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Field Line Alfvén Oscillations at Low Latitudes

V. A. PILIPENKO*, K. YUMOTO, E. N. FEDOROV*, N. KURNEVA* and F. W. MENK**

Abstract

Pc3 geomagnetic pulsations, recorded along the 210° magnetic meridian, sometimes show peculiar behavior at low latitudes: increasing period with decreasing latitude. Numerical modeling of the Alfvén resonator reveals several distinct features of the field line oscillations at low latitudes. These characteristic features comprise non-monotonic period-latitude dependence, enhanced ionospheric dissipation and modified field aligned structure of the standing waves.

1. Introduction

Magnetospheric ULF field line oscillations at middle and high latitudes have been thoroughly studied for many years. A variety of geophysical facilities have been used for the determination of ULF spatial structure at these latitudes: ground-based magnetic networks, satellites, ionospheric radars, etc. (see references in reviews by YUMOTO (1986), SAMSON (1988), PILIPENKO (1989)). At the same time much less is known about the physical picture of ULF waves at low and near-equatorial latitudes. This is due to the absence of in-situ satellite measurements and the greatly reduced amplitudes of ULF signals at these latitudes, making the ground-based measurements rather difficult.

Meanwhile, at low latitudes geomagnetic field line oscillations may have a number of characteristic features which are different from the well-known mid-latitude geomagnetic pulsations. These peculiarities are related to the essential influence of the ionospheric ions on field line oscillations. HATTINGH and SUTCLIFFE (1987) discussed the possibility of abnormal variations of pulsation period with latitude, caused by the mass-loading of field lines with heavy ionospheric ions. This effect was studied in detail by POULTER *et al.* (1984) with numerical model of the magnetospheric resonator based on the mathematical ion density model of BAILEY (1983). The results on POULTER *et al.* (1984) predict the appearance of a minimum in the latitudinal variation of ULF eigenperiod, $T_A(\Phi)$, near 30° geomagnetic latitude ($L \simeq 1.33$). Subsequently, POULTER *et al.* (1990) showed using numerical modeling that at these latitudes, which correspond to the transition between hydrogen dominated to oxygen dominated flux tubes, the field aligned structure of Alfvén eigen oscillations is fundamentally modified. All these conclusions were made on the basis of numerical modeling and have not been confirmed experimentally yet. The only exception is the already mentioned paper by HATTINGH and SUTCLIFFE (1987), where deviations from the typical

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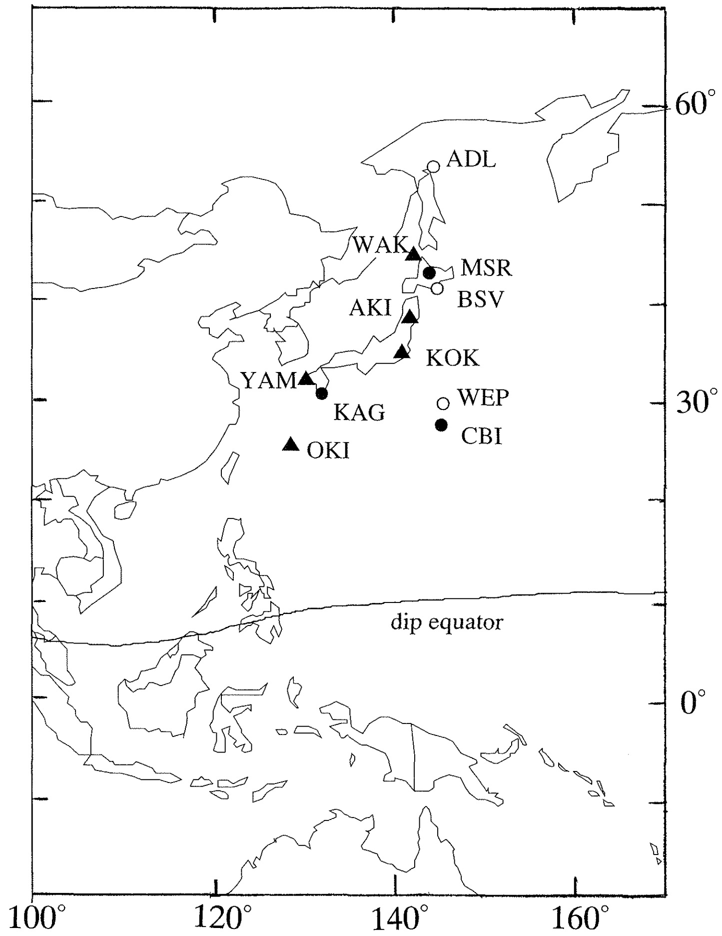

Fig. 1. Geographical positions of the magnetic and ionospheric stations of 210° MM array (dark circles denote magnetic stations in the northern hemisphere, open circles; conjugate points of magnetic stations in the southern hemisphere, dark triangles; ionospheric stations).

period-latitude dependence were reported. However, because of insufficient station coverage (L=1.84−1.37) the expected minima and maxima of period-latitude profile were not studied. It has thus not yet been established that the effects predicted by POULTER *et al.* (1984, 90) can be experimentally observed. In fact, YUMOTO *et al.* (1995) showed that ULF waves at low latitudes must undergo much heavier damping because of the violation of "thin" ionosphere approximation.

There exists another well-known peculiarity of ULF fields near the Earth's geomagnetic equator; equatorial enhancement of ULF amplitudes. However, this particular feature is just related to the ionospheric spreading of currents, and not with the properties of the magnetospheric resonator. So, we shall not consider these features herewith.

Important new facilities for the experimental study of the spatial-spectral structure of ULF pulsations became available with the onset of the "210° Magnetic Meridian" project (YUMOTO *et al.*, 1992). Within the framework of this project a network of permanently operating magnetic stations has been installed along the 210° geomagnetic meridian from the Earth's equator to middle latitudes in both hemispheres. In the present paper we consider some peculiarities of Pc3 pulsations observed at low latitudes using data from the first stage of the "210° MM" project, and compare these with the results of new numerical

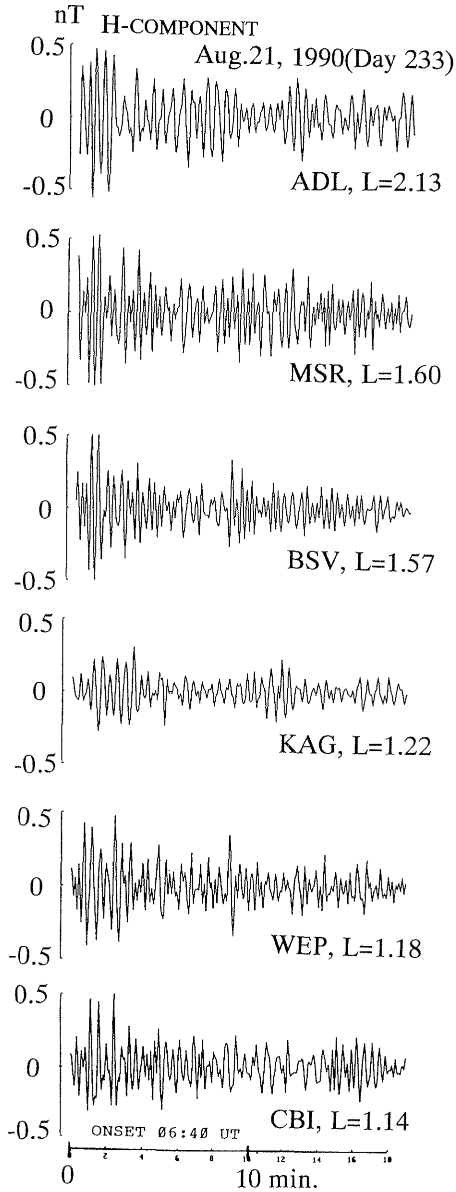

Fig. 2. H-component amplitude-time records of Pc3 pulsations recorded on August 21, 1990 (Day 233) 6:40–7:00 UT. Records have been band-pass filtered over 20–100 mHz. Amplitudes are in nT, time scale is in min. Stations are shown with L value, decreasing from the top downward. Abbreviated names of stations are indicated.

models of the magnetospheric resonator.

2. Experimental verification

For the experimental verification of the effects predicted by the numerical modeling we have used data from the first stage of the "210° MM" project (YUMOTO *et al.*, 1992), when 6 stations were operating. These stations are sited along the 210° magnetic meridian and cover the range of L values from L=2.13 to L=1.14 (LT=UT+9.5). Figure 1 shows the locations of these stations: MSR (L=1.60), KAG (L=1.22), CBI (L=1.14) in northern hemisphere and ADL (L=2.13), BSV (L=1.57), WEP (L=1.18) in southern one. The coordinates and the full names of stations, details of the instrumentation and calibration appeared in YUMOTO *et al.*, (1992, 96).

Several different forms of spectral-spatial distribution have been observed for low latitude Pc3 pulsations. Usually clear H-component Pc3 activity is observed only at stations with L>1.5. At the two near-equatorial stations WEP (L=1.18) and CBI (L=1.14) the amplitudes of ULF signals typically merge to background noise level (~ 0.1 nT). Probably, this distribution indicates to a low Q values of the magnetospheric resonator at near-equatorial latitudes. Nonetheless, by visual inspection short intervals of Pc3 series were selected when Pc3 amplitudes were above the noise level at two near-equatorial sta-

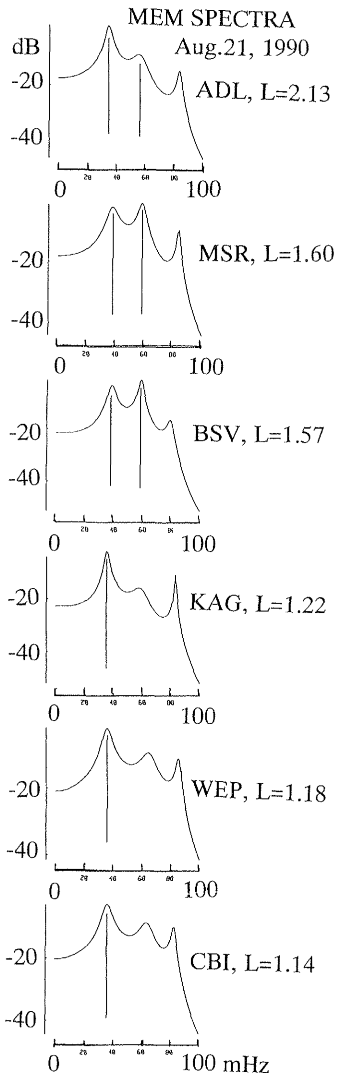

Fig. 3. Spectral estimates of the Pc3 event shown in Fig 2, obtained using the MEM (AR order is 15). The spectral amplitudes are in db, frequency is in mHz. The spectral peaks of interest are indicated by vertical lines. The spectral peaks at f≃90 mHz at near-equatorial stations are due to artificial interference.

tions.

An example of events with specific period-latitude behavior (August 21, 1990, Day 233, 6 : 40-7 : 00 UT, $K_p = 2_-$) is presented in Fig. 2. Amplitude-time series of H-component (band-pass filtered in the range 20-100 mHz) Pc3 pulsations, recorded at 6 stations along the geomagnetic meridian, are shown. The corresponding spectral estimates, made with the use of the maximum entropy method (MEM), are presented in Fig. 3. At L=2.1 (ADL) the frequencies ~35 mHz and ~60 mHz dominate the spectrum. These frequencies may be attributed to fundamental mode and second harmonic of local field line oscillations, resonantly excited by a source with a proper spectral content. At L=1.6 (MSR/BSV) the ULF signal near 40 mHz weakens, while the high-frequency part of the spectrum is resonantly amplified. The corresponding frequency, ~60 mHz, is related, on our opinion, to fundamental Alfvén mode at the given latitude. The field aligned structure of ULF wave in the magnetosphere can be determined by examination of the phase relationships between the conjugate stations. Within the timing accuracy the H components at MSR and BSV are in phase and the D components are out of phase. Assuming that MSR and BSV are ideally conjugated, these relationships are compatible with the assumption that the resonant oscillations at $L \simeq 1.6$ with $f \simeq 60$ mHz are the fundamental mode of field line oscillations. The occurrence of resonant peak in meridional

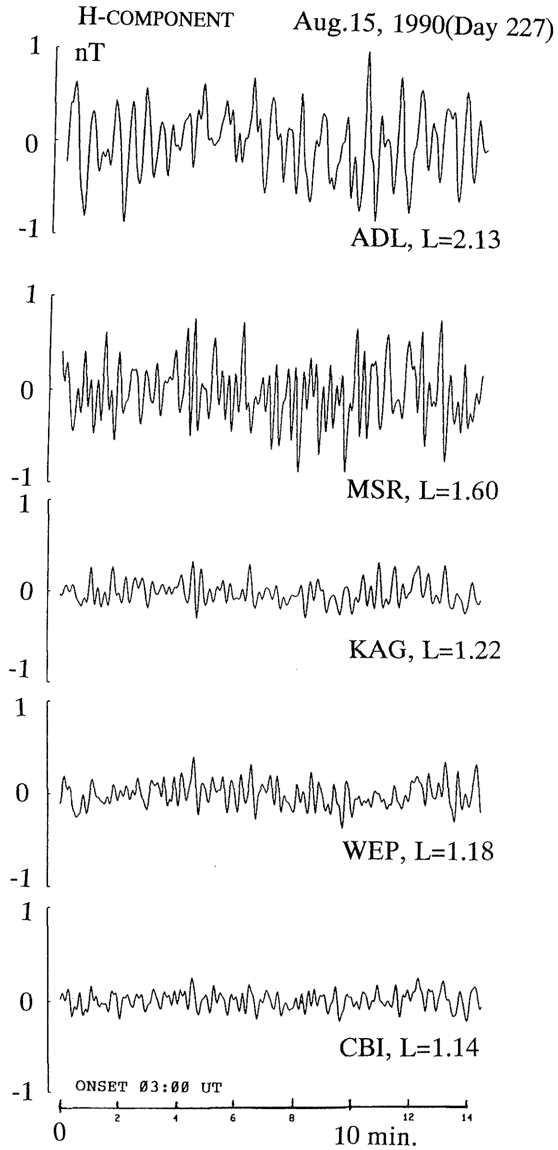

Fig. 4. Pc3 pulsations (band-pass filtered between 20-100 mHz) recorded along the meridional profile on August 15, 1990 (day 277) at 2 : 52-3 : 12 UT. The same format as Fig 2.

distribution of high-frequency Pc3 pulsations near these stations was previously reported by YUMOTO *et al*. (1992). At lower latitudes (KAG, WEP, CBI) just a gradual decrease of ULF amplitudes toward the equator can be seen (Fig. 2). The central frequency of the spectral peak (34–36 mHz) remains practically the same at all stations. For this type of events the resonant effects at $L \leq 1.5$ are turned out to be relatively weak to distort essentially a source spectrum.

The another type of observed meridional distribution of Pc3 pulsations differs from the previous one by the presence of peculiar form of spectral variation between near-equatorial stations. As an example, the event on August 15, 1990 (day 227) 02:52 - 03:12 UT, $K_p = 2_+$, is considered. Fig. 4 shows the band-pass filtered amplitude-time series of Pc3 activity recorded with the meridional profile (data from station BSV are absent for this event). The corresponding MEM spectra are shown in Fig. 5. The spectral variations observed between L=2.1 (ADL) and L=1.6 (MSR) are similar to those, observed in the previous event: the low-frequency part of the signal ($f \simeq 31$ mHz) decays, while the high-frequency ($f \simeq 67$ mHz) part is resonantly amplified at MSR. But, at lower latitudes the spectra behavior is entirely different. The frequency of the spectral peak shifts gradually from 67 mHz at MSR to lower values: 62 mHz at L=1.22 (KAG), 51 mHz at L=1.18 (WEP), and 45 mHz at L=1.12 (CBI). The dependence of the field line eigenperiod on L must have a minimum at some latitude between 38° (MSR) and 25° (KAG).

Another event with non-monotonic period-latitude dependence (August 16, 1990, Day 228, 00:35 - 01:00 UT, $K_p = 3_o$) is

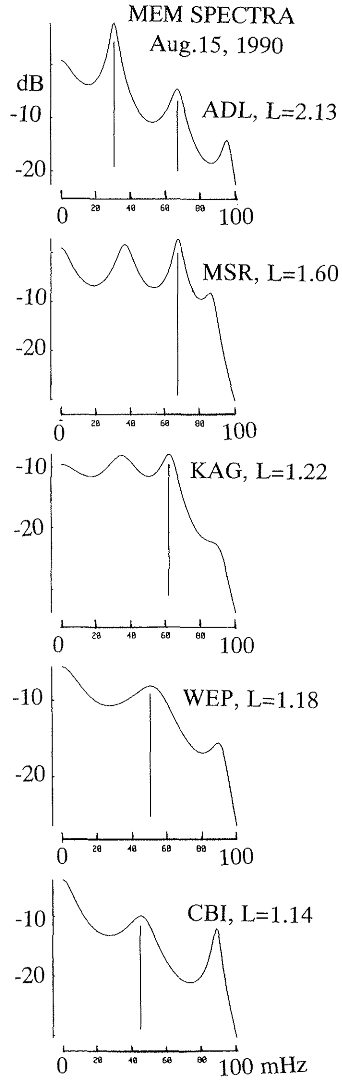

Fig. 5. MEM spectra of the ULF pulsations shown in Fig 4. The same format as Fig 3.

shown in Fig. 6. As can be seen from the MEM spectra (Fig. 7), at latitudes $\Phi > 35°$ the usual increase of peak frequency, probably corresponding to fundamental resonant frequency f_A with decreasing latitude takes place: f(ADL)≃37 mHz, f(MSR)≃74 mHz. However below ~30° the reverse dependence f(Φ) is observed; the frequency decreases monotonically toward the equator: f(KAG)≃65 mHz, f(WEP)≃50 mHz, f(CBI)≃45 mHz.

Strictly speaking, the peak frequency in a pulsation spectrum does not necessarily coincide with a local resonant frequency for that particular L-shell. A more reliable estimate

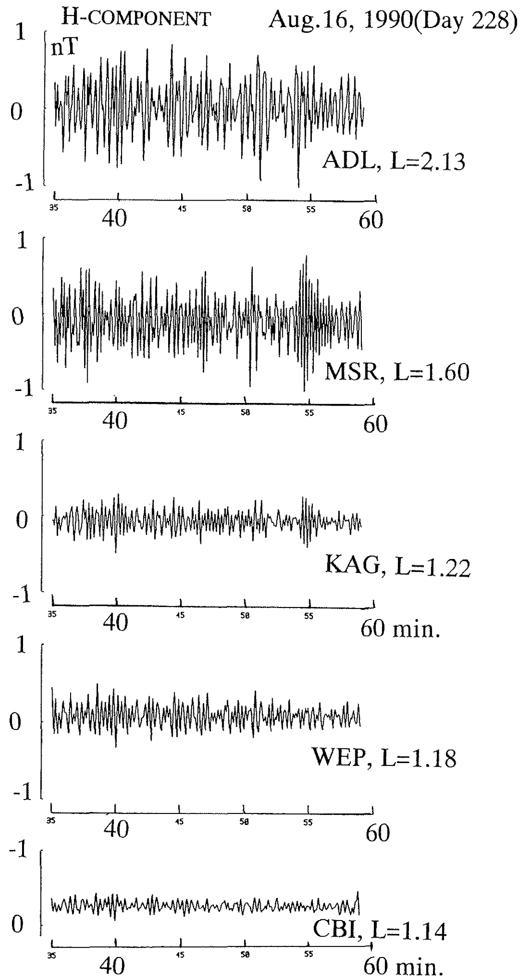

Fig. 6. Band-pass filtered (20-100 mHz) H-component signals recorded along the meridional profile on August 16, 1990 (day 228) at 0:35-1:00 UT. BSV data are not shown for this particular interval.

of f_A might be obtained with the use of H(f)/D(f) ratio (BARANSKY *et al.*, 1990). The ratios of power spectral densities of H and D components for the event August 16, 1990 are shown in Fig. 8. The obtained values of $f_A(L)$ differ by 1-2 mHz from the peak frequencies of the H -component spectra. The H/D plots confirm the existence of second harmonic at ADL (~70mHz) and the non-monotonic variation of fundamental resonant frequency with latitude.

All the above spectral estimates have been made with the use of MEM. Numerous studies, in particular RADOSKI (1976) and FOUGERE (1985), proved the superiority of MEM as compared with the usual spectral methods, based on FFT. Really, the modeling of the ULF time series as an autoregressive (AR) process, i. e. a white noise passed through a filter of certain order, corresponds well to the physical nature of Pc3-4 pulsations. The possible instability of spectrum and the emergence of multiple false peaks so characteristic of MEM

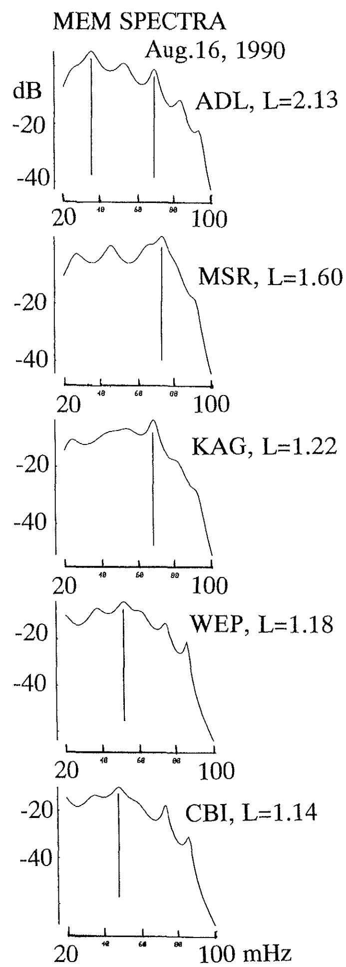

Fig. 7. MEM spectra of the time intervals shown in Fig 6.

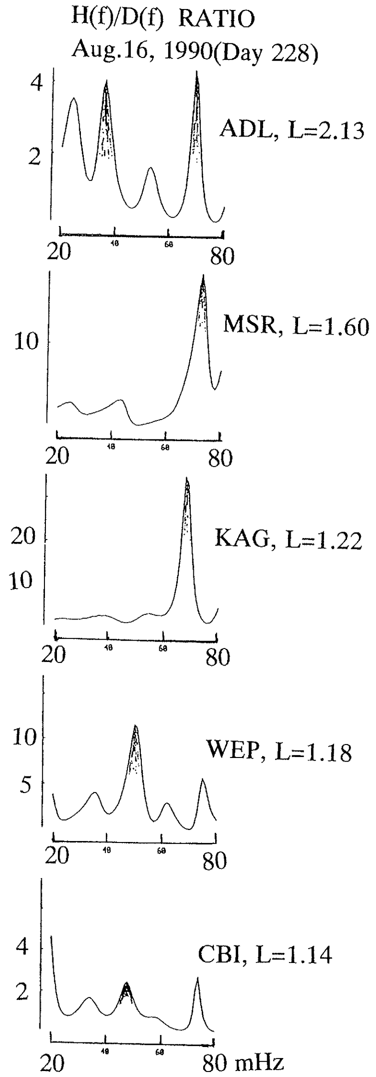

Fig. 8. Spectral plots of the ratio H(f)/D(f) for each station for the event on August 16, 1990 shown in Fig 6. Physically significant peaks have been highlighted.

become evident only for high order of the AR filter. In our calculations the absence of spirituous peaks has been guaranteed by the choice of low AR order, namely-less than 5% of data samples. Nevertheless, to exclude any doubt in the independence of the described effect on a spectral method, the results have been verified by the standard Blackmann-Tukey (BT) method. As an example, in Fig. 9a the BT spectra of Pc3 time series, recorded on 27. 07. 90

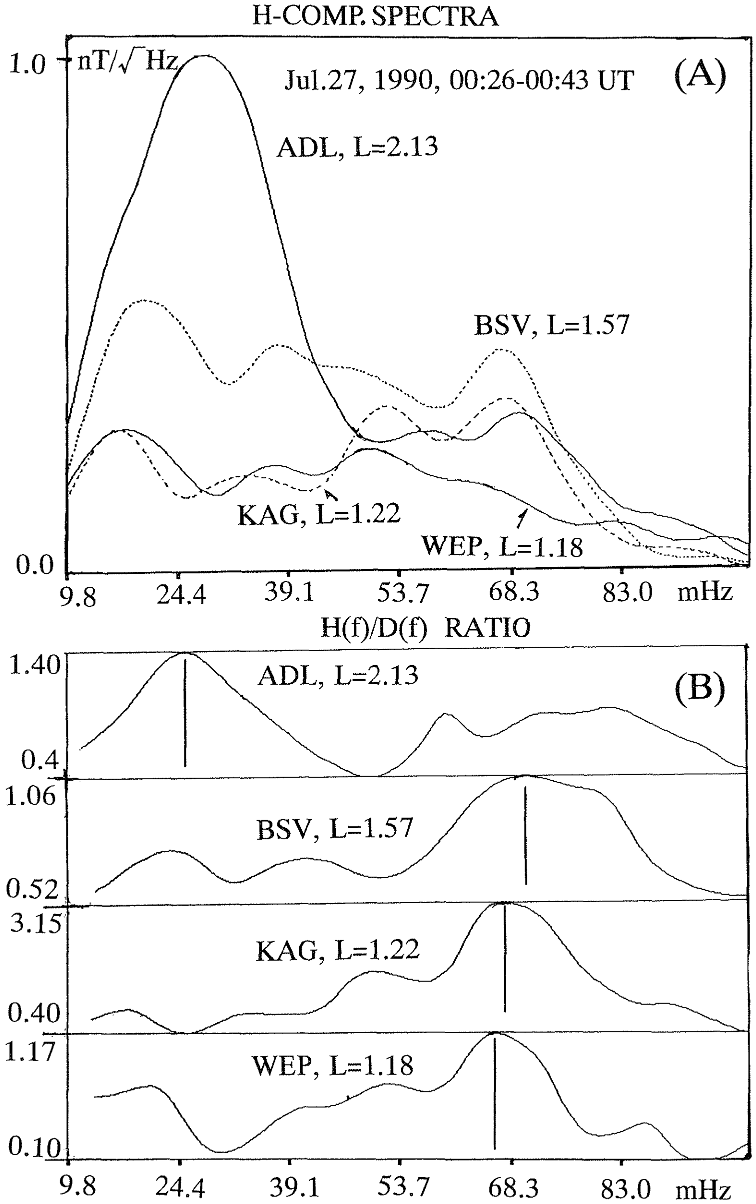

Fig. 9. a). BT spectra (in db) of Pc3 time series, recorded on 27. 07. 90 at 00 : 26-00 : 43 UT ; b). H(f)/D(f) ratio. Frequencies f_A are indicated by vertical lines.

at 00 : 26 - 00 : 43 UT, are shown. As in the previously considered events, in this case the maxima of the H/D ratio (Fig. 9b) also indicates a regular decrease of $f_A(L)$ starting from L ~1.6 (BSV) with the decrease of L-value.

During mid-July~August, 1990, 16 Pc3 events have been retrieved with discernible pulsation activity at stations WEP and CBI. In several cases the non-resonant behavior with steady peak frequency (similar to Day 233 event) at low latitudes has been observed. All other events revealed peculiar behavior with non-monotonic period-latitude variation. But, even when Pc3 amplitudes at WEP and CBI were below noise level, the relationship, f(KAG) ≤f(MSR), between peak frequencies from MSR and KAG held, indicating the probable occurrence of $T_A(\Phi)$ minimum at some latitude between these stations. More definite conclusion about persistence of the effect of non-monotonic $T_A(\Phi)$ variation could be drawn with better station coverage between MSR and KAG, i. e. at $\Phi \simeq 30°$.

3. Comparison of experimental data with the numerical model of the Alfvén resonator

The results of previous numerical models of the magnetospheric resonator (POULTER *et al.*, 1984, 1988, 1990 ; HATTINGH and SUTCLIFFE, 1987) were presented only for certain values of geophysical parameters. Therefore, they can be used only for qualitative comparison with particular experimental data. Moreover, the models of the low-latitude magnetospheric resonator by POULTER *et al.* (1988, 1990) and HATTINGH and SUTCLIFFE (1987) do not account for ionospheric dissipation, which might play a crucial role at small L values. Calculations of the ionospheric dissipation made, for example, by NEWTON *et al.* (1978) or by ALLAN and KNOX (1979) are not valid at low latitudes (YUMOTO *et al.*, 1995). For this reason another numerical model of the magnetospheric resonator has been developed.

The magnetospheric Alfvén resonator is formed along a geomagnetic field line between the conjugate ionospheres. The parameters of the resonator and the wave field distribution in it are determined by the system of MHD and Maxwell's equations (see YUMOTO *at al.*, 1995).

$$\begin{aligned} \text{rot}\ \mathbf{E} &= ik_0\ \mathbf{B} \\ \text{rot}\ \mathbf{B} &= -ik_0\ \varepsilon_\perp\ \mathbf{E} \end{aligned} \tag{1}$$

where $k_0 = \omega/c$ is a vacuum wave number, c is the velocity of light, and i denotes the imaginary unity. The complex permeability $\varepsilon_\perp$ comprises the dielectric permeability of the magnetosphere $\varepsilon_A = (c/c_A)^2$ (c_A denotes an Alfvén velocity) and Pedersen conductivity of the ionosphere $\sigma_\perp$

$$\varepsilon_\perp = \varepsilon_A + i\ (4\pi\sigma_\perp\omega^{-1}) \tag{2}$$

According to the spectral theory of MHD resonators developed by KRYOV *et al.* (1979, 1980, 1981) and LIFSHITZ and FEDOROV (1986), the spectral properties of an Alfvén continuum of the system described by (1) is determined by two sets of non-local dispersion equations. These dispersion equations coincide with the well-known Dungey ordinary differential equations, derived previously from (1) only for the extreme cases when azimuthal wave number m ≪1 or m≫ 1. In a dipole curvilinear coordinate system the equations corresponding to the toroidal (i. e. with finite m) Alfvén mode have the form

$$\frac{db_\varphi}{dx}=ik_0(1+3x^2)\,\varepsilon_\perp e_\nu$$
$$\frac{de_\nu}{dx}=ik_0(LR_E)^2 b_\varphi \tag{3}$$

where field aligned coordinate $x=\cos\theta$ (θ is co-latitude, measured from the north pole), and R_E is the Earth's radius. Here b_φ and e_ν denote the covariant components of the Alfvén wave magnetic and electric fields, which are related with physical components B_φ and E_ν by

$$B_\varphi=\frac{b_\varphi}{LR_E(1-x^2)^{3/2}}$$
$$E_\nu=\frac{(1+3x^2)^{1/2}}{(LR_E)^2(1-x^2)^{3/2}}e_\nu \tag{4}$$

Boundary conditions for the system (3) stem from the requirement of the non-penetration of a vertical current into the insulating atmosphere and the vanishing of a wave magnetic pressure:

$$j_n(x=\pm x_i)=0$$
$$b_\mu(x=\pm x_i)=0 \tag{5}$$

where $x_i=(1-1/L)^{1/2}$ is the intersection of a field line with the lower boundary of the ionosphere, and sign $+(-)$ corresponds to the northern (southern) ionosphere. The condition (5) actually means that at the lower edge of the ionosphere

$$b_\varphi(x=\pm x_i)=0 \tag{6}$$

The complex eigen frequencies ω_n ($n=1, 2, \cdots$) and eigen functions $b_\varphi(x)$, $e_\nu(x)$ are determined only by the local distribution of the plasma parameters and geomagnetic field geometry along a certain field line. The above mathematical formalism is, in fact, the basis of numerous analytical and numerical models of the magnetospheric resonator. The essential difference between them consists generally only in the choice of the law of the plasma density distribution in space.

In the model developed here the parameters of the resonator at a given latitude are found by numerical integration of (3) with boundary condition (6) over the ionosphere and magnetosphere. The spatial distributions of ionospheric parameters, necessary for the calculation of (2), are determined from the empirical ionospheric model IRI (BILITZA, 1992). The IRI topside profiles are joined to the field aligned distribution of ANGERAMI and THOMAS (1964) (AT) model describing the diffusive equilibrium distribution. Usually, the electron densities and temperatures reconstructed from the northern and southern ionospheres using the IRI model do not coincide (RYCROFT and JONES, 1987). In this case the parameters of AT model were changed to obtain the mean values of N_{eq} and T_e at the magnetospheric equator.

In an alternative version of the model, the parameters of the AT functions are adjusted to the plasmaspheric electron density distribution in the equatorial plane given by the simple power law

$$N_{eq}(L)=N_{eq}(L_o)\cdot(L/L_o)^{-p} \tag{7}$$

The law (7) corresponds well to experimentally observed plasmaspheric densities with parameters in the following range: N_{eq} $(L_o=3)=1\sim2\cdot10^3\ \mathrm{cm^{-3}}$, $p=2\sim4$ (RYCROFT and

JONES, 1987).

For a better physical insight to the low-latitude properties of ULF field line oscillations the structures of the resonator and of the eigen functions along the field line are considered by following POULTER *et al.* (1990). Using the above IRI model, the field aligned distribution of plasma parameters and the structure of ULF eigen oscillations were calculated for two characteristic L-values: L=1.6 and L=1.2. The parameters of the IRI model were chosen to correspond to the geophysical situation experienced by the magnetometer array during the observational period: the monthly mean sunspot number R=200, Month=8 and UT=0. The field aligned Alfvén velocity distribution $c_A(x)$ at L=1.6 (Fig. 10a) exhibits a minimum in the magnetospheric equatorial plane (x=0). Two narrow spikes in the $c_A(x)$ profile near the ends of the field line denote the regions of the ionospheric Alfvén resonator. This resonator is formed between the lower ionosphere (h≃90 km) and the region of steep field aligned gradient of Alfvén velocity at ~$2 \cdot 10^3$ km altitude. The ionospheric Alfvén resonator can accumulate and retain wave energy in the frequency range (0.1~1) Hz and exerts no significant influence on pulsations in Pc3 frequency range. Besides the fact that the minimum of $c_A(x)$ is relatively shallow, in general, this $c_A(x)$ distribution is rather similar to that at middle and high latitudes.

However, the whole picture

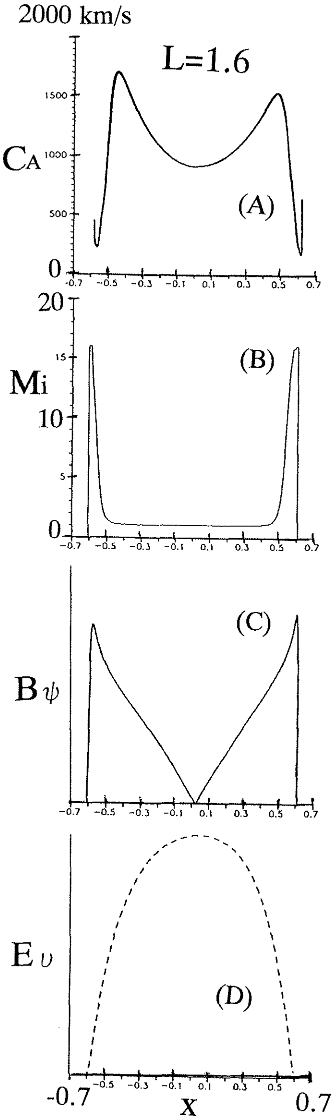

Fig. 10. The field aligned distribution of parameters of the magnetospheric resonator at L=1.6 ($x=\cos\theta$): a) the Alfvén velocity $c_A(x)$; b) the mean ion mass $M_i(x)$; c) the magnetic component $B_\varphi(x)$ (in arbitrary units) of a fundamental standing Alfvén mode; d) electric component $E_\nu(x)$ (dashed line) in arbitrary units.

changes fundamentally at near-equatorial latitudes, L=1.2 (Fig. 11a). Instead of a minimum, Alfvén velocity has a high maximum at the magnetospheric equator. The origin of this modification in the field aligned distribution of $c_A(x)$ can be understood by comparing Fig. 10b and Fig. 11b, where the distribution of mean ion mass, M_i, along the field line is shown. At lower latitudes the heavy ionospheric ions embrace a significantly larger portion of a field line.

These important changes in the distribution of magnetospheric parameters result in the modification of the eigen oscillation structure. Fig. 10c, d and Fig. 11c, d depict the physical components of magnetic field B_φ and electric field E_ν for a standing Alfvén wave (fundamental mode) in the resonator, calculated using equations (4). A usual standing Alfvén wave structure can be seen at L=1.6: the wave amplitude tends to be localized in the region with minimum phase velocity, i. e. near the magnetospheric equator, and the wave structure is symmetrical according to the equatorial plane. At near-equatorial latitudes (L=1.2, Fig. 11c, d) the magnetic and electric components of the wave field are spread more away from the magnetospheric equator, much closer to the ionospheres. Thus it is reasonable to expect a more pronounced influence from the ionospheric plasma on the field line eigen oscillations. Also, the asymmetry of the wave field aligned spatial structure becomes noticeable. The amplitude of the magnetic component in the northern ionosphere is about 1.5 times larger than in the southern one. However, the question about the possibility to observe an asymmetry of ULF amplitudes in conjugate points on the ground requires further investigation.

Now we try to analyze whether the ionospheric influence may cause the obser-

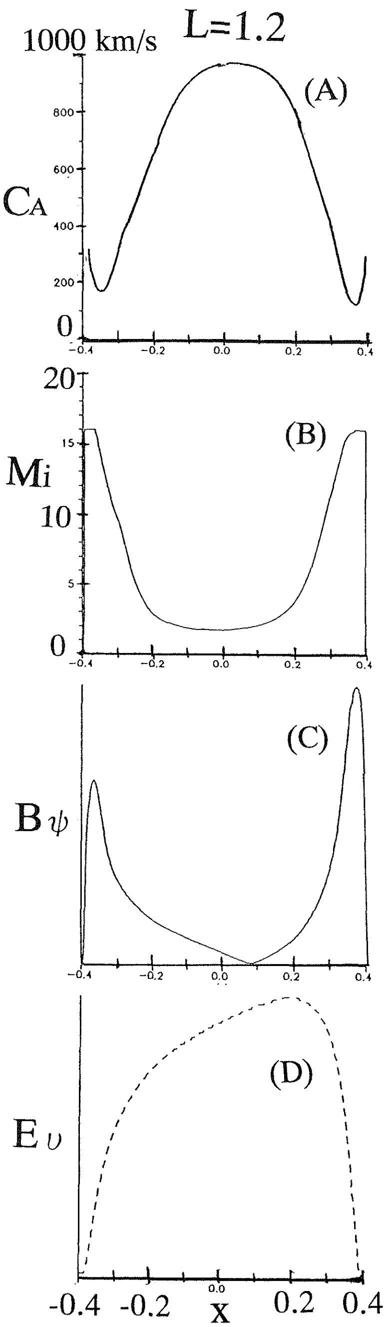

Fig. 11. The same as in Fig 10, but for L=1.2.

ved peculiarities in the meridional ULF spectral distribution. The "diving" of a field lone into the ionosphere causes its mass loading by the heavy ionospheric ions and this results in a decrease in the period of Alfvén oscillations. Comparison of the experimentally observed periods of ULF oscillations with the results of these calculations is presented in Fig. 12. It can be seen that the IRI/AT model describes well the observed ULF eigen periods at near-equatorial stations (KAG, WEP and CBI), i. e. at $\Phi < 30°$. At the same time this model gives values of T_A, which are considerably larger than those observed at mid-latitude stations ADL

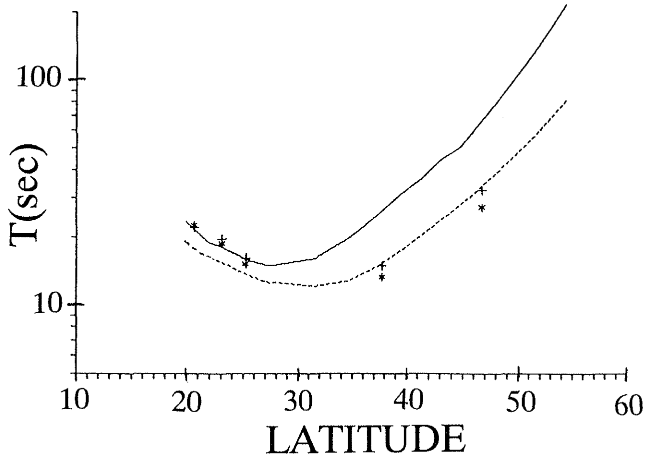

Fig. 12. The latitudinal distribution of the resonance period T_A (Φ) in a day-time magnetosphere for the IRI/AT model (solid line) and for the power-law radial profile of equatorial plasma density (dotted line). The results of observations are indicated by asterisks (day 227) and crosses (day 228).

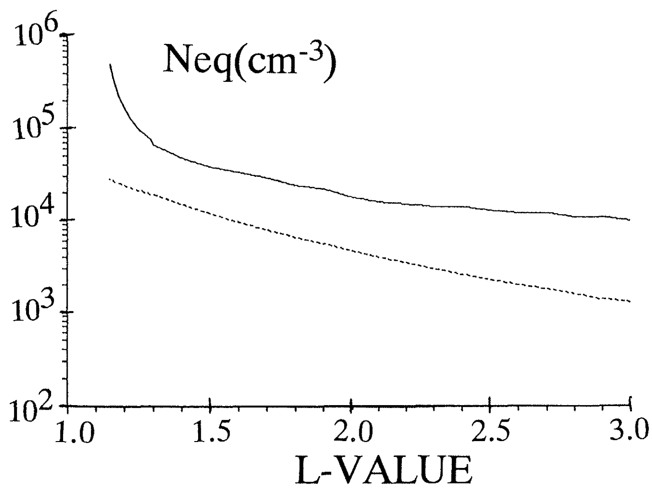

Fig. 13. Radial distribution of plasmaspheric electron density in the equatorial plane according to IRI/AT model (solid line) and as modeled by the power-law function with the parameters $N_0(L_0=3)=1.3 \cdot 10^3$ cm^{-3}, $p=-3.2$ (dotted line).

and MSR (Fig. 12). The discrepancy between the observations and the model at $L \geq 1.5$ is caused by the fact that restoration of the plasmaspheric equatorial plasma density using the diffusive equilibrium functions results in high values of N_{eq}. Figure 13 shows the radial profile of $N_{eq}(L)$, restored with the IRI/AT model, and the power-law profile. The parameters of the latter were chosen to fit the observed periods at $L=1.6$ and $L=2.1$, namely $N_0(L_0=3.0)=1.3\cdot10^3$ cm^{-3}, $p=3.2$, and are within the range of typical values for the day-side plasmasphere. The dependence (7) can not be applied at near-equatorial latitudes, i. e. $\Phi<30°$, where a significant proportion of a field line goes through the upper ionosphere. POULTER *et at.* (1990) presented results for their model also for high solar activity, $F_{10.7}=185$, which approximately corresponds to $R=140$. However, for latitudes near 20° their model predicts an increase in resonant period to about 40-50 sec, well above the values observed in our experiment.

POUTER *et al.* (1990) also suggested that some effects might be possible at low latitudes

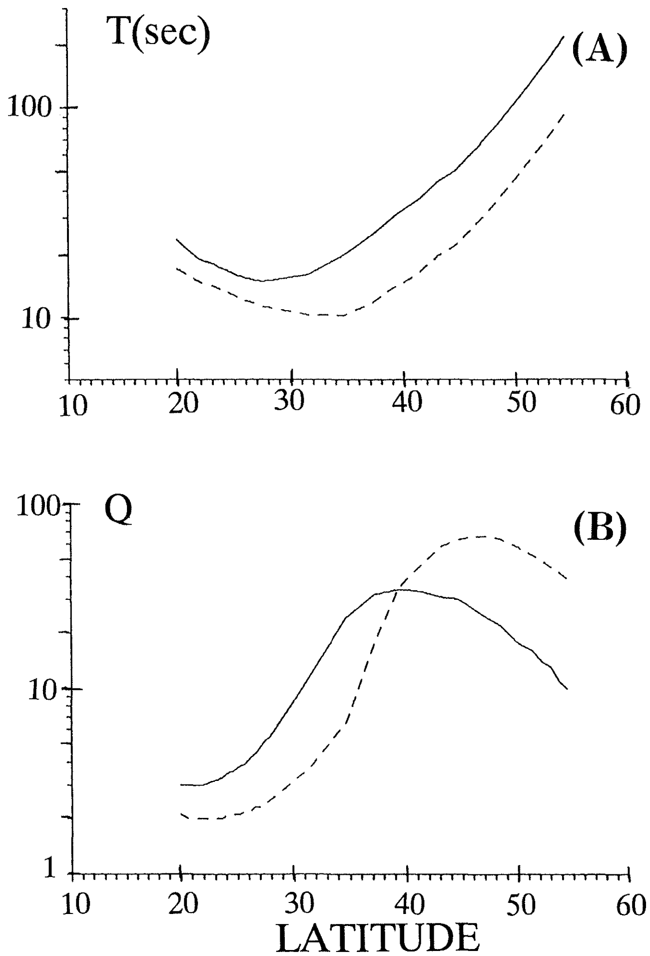

Fig. 14. Parameters of the magnetospheric resonator for the fundamental mode (solid line) and the second harmonic (dashed line): upper plot ; eigenperiods, bottom plot ; Q-factors.

due to coupling between the first and second harmonics. Actually, the IRI/AT model also predicts that at latitudes below 25° the periods of the first and second harmonics become very close, $\Delta T/T \simeq 0.2$ (Fig. 14a). The physical reason for this can be understood by considering the field aligned structure of the second harmonic (POULTER *et al.*, 1990). The maximal displacement of a standing second harmonic of a field line is in the regions dominated by heavy ionospheric ions (Fig. 15). Hence, the mass loading effect for the second harmonic is much stronger than for the fundamental.

However, the excitation of the second harmonic at low latitudes is likely to be doubtful.

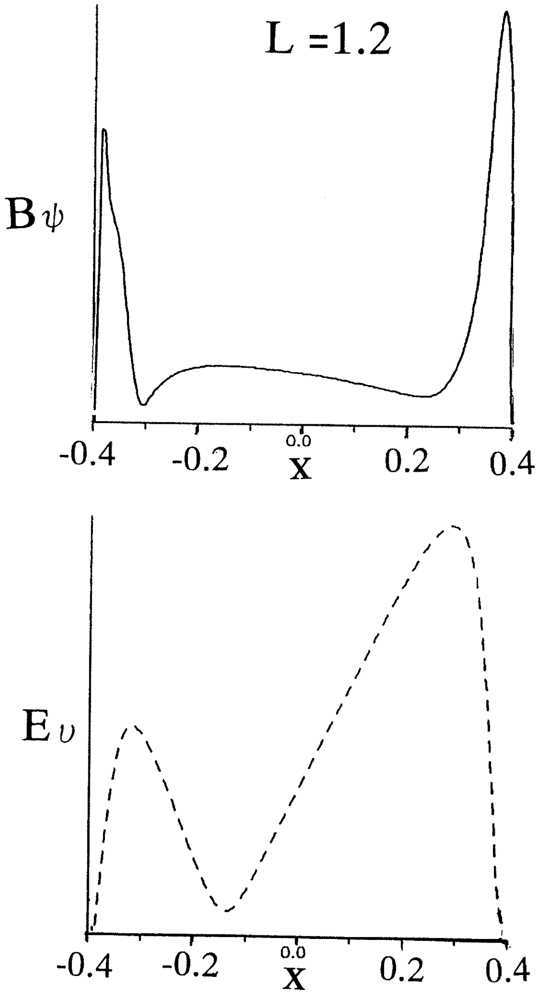

Fig. 15. Field aligned structure of the second harmonic in the magnetospheric resonator at L=1.2. The same format as Fig 10.

It should be remembered that at near-equatorial latitudes a substantial part of an oscillating field line is contained within ionospheric layers with high conductivity. Therefore, Joule dissipation of a standing wave should essentially increase at these latitudes. These qualitative considerations concerning the possible degradation of the resonant properties of the magnetospheric resonator at small L is supported by the numerical calculations with the IRI/AT model. Figure 14b shows the variation of the Q-factor of the resonator with latitude for the fundamental and second harmonic. The sharp decrease of Q at $L<1.5$ is evident for both modes. The very low intensity of Pc3 activity at the stations WEP and CBI might be explained by this predicted degradation in the quality of the magnetospheric resonator at low latitudes. As evident from Fig. 14b, even if the excitation rate in the plasmasphere of both modes is the same, nonetheless the second harmonic should disappear sooner when approaching the Earth's equator.

The previous treatment shows that the ionospheric-magnetospheric models generally give the correct type of $T_A(L)$ variation at low latitudes. Nonetheless, for the one set of parameters used these models cannot describe in detail the meridional profile of $T_A(L)$ in a wide range of latitudes, as Fig. 12 shows. Therefore, some ambiguity remains concerning the correspondence between the observed spatio-spectral structure of ULF waves and the estimated parameters of the magnetospheric resonator.

Fortunately, the 210° MM profile of magnetic stations is partially overlapped by a network of Japanese vertical incidence ionospheric sounding observatories (Fig. 1). The data of these observatories, published in *Ionospheric data in Japan* (1990), have been used to correct the parameters of the ionospheric model. Using standard 1-hour values of f_oF2 and h_mF2, the IRI parameters were corrected to fit the model topside vertical profiles to the ionospheric observations. The parameters of the IRI model determined this way, were then used to reconstruct the electron and hydrogen distribution along a field line in the plasmasphere over the observation sites. The overall radial distribution of the plasmaspheric electron density

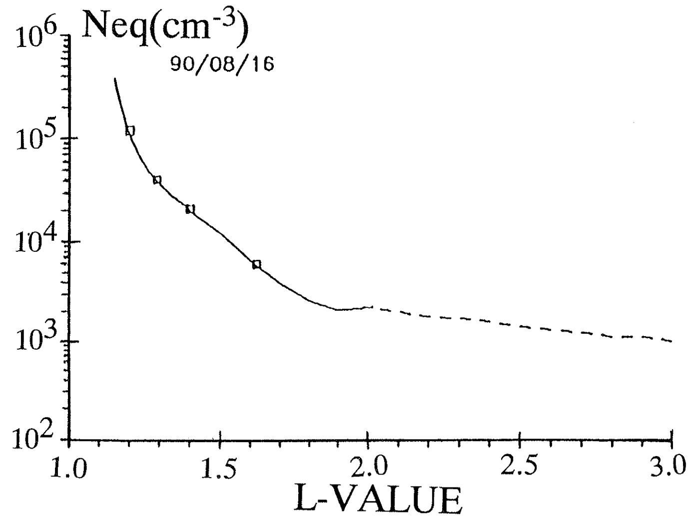

Fig. 16. Meridional profile of the equatorial plasma density, reconstructed using the ionospheric observatory data (solid line) and predicted by the empirical whistler/ISEE model (dashed line).

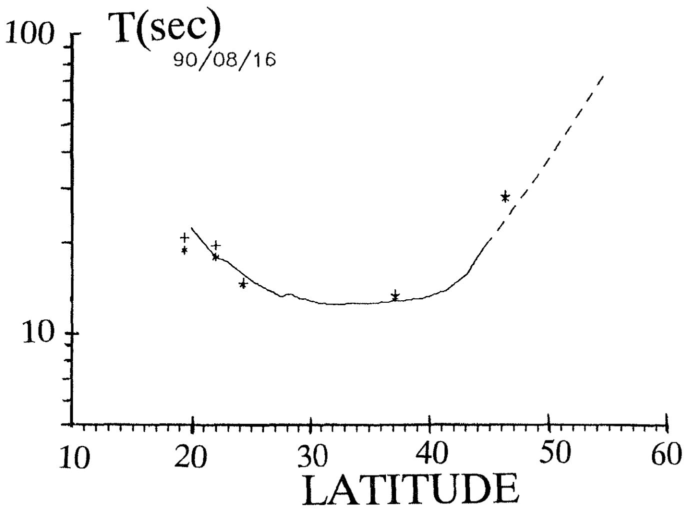

Fig. 17. Latitudinal distribution of the resonance period $T_A(\Phi)$ for the event of August 16, 1900 for the IRI/AT model (solid line), corrected using the ionospheric observatory data, and for the empirical whistler/ISEE model (dashed line). The results of observations are marked by asterisks (H peak maxima) and crosses (H/D ratios).

in the range L=1.15～2.0 has been obtained with a polynomial interpolation of the predetermined values of N_{eq}. The radial profile of electron plasma density for the event of August 16, 1990 is shown in Fig. 16 by a solid line. The ionospheric stations (their data are shown by the squares in Fig. 16) only cover L<2. In order to have some reference level of N_{eq} at higher L, we have employed the empirical equatorial electron density model of CARPENTER and ANDERSON (1992). This model is based on whistler and ISEE data, and can be applied to the saturated plasmasphere at L>2.25. Nevertheless, we have extrapolated this model to L=2, as shown in Fig. 16 by the dashed line. Because this model does not account for the possible presence of heavy magnetospheric ions, it gives a lower estimate of the equatorial plasma density. Comparison of Fig. 13 and Fig. 16 shows that for high solar activity the IRI/AT model predicts essentially higher values of N_{eq} than the CARPENTER and ANDERSON (1992) model.

The latitudinal variation in the fundamental eigen period of the magnetospheric resonator and the observational results is presented in Fig. 17. The equatorial hydrogen distribution corresponds to the one shown in Fig. 16, while the field-aligned distribution of the heavy ionospheric ions has been taken from the IRI/AT model. The correspondence between the numerical model results, based on the ground ionospheric data, and observational results is good, keeping in mind the roughness of the available ionospheric information. The correspondence between the eigen period at ADL(L≃2.1) and the whistler/ISEE model is worse. However, this is not unexpected, since ADL is beyond the range over which we expect this model to be valid. Also, it is difficult to estimate how far the plasmasphere is at the moment of ULF event from being saturated. For all the other ULF events under consideration the correspondence between the observed profile of T_A (Φ) and the IRI/AT model of the magnetospheric resonator has been improved after using the vertical ionospheric sounding data.

4. Conclusion

Data from the "210° MM" network reveal a number of specific features of low-latitude Pc3 pulsations, including abnormal dependence of resonant period T_A (L) on L and drastic increase in ionospheric damping. These features are well described by a model developed for the ionosphere-magnetosphere resonator. The predicted non-monotonic dependence of ULF eigenperiod on latitude (POULTER *et al*., 1988, 1990) was experimentally supported. However, the observed periods were much lower than given by the POULTER *et al*. (1988, 1990) model. At the same time, the IRI/AT model agrees well with the experimental data at near-equatorial stations, but does not fit the observations at mid-latitude stations. Thus, according to our ULF data, the BAILEY (1983) model overestimates the role of oxygen ions compared with the empirical IRI model, while the AT diffusive equilibrium model overestimates the plasmaspheric plasma density, as compared with the BAILEY (1983) model. This preliminary result requires a detailed comparison between the various ionospheric models for given geophysical situations and observational data before any definite conclusion can be drawn. However, correction of the IRI/AT model parameters to account for observed ionospheric critical frequencies has improved the agreement with the ULF data. Joint analysis of the ionospheric and magnetic data encourages the prospect that ULF observations could be used as a low-latitude extension of whistler observations to monitor plasma density variations in the plasmasphere.

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