TERRESTRIAL ELECTROMAGNETIC NOISES

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The terrestrial electromagnetic noise environment in the frequency range from ULF to VLF/ELF has been reviewed mainly on the basis of our latest results, and important new findings have been described.

1. INTRODUCTION

The electromagnetic wave phenomena near the Earth in these frequency ranges, include, 1) magnetospheric Pc1 pulsations, 2) ELF and VLF sferics, 3) VLF/ELF magnetospheric waves and 4) seismo–electromagnetic waves. The emphasis in this report is placed on the direction finding measurements for these waves observed on board satellites and on the ground for the detailed understanding of these waves. We will present the essential summary of our recent achievements in the following.

2. MAGNETOSPHERIC ULF EMISSIONS

Magnetospheric pulsations in the high frequency range (0.2 – 5 Hz) (so-called Pc1 pulsations) have been investigated by many workers [e.g., 1], but these studies have been based on the amplitude measurement. Only a few papers have dealt with the polarization studies [2–6]. Two papers on Pc1 pulsations have been by the authors by making full use of the polarization studies. We will summarize the important and new findings.

The polarization of irregular pulsations of diminishing period (IPDPs) observed in Iceland ($L = 6-7$) and at Syowa has been investigated and some new findings have emerged: 1) the IPDP event which has so far been considered to be one single event, normally consists of a few subelements (or slopes) and 2) in general the first major element occupying the lowest frequency range is left–handed circularly polarized and the second major element in the higher frequency range is right–handed polarized. A hypothesis is presented to account for these observational facts. The first fact is indicative of the nature of successive particle injections during a substorm. The protons with higher energy during the first injection seem to encounter the bulge of the plasmasphere or plasmatail in the local time (L.T.) sector of 15 – 18 h and at $\bar{L} = 6-8$, which would result in the generation of ion cyclotron waves. This expectation is supported by observational fact, especially the left–handed circular polarization of the first element observed in Iceland. Furthermore, the delay time of drift of protons for the first injection in a time–dependent convection electric

field is calculated, and is compared with the observed time delay and the slope of the fine structures. Then, if we suppose that protons with lower energy are injected during a subsequent burst, they meet the plasmapause body at $L < 5$ and at L.T.> 18 h and, due to the ionospheric duct propagation over the great distance between the generation region and observing stations, the polarization in Iceland would be right–handed, which is consistent with observations. See the details in Hayakawa et al. [7].

The statistical dependence of the occurrence rate of polarization (left–handed, right–handed and linear) of Pc1 micropulsations on local time and wave frequency has been deduced on the basis of the data observed in Iceland and in Antarctica ($L = 6 - 7$) during the whole year of 1985. It is found that left–handed polarized pulsations tend to be most numerous until L.T. = 14:00 and at wave frequency of 0.4 – 0.6 Hz in Iceland, while the corresponding peak occurrence rate of right–handed polarization is found to take place at later L.T.s and at a frequency of 0.2 – 0.4 Hz in Iceland. The joint consideration of these statistical characteristics with the previous classification of Pc1 pulsations, and also simultaneity and conjugacy of polarization at different stations are discussed. See the details in Hayakawa et al. [8].

3. ELF AND VLF SFERICS

ELF/VLF sferics are originated from lightning discharges in the atmosphere, and they propagate in the Earth–ionosphere waveguide [1]. We have given a new life to this old subject of ELF/VLF sferics, and we will summarize the essential findings.

The small dispersion effects of tweek sferics were analyzed to deduce the propagation distance and the ionospheric reflection height [9], but the accuracy was terribly bad. The propagation characteristics of tweek sferics (with small dispersion effect) have been analyzed by a new method in which the observed tweek signal is mixed with its corresponding pseudo–sferic signal, and the resulting nearly–stationary signal is analyzed by a conventional spectral analysis. Then, the propagation distance and ionospheric height are estimated in such a way that the squares of the difference of the instantaneous frequencies of the observed and pseudo sferic signals are made minimum. The method is applied to the VLF/ELF data simultaneously observed at Moshiri, Sakushima and Kagoshima in order to demonstrate the effectiveness of the method, and the accuracy in derermining the propagation distance and ionospheric height is estimated to be less than 1%. The locations of many sferics determined by this method were compared with the corresponding those by the cloud map of the meteorological satellite, and we had a good agreement between the two. As the conclusion, we want to emphasize the ease of this method (just the measurement of wideband signals, but at a few spaced stations). Further details are found in [10].

Another new direction has been carried out by our group for tweek sferics. In this experiment we need the simultaneous measurement of three field components (two horizontal magnetic and one vertical electric) for our field-analysis direction finding. We developed this direction finding system for magnetospheric VLF/ELF radio waves which are generally elliptically polarized, but it can be applied to any elliptically polarized waves. Hence, we have applied this direction finding technique to tweek sferics in order to estimate the detailed wave characteristics (incident and azimuthal angles, wave polarization, and their frequency dependencies) of tweek sferics observed in South China. It is then found that the wave polarization of the 1st-order mode at the frequency above its cutoff frequency ($f_{1c} = 1.7 - 1.8$ kHz) is always left-handed and it becomes exactly left-handed circular when the wave frequency decreases down to the f_{1c}, together with the fact the incident angle becomes zero (vertical). Whereas, the 0th-order mode at frequency below f_{1c} is found to be linearly polarized. These wave properties are first interpreted qualitatively, and then we try to explain them in terms of the full wave theory in the Earth-ionosphere waveguide in which the realistic electron density profiles of the lower ionosphere are assumed. Finally, it is suggested that the measurement of wave polarization would be useful in studying the formation mechanism of tweek tails, the coupling into whistler mode waves of lightning discharges, the lower ionospheric density profile etc. Further details are given in [11].

Some analytical studies have been done for the wave solution for the VLF modes near cut-off frequencies in the high-latitude Earth-ionosphere waveguide. The vertical inhomogeneity of the lower D-region of the ionosphere is included in the form of a simple exponential profile of the conductivity. The E-region is represented as a magnetoactive plasma with sharp bottom, at which the electron density increases strongly and then varies slowly at the scale of the local wavenumber. Approximate expressions are derived for the phase velocities and attenuation rates of the VLF modes near cut-off frequencies ($f_{1c} \sim 1.5 \div 1.7$ kHz, $f_{mc} \sim m f_{1c}$, $m = 1, 2, \ldots$, in the night-time ionosphere conditions). They indicate a strong dispersion of the QTE modes (left-hand polarized near the corresponding cutoff frequencies). Taking into account the D-region vertical inhomogeneity results in a small strengthening of the QTE modesdispersion, but it is in principle necessary for correct description of the VLF signal amplitude (in particular, tweek sferics and whistlers with additional traces in the Earth-ionosphere waveguide). Further details are given in [12].

4. VLF/ELF MAGNETOSPHERIC WAVES

Two noses are treated as magnetospheric and ionospheric waves; 1) whistlers and 2) VLF/ELF emissions.

There has been published a recent review paper on low- and equatorial-latitude whistlers [13]. The propagation (ducted or no-ducted) of whistlers at low latitudes has been discussed based on the ground and satellite observations of both natural whistlers and VLF transmitter signals.

The propagation mechanism of low-latitude and equatorial latitude whistlers is investigated on the basis of spaced direction finding measurements in South China. Observations were made continuously in the local time interval from 00h to 04h during the period of January 5–11 1988 at the three stations (Zhanjiang (geomagnetic latitude 10.1°), Guilin (14.1°), and Wuchang (19.4°)) and two horizontal magnetic components and one vertical electric field component were simultaneously recorded over a wide frequency range to enable comprehensive direction finding. Two major occurrence peaks and two minor ones have been analyzed and the following experimental results have emerged.

1) The whistler occurrence at very low latitudes is generally very small compared with that at low latitude (geomagnetic latitude > 20°), but once it occurs, the occurrence rate becomes comparable to that at low latitudes.

2) The whistler dispersion is single-valued at any particular local time.

3) The ionospheric exit region of whistlers is very much restricted to the geomagnetic latitude range of 10° – 14°, and there are no observed whistlers whose path latitude is between 14° and 20°.

4) The extent of their ionospheric exit region is very stable on different days, and the radius of the distribution is less than 40 – 50 km.

5) Surprisingly high occurrence of echo train whistlers is observed.

6) The propagation of whistlers in the Earth-ionosphere waveguide after ionospheric transmission is more likely toward higher latitudes than toward the equator and the subionospheric propagation seems to exhibit a horizontal beaming around the magnetic meridian plane. We attempt to interpret these characteristics of the observations in terms of either nonducted or field-aligned propagation, but discussion indicates that especially findings 4 and 5 are strongly indicative of field-aligned propagation for very low latitude whistlers localized in geomagnetic latitudes of 10° – 14°. See the details in [14].

Then, we have located simultaneously the causative sferics of above-mentioned very low latitude whistlers, in order to aid our understanding of the magnetospheric propagation mechanism of very low latitude whistlers [15]. It is found that the causative sferics of very low latitude whistlers are very widely distributed in a range from 500 to ~ 2500 km from the conjugate point of whistler ionospheric exit region previously determined. This fact lends further support to our previous implication that magnetospheric preferred paths supporting field-aligned propagation are extremely rare in occurence and that there has existed a preferred and stable magnetospheric path in a very restricted location on the day of high whistler activity.

The subionospheric propagation before entering the duct in the opposite hemisphere and/or after the ionospheric penetration in the observer's hemisphere, has been studied in [16]. An analysis of the excitation of a night-time Earth–ionosphere waveguide near the cut-off frequencies of the waveguide modes ($f_{1c} \sim 1.5-1.7$ kHz, $f_{mc} \sim mf_{1c}$) is presented as applicable to very unusual whistlers with additional dispersion. Additional dispersion of a whistler in a night-time Earth–ionosphere waveguide is caused by weakly-attenuated QTE_m waveguide modes (left-hand polarized near respective cut-off frequencies0, excited by the whistler inside the waveguide as a result of anisotropy of the ionosphere. Far from the corresponding cut-off frequencies f_{mc} (separated by several hundred Hz), the attenuation of the first QTE_m modes at medium and low latitudes is appreciably higher for West–East propagation compared with East–West propagation. Close to the cut-off frequencies ($f - f_{mc} < 100$ Hz), these modes have attenuation coefficient minima which exhibit a relatively weak dependence upon azimuth.

Another important noise source in VLF/ELF is VLF/ELF emission generated in the ionosphere and magnetosphere. Recently a series of review papers have been published by the authors on chorus [17], mid-latitude and plasmaspheric hiss [18], auroral hiss [19], and periodic and quasi-periodic VLF emissions [20], and you will be able to learn the present situation of the investigation of different kinds of VLF/ELF emissions. These reviews are based on the observations on board satellites and on the ground.

The importance of in-situ direction finding in the study of above VLF/ELF emissions has been emphasized in [21]. In this report, recent direction finding results for a few categories of VLF/ELF emissions have been presented in order to discuss their generation mechanism. The wave phenomena treated there are half-gyrofrequency VLF/ELF emissions, ELF hiss in detached plasma regions of the magnetosphere, plasmaspheric ELF hiss, VLF/ELF chorus and hiss-triggered chorus. Especially, it is found that half-gyrofrequency VLF/ELF emissions are generated near the equator, at the frequency above one half the electron gyrofrequency and that they are quasi-electrostatic whistler-mode waves, with wave normals very close to the oblique resonance angle. Also, the detailed spectral analysis and direction finding have suggested that a chorus is triggered from a monochromatic signal (called a wavelet) existing in the hiss band, such that the mechanism is exactly the same as the coherent-wave particle interaction for triggered emissions from the VLF transmitter signal.

5. SEISMO-ELECTROMAGNETIC ULF AND ELF/VLF EMISSIONS

An additional noise source is seismo-electromagnetic emission in ULF and VLF/ELF ranges. The measurements of emissions in the frequency range 8 Hz – 20 kHz during 180 orbits of the Intercosmos-24 satellite from November 16, 1989 to December 31, 1989, are analyzed. Twenty-eight rather strong earthquakes (5.2 ¡ Ms ¡ 6.1) took place during this period. The following findings have emerged from the analysis of these events.

1) Emissions in the two frequency bands with spectrum maxima at ULF–ELF ($f < 1000$ Hz) and a VLF ($f = 10 - 15$ kHz) are typcially observed as bursts in the region nearly above the earthquake epicenter.

2) ULF–ELF emission spectrum intensity decreases with increasing frequency.

3) Only VLF emissions are observed far from the epicenter but near the appropriate L shell.

4) Emission occurrence probability is a maximum at 12–24 h before the main shock.

Finally, the possible theoretical concepts are discussed in connection with the experimental results, and we suggest a plausible mechanism of precursory ELF and VLF emissions of earthquakes. Further details are given in [22].

6. SUMMARY

Recent achievements on terrestrial electromagnetic noises have been summarized, and they would contribute to the further understanding of the characteristics and nature of different kinds of noises in the lower frequency range.

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