Evidence of a new electromagnetic resonance discovered at Teoloyucan geomagnetic station, México?

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Resumen

Se presenta evidencia de una nueva estructura de resonancias geomagnéticas observada en la estación Teoloyucan, México (ERT, Estructura de las Resonancias en Teoloyucan) en el periodo 1999-2001. Se observan dos líneas resonantes en las bandas de frecuencias f_{R2}=10.2-11.1 *mHz* y f_{R2}=13.6-14.5 *mHz*, a veces acompañadas de harmónicos de bajo y alto nivel. La polarización de la resonancia es practicamente lineal: aparece solamente en la componente H- (componente horizontal), y no hay ninguna firma en las componentes Z- o D- (componentes vertical y declinacion). La intensidad de la resonancia muestra cierta dependencia horaria, ambas líneas resonantes casi desaparecen durante el periodo 10-18 UT (04-12 LT). No se observa ninguna estructura similar en las estaciones de referencia más cercanas a la estación Teoloyucan (TEO), como Los Alamos (LAL, USA), y Jicamarca (JIC, Perú). Se muestra que hay una correlación de las resonancias con la actividad geomagnética, así como de un cambio de su estructura durante grandes y moderados terremotos. Se discuten posibles modelos responsables de la generación de la ERT.

Palabras clave: Guía de ondas en la ionosfera, resonancia electromagnética, velocidad de Alfvén.

Abstract

Evidence of a new geomagnetic resonant structure observed at Teoloyucan station, Mexico (TRS, Teoloyucan Resonant Structure) in the period 1999-2001, is presented in the paper. Two resonant lines were observed at the frequency bands f_{R2}=10.2-11.1 *mHz* and f_{R2}=13.6-14.5 *mHz*, sometimes accompanied by low and high level harmonics. The polarization of the resonant structure is purely linear: it appears in the H-component (horizontal component) only, and no resonant line is observed either in Z- or D-components (vertical and declination components). The intensity of the resonance structure displays certain time dependence, both resonant lines almost disappear during the period 10-18 UT (04-12 LT). No similar resonant structure was observed at the nearest to Teoloyucan (TEO) referent stations, such as Los Alamos (LAL, USA), and Jicamarca (JIC, Peru). It was shown that there is a correlation between the resonances and geomagnetic activity, and that there are changes in their structure at the time of major and great earthquakes. Possible source models responsible for the TRS generation are discussed.

Key words: Ionosphere waveguide, electromagnetic resonance, Alfvén velocity.

Introduction

Two global EM (electromagnetic) ionosphere resonances named after physicists Schumann and Alfvén, were discovered in the last century, and their properties are now well studied. Schumann ionosphere waveguide, mathematically predicted by Winfried Otto Schumann (Schumann, 1952), is formed in the cavity between the Earth's surface and the conductive ionosphere, generating EM resonances at frequencies f ~ 7.8, 14, 20, 26, 33, 39, 45, 60 Hz (Schumann, 1952; Bliokh *et al*., 1980; Sentman, 1987). The existence of Schumann Resonances (SR) is considered to be the result of EM noise trapping in the ionosphere waveguide, which comes from 3 global sources of thunderstorm activity: South-East Asia, South-East Asia and South America. Accordingly, there are 3 dominant temporal maxima in the intensity of the resonant structure, at 9 UT (Universal Time) peak, 14 UT and 20 UT that allow for the monitoring of the global thunderstorm activity. This after excluding the local time dependence, due to changes in D region in the ionosphere (Sentman y Fraser, 1991). Another quite localized and rather curious generation mechanism, just for the 8th SR mode, comes from the North American power grid, which operates at almost the same frequency, 60 Hz. Recent studies confirm the dependence between the SR and Solar activity: resonant frequencies rise slightly during a solar X-ray burst (Roldugin *et al.*, 2003). Also, it has been theoretically shown that the penetration of the SR components (especially, magnetic ones) into the atmosphere is 2-3 times deeper than it was thought of before (Grimalsky *et al.*, 2005).

The IAR, Ionosphere Alfvén Resonator, was theoretically predicted (Polyakov, 1976) by analogy with the ionosphere waveguide (Schumann Resonance), operating in the vertical direction on the shear Alfvén wave. Polyakov and Rapoport (1981) and later Lysak (1993), have shown that such waves can be trapped in the cavity with 2 borders (F-layer of the ionosphere as the lower border and at about 3000 km in the magnetosphere as the upper border), characterized by sharp gradients of the Alfvén velocity. Experimental evidence for the existence of IAR came from Belyaev *et al.* (1989, 1990). Up to 15 modes of the IAR can be resolved starting from f = 0.1-10 Hz (PC1 pulsations frequency band) up to the the 2nd SR mode at *f = 14* Hz. After the confirmation of the existence of IAR at medium latitudes, they proved that there is a global character of the event, presenting observations at high altitudes (Belyaev *et al.*, 1998, Yahnin *et al.*, 2003). The properties of the IAR depend strongly on the ionosphere properties, especially of the most ionized F-layer of the ionosphere. More recent studies indicate that the occurrences of IAR as well as the frequency difference between the IAR modes are much higher during the local night time compared to day time, and in the same way, during the local winter unlike to the summer season (Bosinger *et al.*, 2002; Yahnin *et al.*, 2003, Molchanov *et al.*, 2004). Similar tendencies are also observed in relation with Space Weather: the mentioned parameters increase during solar activity maximum and during geomagnetic storms. Analogously to the Schumann resonance, many studies consider that the energy for the generation of IAR has the same origin and is driven by 3 global sources of thunderstorm activity. Nevertheless, modern studies show theoretically and experimentally (Fedorov *et al.*, 2006) that other generation mechanisms (such as local discharges, discharges at conjugated point and even neutral wind fluctuations at the height of the ionosphere E-layer) can take place and even be much more considerable.

In this paper we present evidence of the recently discovered electromagnetic resonance based on the experimental observations in the Teoloyucan geomagnetic station (México) and provide a discussion on the possible mechanisms of their generation. Prior publications (Kotsarenko *et al.*, 2005a 2005b, 2007) were oriented primarily to seismo-related application with the observed phenomena. The aim of the present paper is to summarize and extend studied results and give provisional discussion on the possible mechanisms of the observed resonances.

Experiment and results

The new resonance structure (TRS) of the geomagnetic field was discovered during the analysis of the data recorded at Teoloyucan geomagnetic station (Central Mexico, magnetic coordinates: *MLat=29.1 MLong=330.1*, *L=1.31*). This station was equipped with a 3-axial Fluxgate magnetometer designed at UCLA, operating at 1 Hz sampling rate frequency, with a GPS system for data synchronization. The precision (noise power) of the instrument is 10^{-3} nT^2/Hz at 1 Hz. In our study we also used data from the reference geomagnetic stations: Los Alamos (LAL, USA, *L=1.97*), and Jicamarca (JIC, Peru, *L=1.0*), integrated to the Mid-Continent Magneto-seismic Chain (McMAC, see Chi *et al.*, 2005) and Beijing (BJI, China, *L=1.30*) station equipped with the same instrument.

The resonances have been observed in the *H*-component at the frequency bands f_{R1}*=10.2-11.1 mHz* and f_{R2}*=13.6-14.5 mHz* (Fig. 1). The resonance structure has a proper hourly character: it almost disappears during the period 10-18 UT (Fig. 2), and the central maximum is sometimes followed by higher and lower harmonics (Fig. 1 and 3). The polarization of both resonances is practically linear. In turn, nothing similar was found at the nearest to Teoloyucan (TEO) geomagnetic stations, such as Los Alamos (LAL, USA), and Jicamarca (JIC, Peru) (Fig. 3). A very similar resonance structure was also observed at Beijing (BJI) geomagnetic station, but it was not found at the nearest to it Chinese station (situated at about 150 Km from Beijing). The frequency of the first resonant line observed at BJI was the same as that of Teoloyucan f_{R1}, but with an elliptical polarization. In fact, the elliptically polarized resonances were observed in Teoloyucan during 21-22 September, 1999. A wide spectral resonant structure, mostly polarized in H- and D-components (Fig. 4, area marked by ellipse), was generated approximately at 18 UT hrs, September 21, 1999 during quiet geomagnetic conditions and disappeared at 12-13 UT, September 22 just with the beginning of an intense magnetic storm with SSC (Sudden Storm Commencement).

It was shown (Kotsarenko *et al.*, 2005b) that there is a moderate correlation of the intensity of the resonances with solar activity (estimated by Dst geomagnetic index): $Kcorr_{max}$ ~ 0.70 with about 2 hours time lag. In addition, the resonant structure reveals changes in their properties probably related to the processes of the earthquake preparation. We observed obvious modifications of the TRS in the long-time scales: growth of the frequency of

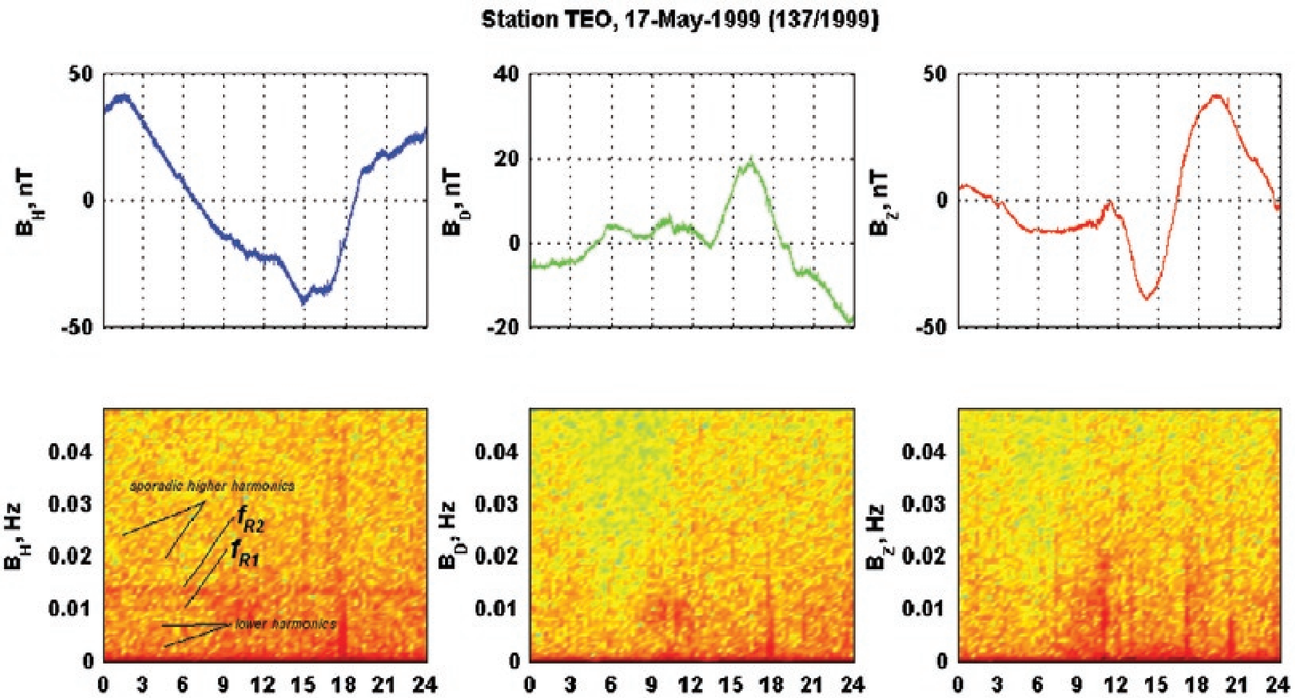

Fig. 1. Observations of the new electromagnetic resonance structure. Teoloyucan station, May 17, 1999. Upper 3 panels: signal, 3 magnetic components. Bottom panels: corresponding spectra.

both resonances in the period of one month to 1 week before the strongest EQs (earthquakes) that occurred in 1999-2001 and a depression of the resonant structure just few days before these EQs (Kotsarenko *et al.*, 2005a, 2005b). The study of the intermediate and short-time (near-seismic) changes in the TRS revealed more details: TRS undergoes pre-seismic, near-seismic and post-seismic depressions or decreases of the resonant quality Q factor (smearing of the resonant structure), possibly related to the mentioned EQs (Kotsarenko *et al.*, 2005b, 2007).

Discussion

The observed phenomena require a variety of arguments "for" and "against" the natural character of TRS. The strongest reason "against" or, in other words, an argument for its *artificial* character is that the quality factor of the resonant structure is too good, which is points more to an electromagnetic interference rather than to a nature source. By this, we mean that it can be generated in the power line as an ULF (ultra low frequency) fluctuation. In favor of a natural cause, another possible source can be proposed, which is rather hypothetical, as coming from an underground flow, which generates EM signals through an electro-kinetic effect. In any case, ground or underground source should have certain geometry: extensive, solitary, straight and oriented in S-W direction perpendicularly to the Teoloyucan geomagnetic station, due to the observed polarization of the resulting resonances in the H- (S-N) component.

Despite the high quality of the resonances, their good correlation with geomagnetic activity argues for a natural origin. Moreover, high sensitivity of the resonant structure to the processes taking place during the EQ preparations (Kotsarenko *et al.*, 2005a, 2005b and 2007) points to the ionosphere as most probable cause of their alteration due to modifications of the ionosphere parameters (Grimalsky *et al.*, 2007). It worth to note that very similar regimes of the IAR response to seismic events were recently reported (Guglielmi *et al.*, 2006 and Potapov *et al.*, 2008).

A possible explanation for phenomena observed at Teoloyucan refers to the possibility of existence of a longitudinal Alfvén resonance, theoretically formulated by Greifinger and Greifinger (1968). Hypothetically, Alfvén wave can be trapped between two cusps of the equatorial ionosphere anomaly which have large Alfvén speed gradients. By that, we mean that a longitudinal Alfvén resonance, in the frequency range $f=10\text{-}14$ *mHz*, $f=V_A/2\pi R_Z$ for the values of Alfven velocity $V_A=400\text{-}600$ *km/s* (effective Alfvén velocity at heights h~2000 km, Gulgielmi and Pokhotelov, 1990) fits well with the observed values. Those resonances are expected but have never been observed.

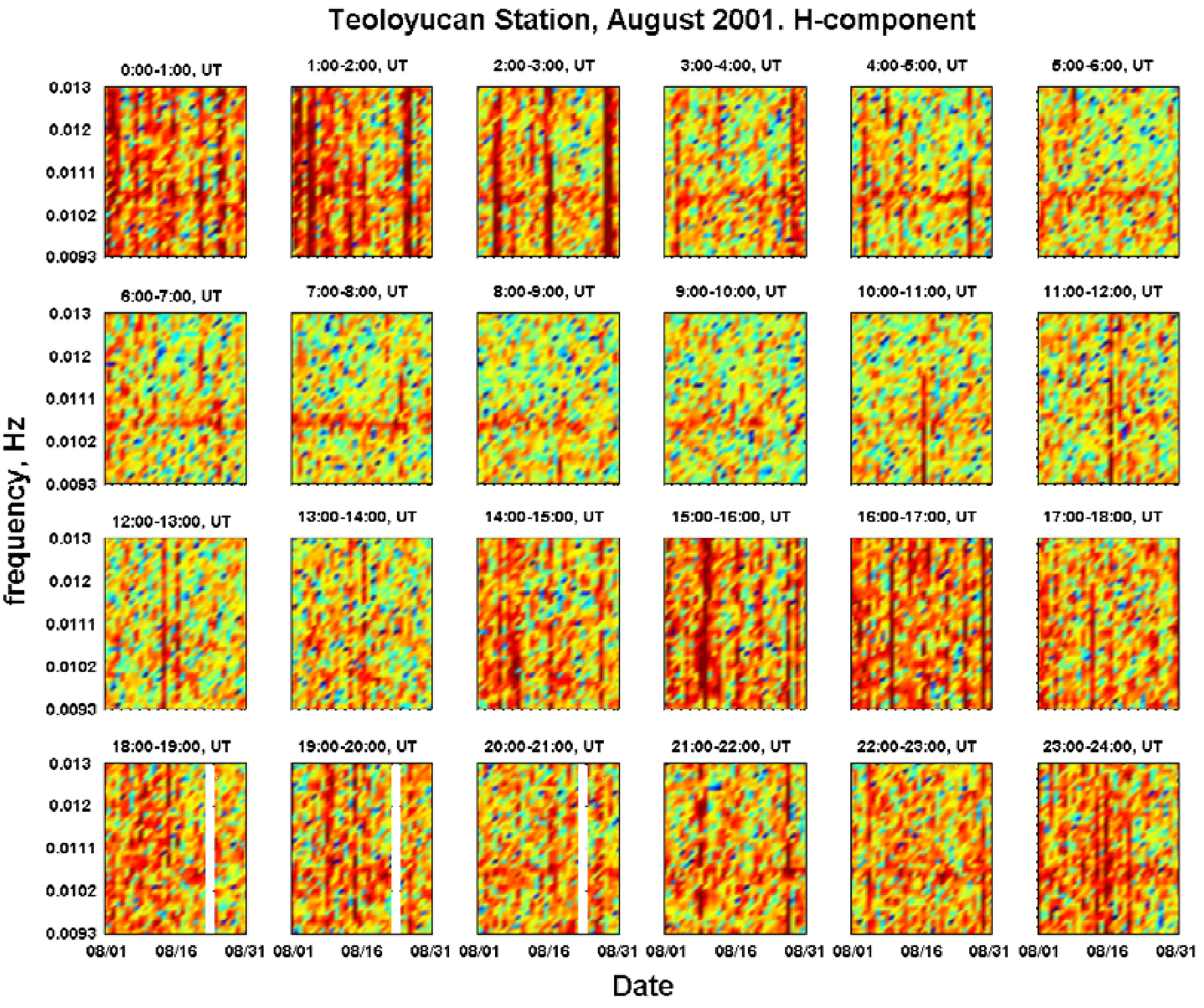

Fig. 2. Temporal evolution of the f_{R1} resonant mode. Teoloyucan station, August, 2001.

Preliminary simulations of the incidence of the ULF Alfvén wave from the magnetosphere downwards have demonstrated that at the Earth´s surface the ULF magnetic field has a linear dominating polarization in the plane that includes the direction of the geomagnetic field and the vertical to the Earth's surface (Grimalsky *et al.*, 2007). The simulations were based on direct solving of the Maxwell equations within the lower magnetosphere – ionosphere – atmosphere – lithosphere (LAIM) together with boundary conditions at the magnetosphere (Z = 800 km, the amplitude of the incident Alfvén wave was given) and at the lithosphere (Z = -30 km, ideal reflection). LAIM was represented by an anisotropic planar structure with effective dielectric permittivity tensor $\hat{\varepsilon}(\omega, Z)$. Therefore, it is possible to mention qualitatively that namely the Alfvén wave can be the origin of the observed resonances. Nevertheless, a direct comparison of new observations and more simulations are still needed.

Finally, there may be a potential difference among the 3 phenomena mentioned before. In this way, the similarity of the frequencies but the difference in the polarizations between resonant structures observed at Teoloyucan and Beijin stations requires more detailed study. Also, the elliptically polarized spectral structure (Fig. 4) can be considered as a special case phenomenon most possibly generated by the forthcoming earthquake (Ms 7.5, September 30, 1999) at the earthquake preparation zone (Kotsarenko *et al.*, 2007) whereas TRS (Fig. 1 and 3) has a more stable and permanently observed character.

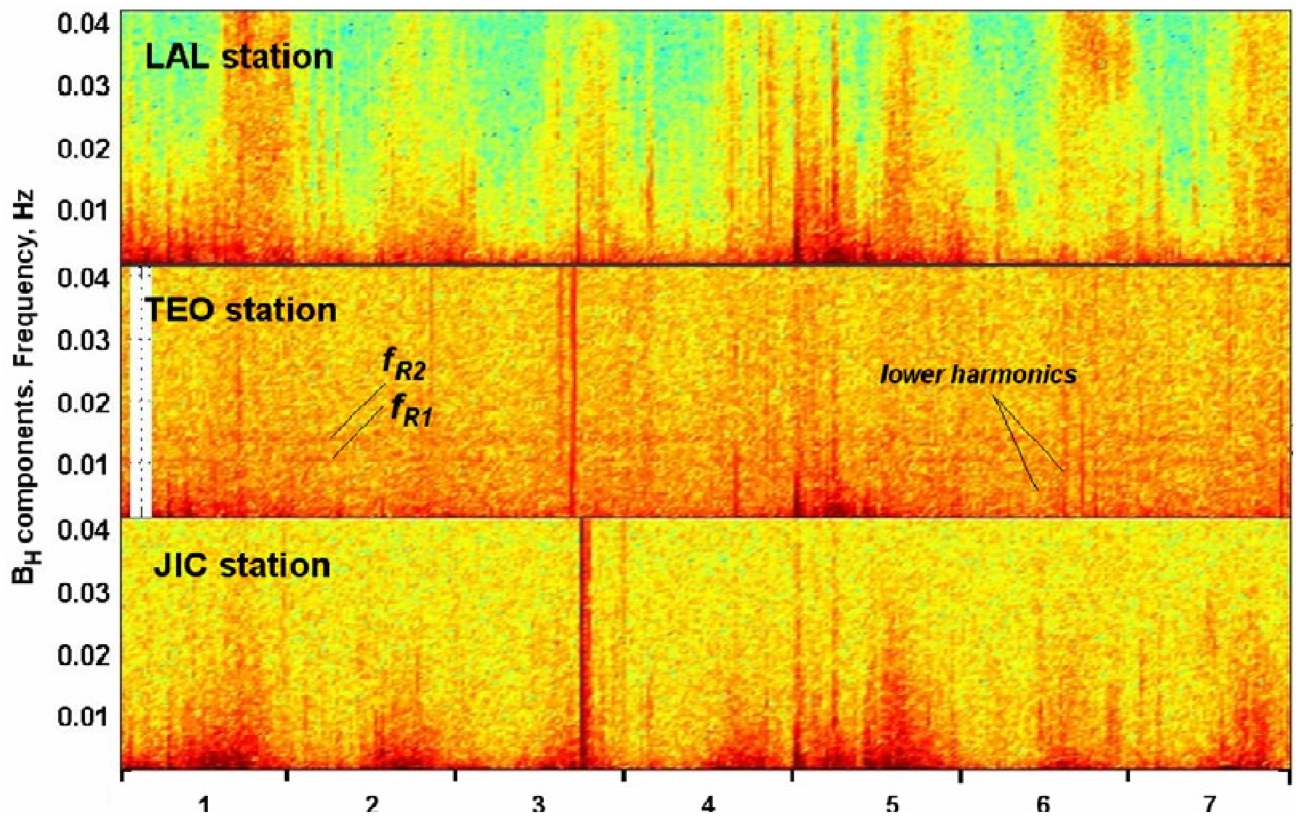

Fig. 3. SRS (Spectral Resonant Structure), observed in Teoloyucan station during 1 week (1999, Doy 104-110), middle panel. Upper and bottom panels: Referent spectra, station LAL (Los Alamos, USA) and JIC (Jicamarca, Peru), accordingly.

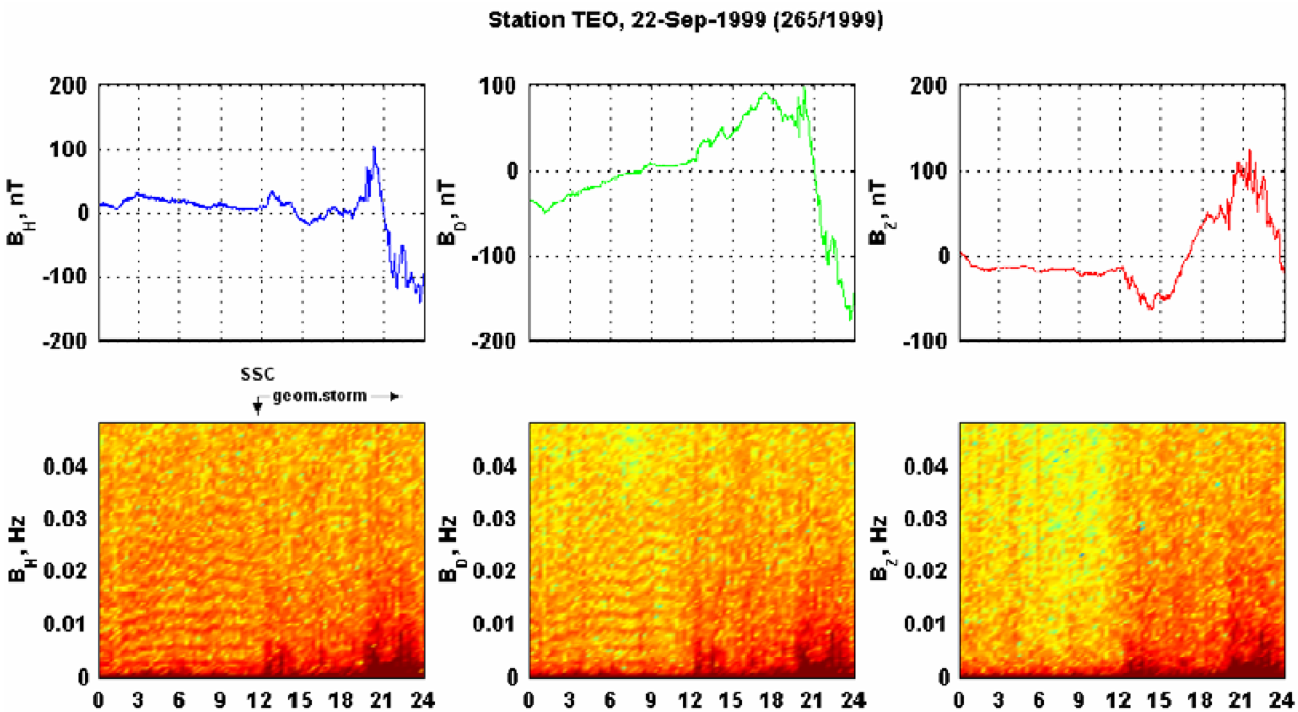

Fig. 4. Wide SRS (Spectral Resonant Structure) observed in 3 magnetic components during September 21-22, 1999. Upper and Lower panels: the same as in the Fig. 1.

Conclusions

We studied the properties of the ULF resonant structure observed at Teoloyucan geomagnetic station. The ULF resonance structure is observed in the *H*-component (dominant linear polarization) as two resonant packets in the frequency bands $f_{R2}=10.2\text{-}11.1\ mHz$ and $f_{R2}=13.6\text{-}14.5\ mHz$, with a certain hourly dependence. The resonance structure shows a moderate correlation with geomagnetic activity and undergoes modifications during the preparation of strong and moderate earthquakes. Different possible source models for their generation are proposed in qualitative form. The generation of the longitudinal Alfvén wave is proposed as a hypothesis for a natural origin of the observed phenomena. A new experimental study and a more detailed analysis of the observed phenomena are under way for the validation of the obtained results.

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