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Variations of the Magnetosphere Resonance Frequencies During Magnetic Storm of July 15—16, 2000

A. Potapov A. Polyakov T. Polyushkina

(*Institute of Solar-Terrestrial Physics, Siberia Branch, Russian Academy of Sciences, Irkutsk* 664033, *Russia*)

H. Zhao

(*National Microwave Remote Sensing Laboratory, Center for Space Science and Applied Research, Chinese Academy of Sciences*)

Abstract ULF observations at two mid-latitude sites during the large geomagnetic storm of July 15—16, 2000 were used to trace variations of resonance frequencies of the field line resonators. A brief description of the geomagnetic disturbance as it was observed on the ground, at the geostationary orbit, and before the Earth's bow shock is given. Then a detailed study of ULF dynamic spectra from Borok and Mondy is performed for 8 succesive 6-hour intervals of July 15 and 16. In conclusion some tasks for the future work are listed.

Key words Magnetic storm, Magnetosphere, Resonances, Plasma density

1 Introduction

The imperious goals of space weather prediction require simple but reliable techniques to monitor global plasma conditions in the magnetosphere especially during major disturbances. Methods of wave diagnostics present such possibility to get information about plasma distribution in the magnetosphere on the whole by observing and interpreting electromagnetic waves both on the ground and in the space.

These methods are based on Dungey spectrum dependence on magnetic field intensity and plasma density along field line conjugated with observation site. Dungey spectrum is the discrete spectrum of Alfvén eigenoscillations of the geomagnetic field lines. Within the limits of dipole approximation the equation of toroidal oscillations has the form[1]

$$-\frac{\mathrm{d}^2\Psi}{\mathrm{d}\xi^2}=\frac{4\pi\rho(0)\omega^2R_e^8}{M^2(1-\xi_0^2)^8}\frac{\rho(\xi)}{\rho(0)}(1-\xi^2)^6\Psi, \quad (1)$$

where Ψ is an oscillation field function, ρ is plasma density, ω is frequency of oscillation, $\xi=\cos\theta$, where θ is co-latitude of current point at the field line, $\xi=0$ corresponds to field line intersection with the magnetic equator, M and R_e is the Earth's magnetic moment and radius, respectively. Assuming plasma density distribution along the field line as $\rho=(1-\xi^2)^{-6}$, above equation can be solved without applying numerical methods. Oscillation frequency ω has the following dependence on magnetic field in the equatorial plane $B(0)$, plasma density $\rho(0)$, and L-value of the magnetic shell[2]:

$$\omega_n(L)\approx BL^{-1}[\rho(0,L)]^{-1/2}. \quad (2)$$

We intend to show here a diagnostic potential of Ultra-Low Frequency (ULF) emissions which frequency lies in the range of the magnetosphere resonance frequencies. It should be noted that the results presented here are preliminary. It is only beginning of the work, and the main goal of this part of study is to understand major problems in order to plan the successive work.

We use ULF observations at two mid-latitude observatories during the large geomagnetic storm of July 15—16, 2000. First we give a brief description of the geomagnetic disturbance as it was observed on the ground, at the geostationary orbit, and before the Earth's bow shock (Section 2). Then in Section 3 a detailed study of ULF dynamic spectra from Borok

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and Mondy will be performed for 8 succesive 6-hour intervals of July 15 and 16. Section 4 formulates conclusions of the paper and lists some tasks for the future work.

2 The Storm Description

The geomagnetic storm of July 15—16, 2000, (see Fig.1) has been one of the largest magnetic disturbances of the current 23rd cycle of solar activity. *Dst* index came down to minus 300 nT (Fig.2). The storm began with arriving to the Earth the interplanetary shock wave at 1437 UT (the moment of SSC). In Fig.3 we can see variations of the solar wind plasma parameters as measured by IMP-8 satellite, which was alongside the Earth's bow shock, its coordinates at the moment of SSC are indicated in figure.

It should be noted that the background against which this storm occurred was not quiet. The solar wind velocity had been enhanced since July 13, 2000, being as high as 650—750 km/s during almost three days before SSC. Then, on July 15, 2000, at 1437 UT, the interplanetary shock front arrived behind which the solar wind velocity increased to more than 1000 km/s (see bottom panel). This shock has a strong density enhancement. The dynamic pressure reaches about 50 nPa. In the 1800—2000 UT interval there is a further increase in the speed (eventually to about 1043 km/s) with the simultaneous density increase, which results in the unbelievable value of dynamic pressure of 68 nPa. Unfortunately, there is a tracking gap after 2000 UT. The disturbance was so powerful that onboard instruments could not stand against it and we have large gaps in satellite data. (In our figures these gaps are interpolated by straight lines.) Due to the gaps, it is difficult to see the specific structure regions of the interplanetary shock wave, such as plasma piston or magnetic region.

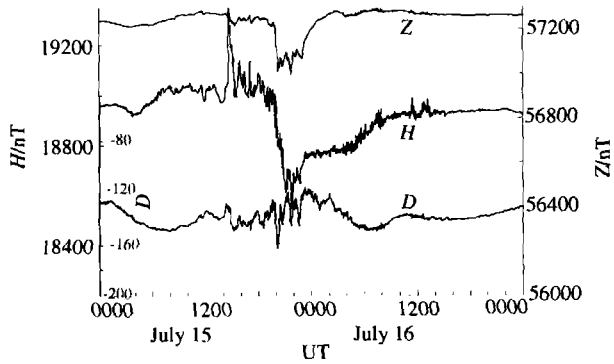


Fig.1 Geomagnetic storm of July 15—16, 2000 as it was observed by Irkutsk magnetic observatory

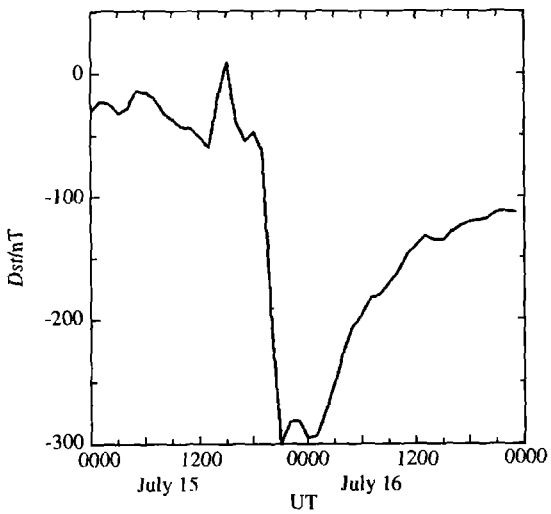


Fig.2 *Dst* variation for July 15—16, 2000 magnetic storm

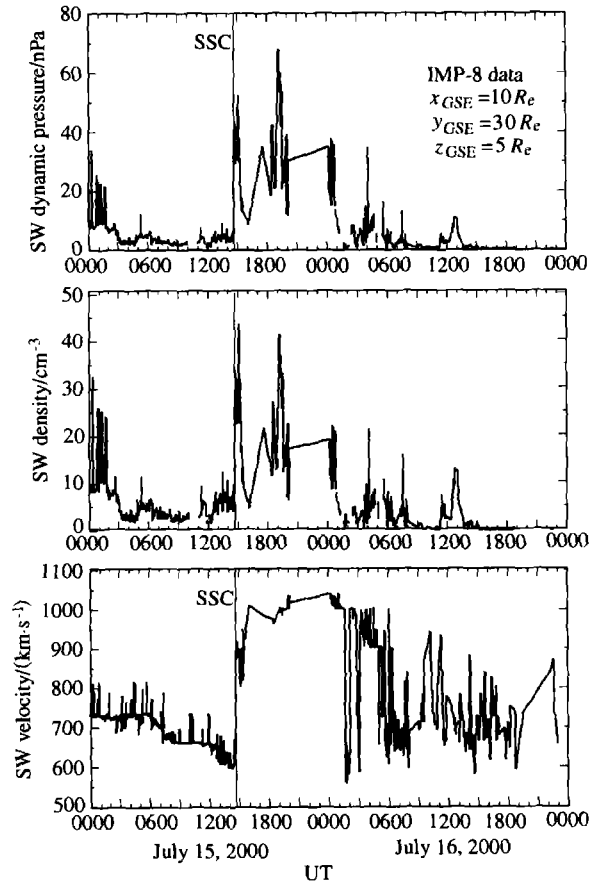


Fig.3 Solar wind plasma parameters as measured by IMP-8 instruments

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On July 16, the solar wind velocity continues to be quite high, with an interesting and substantial decrease occurring at about 0140 UT and lasting until 0209 UT. During this decrease the density also falls, resulting in a dynamic pressure drop to below 1 nPa. The pressure afterwards is about 6.5 nPa. At 0502 UT, IMP first enters the magnetosheath. However, there are still occasional solar wind periods until as late as 1311 UT, when the dynamic pressure is down to just over 5 nPa.

The IMF variations are shown in Fig.4. It only includes magnetic field magnitude $|\boldsymbol{B}|$ (bottom panel) and vertical component B_z (top panel). We see southward turn of B_z at 0615 UT, about 8 hours before the shock front arrival. Enhancement of the IMF magnitude connected with the interplanetary shock wave is not such dramatic as the solar wind dynamic pressure is, $|\boldsymbol{B}|$ increases to 59 nT during the second surge of the dynamic pressure. The most impressive feature of the IMF variations is observation of deep negative value of B_z component, descending below -55 nT.

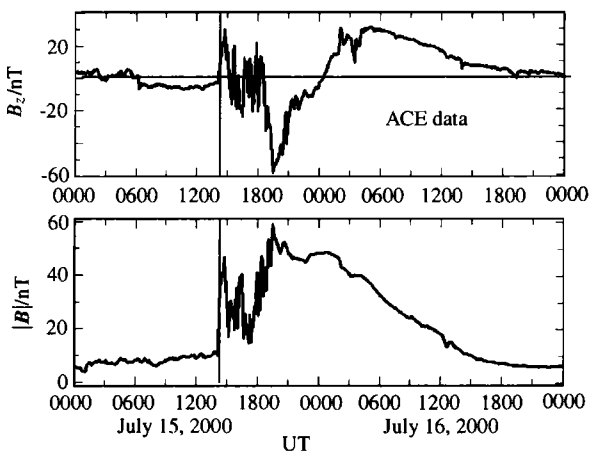


Fig.4 IMF variations measured by ACE spacecraft

Fig.5 shows field variations of the magnetic field inside the magnetosphere at $6.6R_e$ measured by GOES 10 geostationary satellite. Local time of the satellite was UT9. It can be seen that between 1910 and 2220 UT the magnetopause was beyond stationary orbit due to compression of the geomagnetic field, as one can conclude from the sharp changes of H-component to negative values in the day side sector of the magnetosphere.

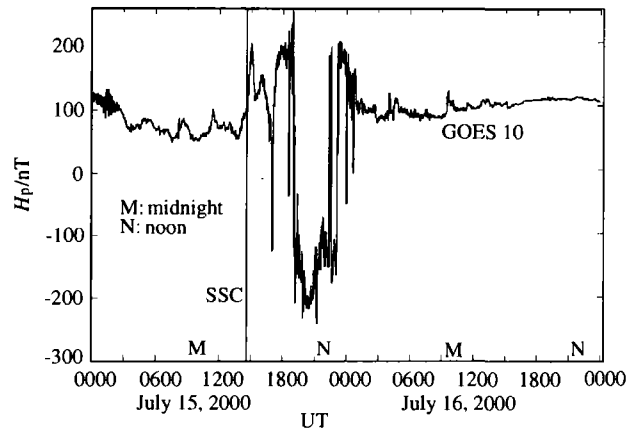


Fig.5 Field variations of the magnetic field inside the magnetosphere at 6.6 R_e measured by GOES 10 satellite

3 Description of ULF Frequency Behaviour at Two Stations

In order to observe resonance structure of ULF emissions during the storm under study we use digital data from two mid-latitude magnetic observatories which parameters are given in Table 1 below.

Both observatories are equipped with search-coil magnetometers and digital system of data acquisition. Sampling frequency is 10 Hz. Amplitude-frequency response has a 6 dB slope. Sensor sensitivity is about 3 pT/μV at 1 Hz frequency. To study resonance structure a spectral-time analysis was performed based on direct and reverse FFT transform in running time window. On the whole, 16 spectrograms were prepared for two storm days at two observatories. Each dynamic spectrum includes more than 7 hours of x-component data in 1.67 to 100 mHz

Table 1 Geomagnetic co-ordinates and L-values are given at the height of the ionosphere above the observatories

observatory	geographic co-ordinates		corrected geomagnetic co-ordinates		L-value	LT
	ϕ/(°)	λ/(°)	Φ/(°)	Λ/(°)		
Borok	58.03	38.97	53.92	114.28	2.93	UT+3
Mondy	51.62	100.75	46.70	173.59	2.16	UT+7

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frequency range. So time intervals of spectrograms overlap.

Fig.6 shows four Borok spectrograms for July 15. The morning and daytime spectra before SSC contain two wide spectral bands with mean frequencies 54 and 15 mHz, first of which corresponds to Pc3 type, and second corresponds to Pc4 type of geomagnetic pulsations. Between them we see a blank band of so-called forbidden frequencies. In lower frequency domain a number of pulses are seen which are not typical for daytime quiet period. To our mind these pulses reflect processes of interaction of the high-velocity solar wind stream with the magnetosphere. SSC at 1437 UT manifests itself as a strong impulse signal covering the whole range of frequencies. It is followed by a series of less powerful impulses. An interesting detail is the almost total absence of wave activity in the period from 1745 till 1950 UT when IMP 8 observed the highest values of the solar wind velocity and dynamic pressure. Such suppression of activity can result from moving of auroral oval to the latitudes that are lower than Borok latitude. Beginning at 1950 UT, we see strong impulses again.

Fig.7 shows the same day spectrograms built on data from Mondy. There are also two spectral bands, but they have lower frequencies. Pc3 band has a 36 mHz frequency, whereas Pc4 band has mean frequency of 8 mHz. The lower band is not very distinct, it consists of the series of quasi-pulses. It is interesting that the wave activity suppression interval before enhancement at 1950 is much less pronounced at Mondy as compared with Borok spectrogram. It can be explained by lower latitude of Mondy observatory, so that auroral oval did not reach this latitude.

In Fig.8 we see Borok spectrogram for the second storm day, July 16th. First two dawn-daytime spectra has also two wide bands similar to ones in Fig.6, but their mean frequencies are more than twice lower now: 25 and 7 mHz. At Mondy, on the contrary, frequency of daytime Pc3 and Pc4 pulsations has increased becoming 50 and 10 mHz, respectively (Fig.9).

In Table 2 values of mean frequency for prenoon spectral bands at Borok and Mondy are given for easier comparison.

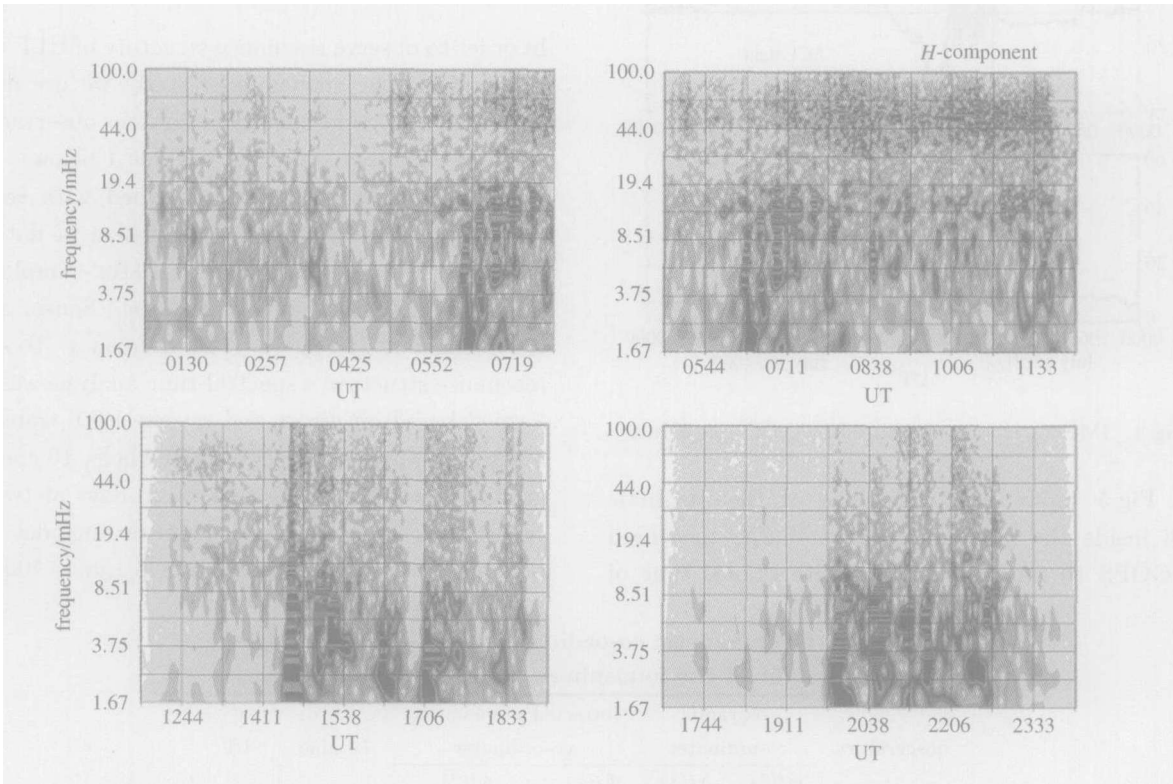


Fig.6 Dynamic spectra of ULF oscillations observed at Borok on July 15, 2000

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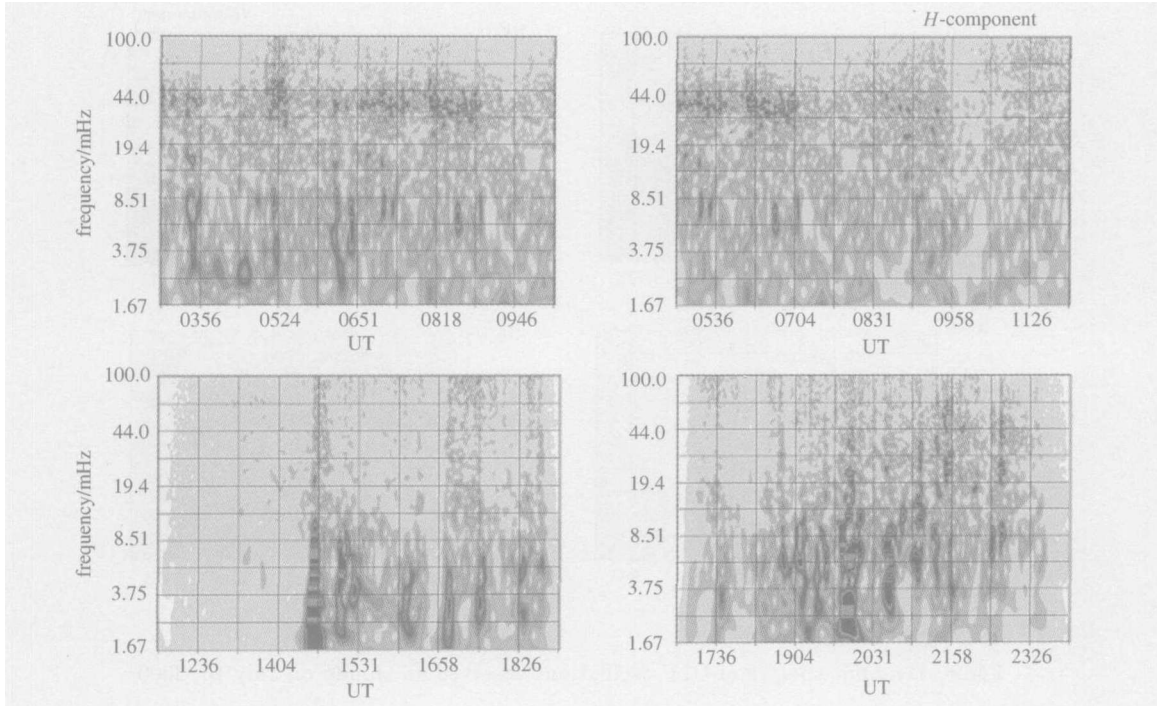


Fig.7 Dynamic spectra of ULF oscillations observed at Mondy on July 15, 2000

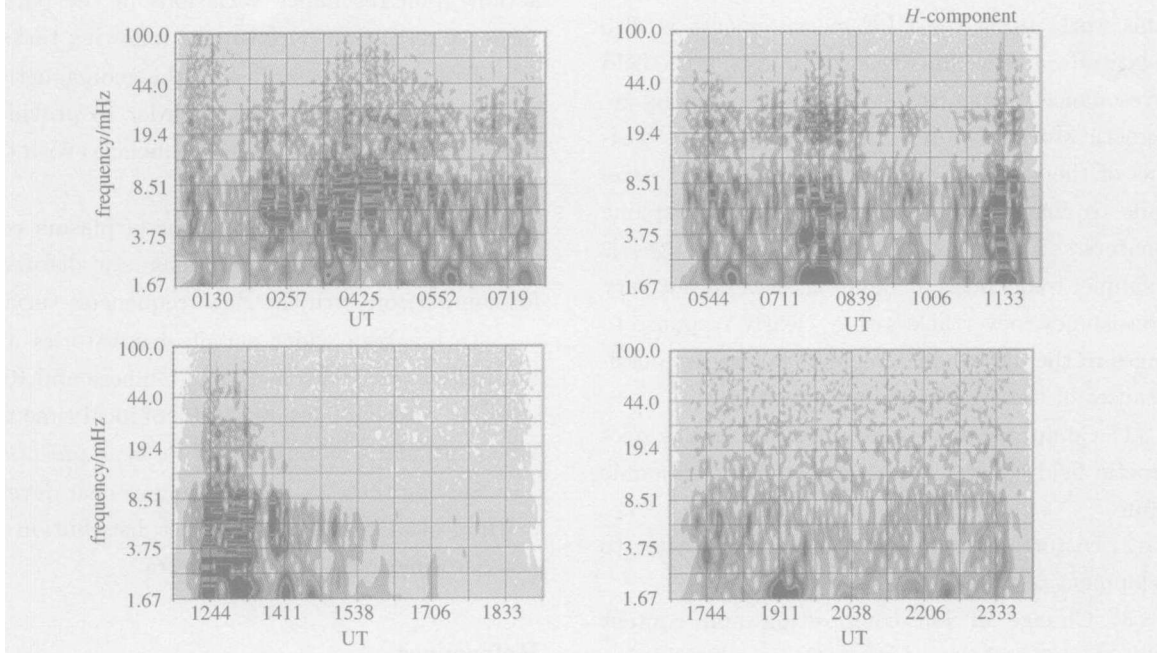


Fig.8 Dynamic spectra of ULF oscillations observed at Borok on July 16, 2000

Table 2 Mean frequency values for pre-noon spectral bands at borok and mondy

observatory	July 15, 2000		July 16, 2000	
	Pc3/mHz	Pc4/mHz	Pc3/mHz	Pc4/mHz
Borok	54	15	25	7
Mondy	36	8	50	10

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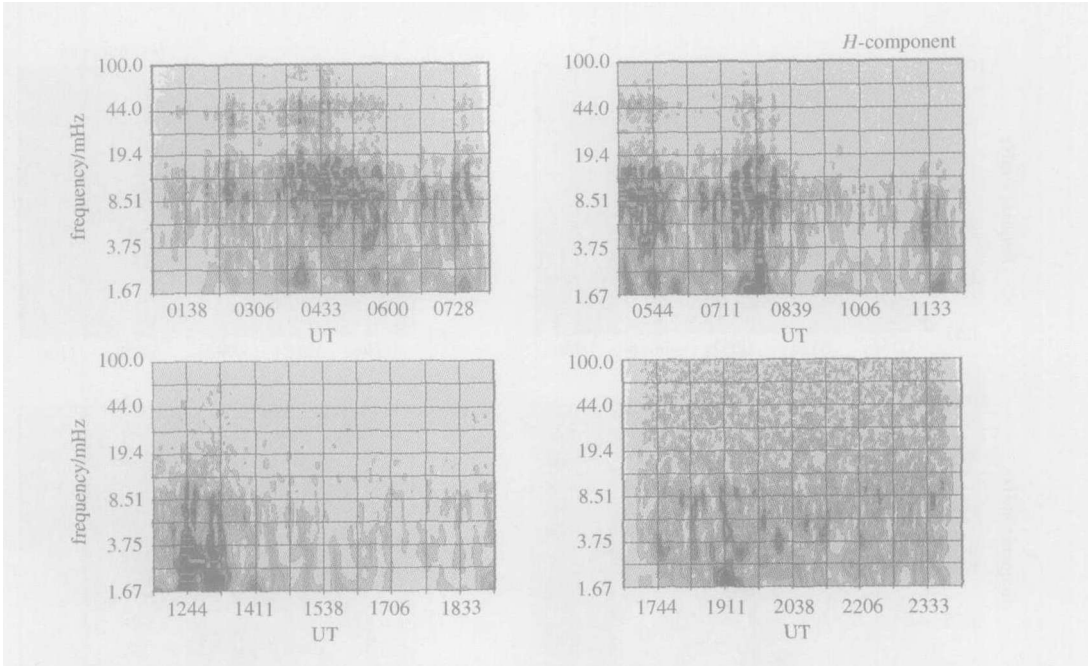


Fig.9 Dynamic spectra of ULF oscillations observed at Mondy on July 16, 2000

4 Discussion and Conclusions

In this work, using the ULF measurements at two mid-latitude sites we have traced changes of the field line resonance frequencies in the course of strong geomagnetic storm. We have found conspicuous variations of the spectral bands frequencies that corresponds to changes in eigenfrequencies of field line resonators. The total picture of these changes is not simple; frequencies at different sites do not vary in consistency, nevertheless they clearly response to changes in the disturbance regime. Let us list possible causes of the eigenfrequency variations.

(1) Compression or decompression of the geomagnetic field by action of the solar wind dynamic pressure.

(2) Distortion of the geomagnetic field owing to development of the ring current.

(3) Change of ion composition and content in the magnetospheric plasma, their redistribution along and across the field lines.

(4) The plasmasphere depletion at the initial phase of magnetic storm and it's refilling at the recovery phase. These processes are the most strong but not the sole reason for changes specified in point 3 above.

In order to understand what mechanisms have action upon resonance variations in the particular cases we must first perform the following tasks.

To use modern models of the geomagnetic field (IGRF, Tsyganenko's etc) in order to provide correct comparison of measured frequencies with the expected ones.

To use satellite observations of plasma content in the magnetosphere during magnetic disturbances for comparison with the eigenfrequencies variations.

To invoke a wider net of observatories aligned both along meridian, including Chinese and Russian stations, and in different sectors of local time to provide continuous monitoring of Pc type pulsations.

Solving these tasks will bring us near developing method of diagnostics of plasma distribution in the magnetosphere using ULF spectra.

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