity in the ionosphere during 1645-1730 UT are plotted versus the magnetic latitude in the right panel of Fig. 3. The peak frequencies of the X component of IMAGE for the same interval are also plotted. There are two spectral peaks at 2.8 mHz and 6.7 mHz for the ionospheric plasma velocities, and the lower spectral peaks are almost same as one of the compressional wave observed by GEOTAIL in the dusk side LLBL. On the other hand, the spectral peaks of Pc 5 waves observed on the ground do not coincide with one of the compressional wave. It is suggested that the compressional wave in the magnetosphere are propagating to the ionosphere, but are not observed on the ground.

The similar compressional wave following the transverse wave was observed by GEOTAIL during 1800-2000 UT on January 30, 1999 in the almost same region of LLBL. In this case, the compressional wave has spectral peaks at 0.9 mHz and 3.3 mHz. Ionospheric oscillations with spectral peaks at 3.3 mHz have been found simultaneously in data of the beam #4 of the Stokkseyri radar. There were Pc 5 activities on the ground, but the frequencies of spectral peaks are different from those of the compressional wave.

Since the beam #4 of Stokkseyri is looking along magnetic longitude line, we are able to examine longitudinal propagation characteristics of the wave by applying phase analysis among each range data. The result is shown in Fig. 5, indicating that the wave is propagating westward with m~13.

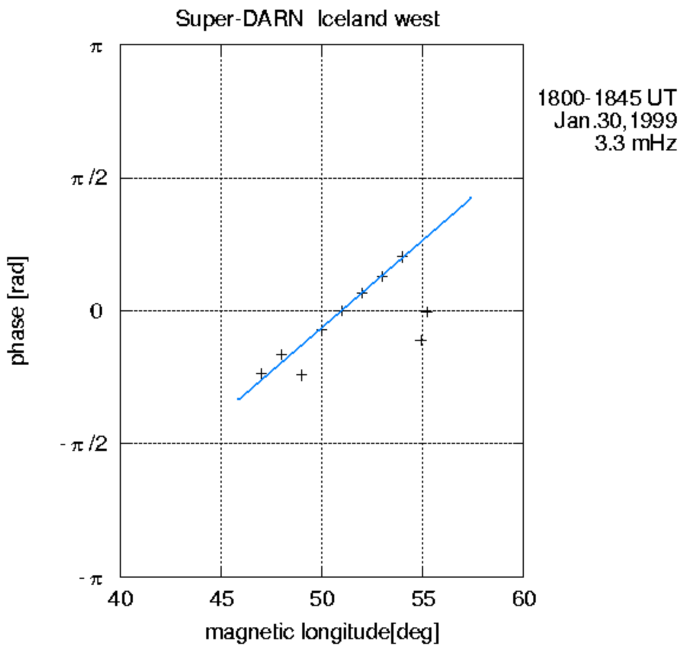

Fig. 5

Summary

We have examined wave characteristics of propagations from the outer magnetosphere to the ground for transverse and compressional waves by using data of the coordinated observation of GEOTAIL, SuperDARN, and IMAGE, which was carried out in January 1999.

The transverse waves in the Pc 5 range were simultaneously observed in the space and on the ground with the same spectrum peak. Although the radar echo was not available during the transverse wave event, it is confirmed that the electric field of the toroidal mode wave is penetrating to the ionosphere, and cause Pc 5 pulsations in the wide region on the ground. The latitudinal polarization profile shows that the transverse waves are propagating eastward and resonating with the field line around the magnetic latitude of 70°. The surface waves excited at the magnetopause by the Kelvin-Helmholtz instability are a possible driving source for this kind of transverse wave.

For the compressional waves, we have found the same spectral peak on plasma velocity in the ionosphere observed by the HF radars. On the other hand, Pc 5 waves simultaneously observed on the ground had no spectral peak at the frequency of the compressional wave. If the spatial scale of the wave is small comparing with the hight of ionosphere, the wave cannot be observed on the ground by the ionospheric screening effect. However, the phase analysis of a longitudinal radar beam shows that the wave is propagating westward with m number of about 13. Therefore, we need another explanation why the compressional waves were not observed on the ground.

Acknowledgements

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