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MODELING THE GENERATION CONDITIONS OF MAGNETOSPHERIC Pc1 EMISSIONS

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Abstract

According to the bouncing-wave model for generation of magnetospheric Pc1 emissions, the generation is possible if the total two-hop gain of an ion-cyclotron wave (ICW), taking into account possible losses, exceeds the unity. In this paper, we study the behavior of the total ICW gain comprising the cyclotron amplification Γ near the equatorial plane due to resonant wave-particle interactions and losses due to the wave reflection from conjugate ionospheres. We calculate the total gain $G= R^{+}*R^{-}*e^{2\Gamma}$ for different local times and seasons at different latitudes. The reflection coefficients in the northern and southern hemispheres, R^{+} and R^{-}, respectively, are calculated using the IRI ionospheric model. For calculations of the Alfven wave amplification Γ, recently published equatorial cold plasma density model is used. To select the favorable conditions for the ICW generation, we apply the constraint G>1. Using this constraint, the generation frequencies as well as the regions of most probable generation are found.

Introduction

It is commonly accepted that generation of geomagnetic pulsations Pc1 (observed in space as electromagnetic ion-cyclotron waves) is due to cyclotron interaction between low frequency waves and energetic protons populating the outer radiation belt. It seems that the most advanced theory of the EMIC waves generation is the theory of Alfven sweep maser (*Polyakov et al., 1983, Belyaev et al., 1984, 1987, Trakhtengerts et al., 2000)*. According to the theory, the cyclotron wave packet amplification occurs near the equatorial plane, and it compensates the losses of wave energy during the non-ideal reflection from conjugated ionospheres. In this view the ionosphere plays an important role forming the wave spectrum due to resonant properties of the ionosphere reflection coefficient. Modification of the reflection coefficient by precipitating ions explains the generation of dispersed elements, which are a remarkable feature of Pc1 spectra (so called "pearls"). The generation of Pc1 pearl pulsations occurs if the condition $R^{+}*R^{-}*e^{2\Gamma} > 1$ is fulfilled, where R^{+} and R^{-} are reflection coefficients in the northern and southern hemispheres, and Γ is an index of cyclotron amplification of Alfven wave. Cyclotron amplification depends on many parameters, such as energy of resonant protons, their amount in the magnetic field tube, anisotropy of the pith-angle distribution, cold plasma density. The reflection coefficient depends on local ionosphere conditions that in turn depend on universal time (for given location), latitude, solar and geomagnetic activity. *Demekhov et al* (2001, 2002) performed a numerical simulation of the wave generation on the basis of the Alfven sweep maser theory and showed that wave spectra are, indeed, similar to Pc1 "pearls". The present paper is devoted to further modelling of Pc1. Our purpose is calculation of total gain $G = R^{+}*R^{-}*e^{2\Gamma}$ for different local times and latitudes to obtain locations, where the generation of Pc1 is more probable, and to determine frequencies, at which the waves can be generated.

Input parameters and models

In this paper we describe the result of calculations of the total gain obtained under some assumptions. To calculate the magnetospheric amplification we suggest the azimuthally symmetric ring current and fix the hot particle amount in the tube $N = 10^{11}$ for any distances within L=4-7 R_E. (The results of other calculation runs based on other suggestions on the ring current configuration will be presented elsewhere).

The Pc1 generation is expected in regions of detached cold plasma outside the plasmasphere (e.g. *Yahnina et al.* (2003)). Thus, for the cold plasma we used the empirical trough density model by *Sheeley et al.* (2001). This model has an advantage over others because it provides the cold plasma density depending on both L and MLT. The model was constructed for quiet magnetic conditions, i.e. for conditions appropriate for the Pc1 generation.

The reflection coefficients from the conjugate ionospheres, R^{+} and R^{-}, were calculated using the numerical "full-wave" algorithm by *Ostapenko and Polyakov* (1990). For implementation of this algorithm it is necessary to have altitude profiles of ionospheric ion and electron densities. For this, the International Reference Ionosphere (IRI) model was used. This model enables to calculate the ionospheric profiles for any day, given location, and universal time. For distinctness the day 15 September 1996 was chosen, and computations were made for latitudinal profile at longitude of Northern Europe (MLT=UT+2). Conjugated coordinates were calculated using the model of magnetosphere magnetic field by Tsyganenko (1996).

Results

Figure 1 presents contour maps of the Alfven wave two-hop amplification in coordinates "UT-frequency" calculated for different L-shells. The largest amplification takes place at frequencies below 1.5 Hz, and the frequency of the amplification maximum decreases when L-shell increases. The larger is L-shell, the narrower is the frequency range of the prevalent amplification. For example, the frequency range does not exceed 0.5 Hz on L=7.13, whereas it is 1.5 Hz on L=4.25.

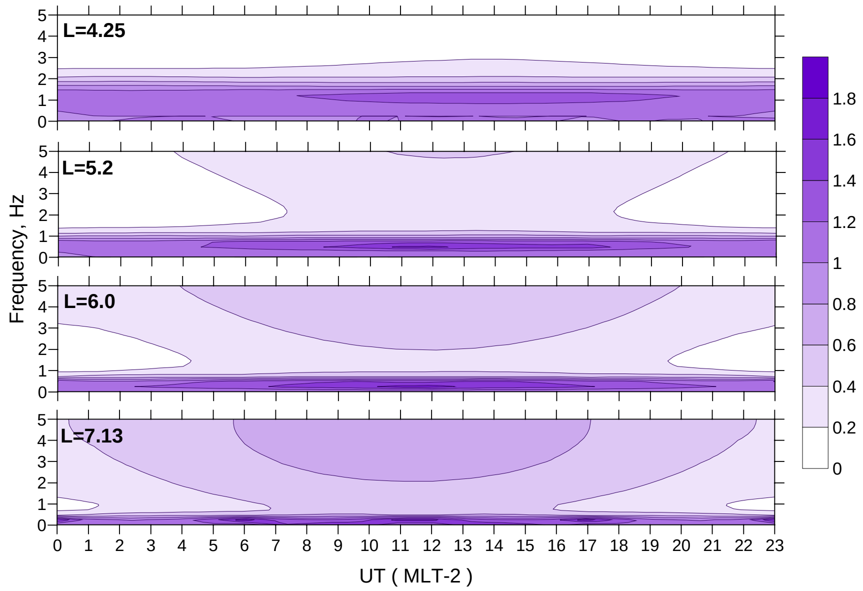

Fig. 1. The Alfven wave two-hop amplification

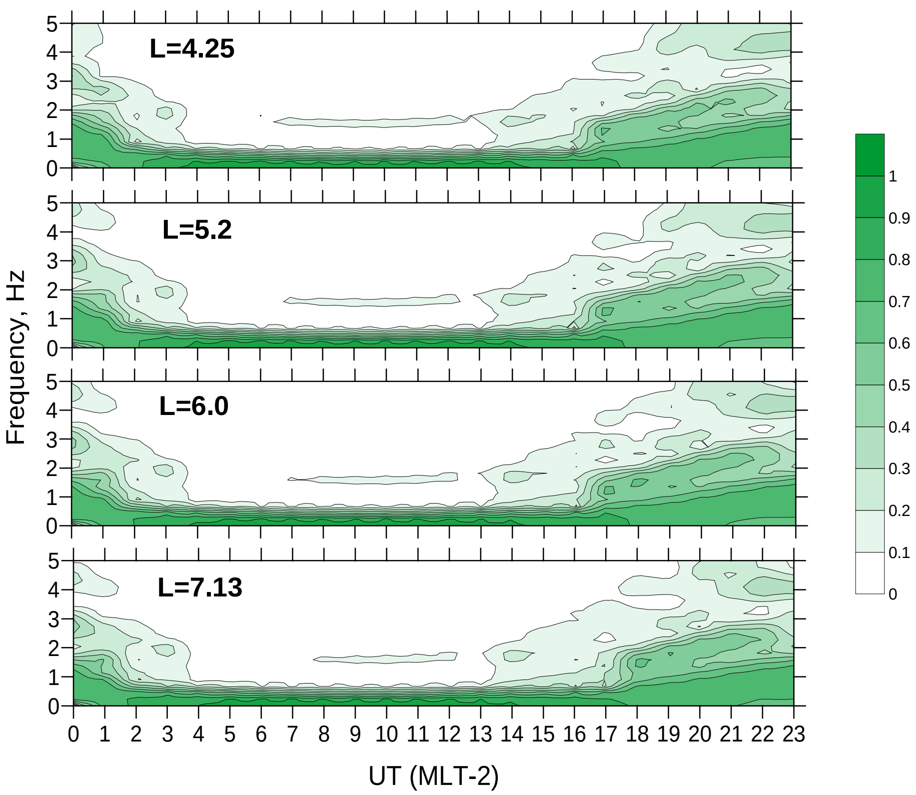

Fig. 2. Product of reflection coefficients in the northern and southern hemispheres for September 15, 1996

Diurnal and latitudinal variations of the product of ionosphere reflection coefficients ($R^+ * R^-$) are shown in Figure 2. This product is less than unity, so one may expect the wave generation only where this product has maximum(s).

Finally, the total gain G is presented in Figure 3. To find favourable locations and frequencies for the Pc1 generation, we apply the constraint G>1. According to the computations, the generation of the Pc1 pearl pulsations may occur on different L-shells, but the highest probability is expected at higher latitudes. The frequency of maximum G increases when latitude (L-shell) decreases. At the same time, the generation is possible in wider time interval on higher L-shell. On L=7.13 the generation of Pc1 is possible for almost whole day, whereas on L=5.2 the generation is more probable in the evening.

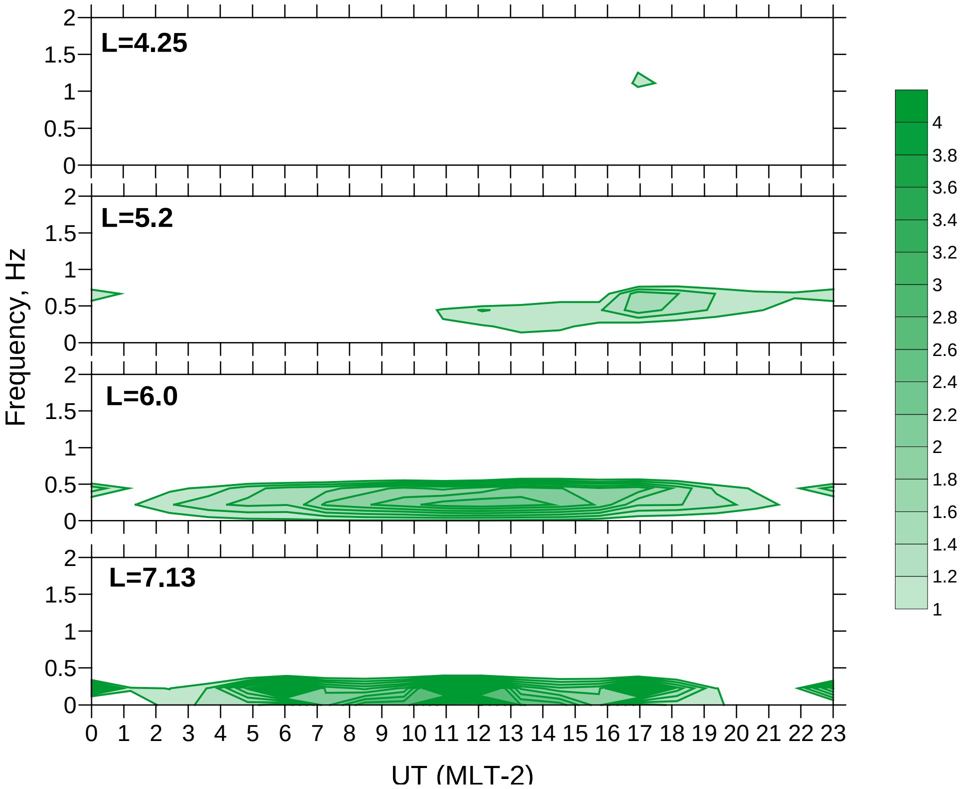

Fig. 3. The total two-hop gain of an ion-cyclotron wave

Discussion

It is interesting to compare the model calculations with morphology of Pc1 (EMIC waves) revealed from observations. The statistical study of the Pc1 pulsation in the equatorial plane has been done by *Anderson et al.* (1992). These authors showed (see, their Fig. 12) that the occurrence rate of the waves is higher at higher latitudes, where the waves are observed at almost all local times. On lower latitudes (L=5-6) the occurrence rate is still high, but the waves are observed mainly in the evening-night hours. On the lowest latitudes (L=3-4) the probability to observe these waves is negligible. Thus, in general, the bouncing-wave model reproduces well the properties of the waves observed in the magnetosphere.

Comparison with the statistical results of the Pc1 ground-based observations also exhibits rather good agreement. *Fukunishi et al.* showed that the occurrence rate of Pc1 (periodic hydromagnetic emissions) at L~6 has maximum at noon sector (6-14 MLT), and at frequency of ~0.5 Hz (see, their Fig. 3).

At the same time, some disagreement can be noted when comparing results of our modelling with some observations of ion-cyclotron waves in the ionosphere (*Erlandson and Anderson, 1996*). The largest probability to observe the EMIC waves in the ionosphere was found in the day sector, but the most probable latitude corresponded to L~3.3, and most probable frequency had maximum at about 1.6 Hz. Unfortunately, this statistical study was made using the data only from low latitudes (L < 5.6) because of high background electric field noise at higher latitudes. Another reason for disagreement with our model predictions can be the fact that observations were made close to the solar activity maximum. According to *Yahnin et al.* (2003), the enhanced solar activity correlates with close location of the Pc1 sources to the Earth, which results in increase of the Pc1 frequency. In contrast, the model calculations used the ionosphere parameters corresponding to the interval of solar activity minimum.

Conclusion

This paper presents the result of the Pc1 generation modelling, based on the theory of the Alfven wave bouncing between conjugated ionospheres. Several different models (of the ionosphere, magnetic field, cold plasma distribution) and assumptions were used as input for calculations. We conclude that the calculations reproduce well some basic morphological features of Pc1. It is clear that there are ways to improve the model, for example, by including more realistic distribution, both in L and MLT, of hot particles.

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