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Abstract

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RELATIONSHIP OF THE DIRECTION OF THE INTERPLANETARY MAGNETIC FIELD TO THE REGIME OF SUSTAINED OSCILLATIONS

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For sustained oscillations of the Earth' s electromagnetic field in the range Pc 2—4, along with control of the amplitude of the oscillations by local time ([1]), there exists an undoubted modulation of the regime as a whole by universal time. Thus, for example, cases are observed of the simultaneous onset or simultaneous termination of sustained oscillations over the entire terrestrial globe, etc. Such cases have been a puzzle for all investigators, and attempts to interpret them have not led to a satisfactory solution of this question. To study the influence of universal time on sustained oscillations, a special network of stations was created, with identical apparatus and distributed in longitude over approximately 120° along the circumference of the Earth. Along with global modulation, days were found (approximately 1—2% of all observational cases) when sustained oscillations were absent altogether, which could in no way be reconciled with the theory of excitation of Pc by a continuous solar wind at the magnetospheric boundary.

Consequently, the source of sustained oscillations must possess such properties whose variations would have a determining effect on the excitation or damping of these oscillations on a planetary scale. Such a determining parameter, as the results of the present work show, is the direction of the interplanetary magnetic field in the plane of the ecliptic. The magnitude of the interplanetary field strength averages approximately $\sim 5\gamma$, and the fluctuations of the field magnitude are considerably smaller than the fluctuations of its direction. However, despite continuous variations, the interplanetary field has a certain preferred direction, coinciding with the direction of the Archimedean spiral.

An analysis of the main characteristics of sustained oscillations was carried out for the period from December 1 to 14, 1963, for which detailed measurements of the interplanetary field were available, performed on IMP I and averaged over each 5.46 min ([2]). The direction of the field in the plane of the ecliptic was used as the parameter of the interplanetary field. This choice of parameter was due

Fig. 1

Figure 1: Fig. 1

Fig. 2

Figure 2: Fig. 2

to the fact that the full vector of the interplanetary magnetic field is situated at a small angle to the plane of the ecliptic, while the field magnitude undergoes comparatively small fluctuations. In all, more than 1500 values from direct measurements of the interplanetary field were used; from these, histograms of the preferred direction of the field during each day were constructed, and a detailed analysis of the regime of global excitation of Pc was carried out. First of all it should be noted that not on all days did the interplanetary field have the same preferred direction. Most often (7 days out of 14) the interplanetary field had a direction coinciding with the direction of the Parker spiral. On some days it is difficult to single out a preferred direction: the magnetic field fluctuates, and its direction changes constantly during the day. During three days of the interval considered, contrary to established notions, the preferred direction of the field was the direction perpendicular to the Sun–Earth line (Fig. 1a).

Such a change in the preferred direction of the interplanetary field from day to day proved to correspond to a definite change in the groups of sustained oscillations, namely: the principal field direction, coinciding with the direction of the Parker spiral, corresponds to the most widespread type of sustained oscillations, Pc 3 ($T = 10$—45 sec);

in a direction approaching the radial one, oscillations of type $Pc4$ ($T = 50$–150 sec) or $Pc3$–4 occur. A completely special case is the case of a field direction perpendicular to the Sun–Earth line, in which stable oscillations are not excited and are absent on the scale of the Earth. Since the data used represent values of the field direction averaged over a small time interval,

Fig. 1. Histograms of the distribution of the direction of the interplanetary magnetic field corresponding to definite types of Pc

it was possible to compare the sequence of changes in the field direction with continuous records of stable oscillations (Fig. 2). The direction of the interplanetary field in the ecliptic plane is plotted directly on the record. The values of the field direction are averaged over unequal time intervals, determined by sufficient constancy of the field direction ($\pm 10^{\circ}$). As can be seen from the example shown (Fig. 2a), stable oscillations of type $Pc3$ correspond to an interplanetary-field direction close to the Parker spiral. At those moments when the field vector approaches a direction perpendicular to the direction toward the Sun, the stable oscillations disappear. In Fig. 2b an example is given of the disappearance of Pc for several hours, while the direction of the interplanetary field was practically constant and directed perpendicular to the Sun–Earth line.

Fig. 3

Figure 3: Fig. 3

Fig. 2. Examples of comparison of records of the regime of stable oscillations and the direction of the interplanetary magnetic field. Petropavlovsk-Kamchatskii. *a*–12 X 1963; *b*–14 XII 1963

A quantitative estimate of the number of cases of coincidence of the regime of stable oscillations with a definite field direction was made separately for each day. On average over the course of a day, coincidence is observed in 85% of all comparison cases, and the less distinctly the predominant field direction is expressed (Fig. 1b), the smaller the percentage of coincidences; but with a characteristically expressed predominant field direction the indicated correlation may reach 99% (for example, 3 XII 1963).

In the case when the field direction coincides with the Parker spiral or is sufficiently close to it, the amplitude of the $Pc3$ oscillations is maximal. When the field deviates from the direction of the spiral, the amplitude Pc decreases, and at the maximum deviation, i.e., when the field is perpendicular to the direction toward the Sun, the amplitude Pc tends to zero.

Thus, the amplitude Pc is apparently determined by the angle of deviation of the interplanetary magnetic field from the preferred direction. As is seen from Fig. 3, a clear inverse dependence is observed between these quantities.

Fig. 3. Dependence between the normalized amplitude $Pc3$ (1) and the angle of deviation of the interplanetary field from the Parker spiral (2). 9 XII 1963

A detailed examination of the change in the preferred direction of the field from day to day within one sector from 2 to 12 XII shows that reversal of the field is accompanied by a preferred field direction perpendicular to the direction toward the Sun. Since such a direction corresponds to a weakening of the intensity of Pc or to their complete absence, it seems possible to suppose that the cases of absence of Pc correspond to the moments of reversal of the interplanetary field, i.e., to sector boundaries. Using the data obtained on Pioneer 6 and IMP-1 ([3]) on the reversal of the interplanetary field, this supposition can be checked. In 75% of all cases of comparison, the field reversal corresponded to a weakening or a decrease to zero of the amplitude Pc. The amplitude of $Pc3$ falls in the direction toward sector boundaries, usually having a maximum in the first half of the sector and decreasing smoothly in the second. Such a change in the amplitude of $Pc3$ within a sector correlates well with the behavior of the solar-wind velocity during the same time. The values of the solar-wind velocity within the sector were obtained both as a result of direct measurements and indirectly, using the relation between this velocity and the periods of Pc obtained in ([4]). A decrease in the velocity at the sector boundary may contribute to the weakening of the intensity of steady oscillations.

Fig. 4

Figure 4: Fig. 4

Fig. 4. Spectrum of the "freezing" of *Pc* over time from 1 to 14 XII 1963, recalculated into linear dimensions of inhomogeneities of the interplanetary magnetic field

The influence of the orientation of the interplanetary magnetic field on the *Pc* regime may be explained by assuming that steady oscillations of the geomagnetic field arise as a result of hydrodynamic instability of the magnetospheric plasma. It is believed ([5],[6]) that oscillations of the *Pc* type are excited when the magnetosphere is flowed around by the solar wind. In this case surface waves are excited, and the steady oscillations observed on Earth are the result of transformation of the surface waves into resonant Alfvén or magnetosonic waves.

When the interplanetary field is directed at an angle to the surface of the magnetosphere, this transformation occurs. If, however, there is only a component of the interplanetary field directed perpendicular to the direction toward the Sun, then the surface waves at the boundary of the magnetosphere are damped, and steady oscillations are not observed on Earth.

On the basis of the results of satellite observations, it is now believed that the interplanetary magnetic field consists of separate flux tubes with a diameter of $\sim 10^6$ km, which intertwine with one another, forming a complex structure. Bends and expansions of the flux tubes have been detected that are not characteristic of the Parker spiral. Such disturbances of the ordered structure of the interplanetary field may serve as those inhomogeneities at which the field is directed perpendicular to the Sun–Earth axis, and the moments of their approach to the boundary of the magnetosphere correspond to the moments of disappearance of sustained oscillations. The dimensions of such inhomogeneities will apparently correspond to the time of "fading" of sustained oscillations. Having continuous records of Pc, one can construct the spectrum of such "fadings" of Pc for a definite group, for example Pc3, and, taking the value of the solar-wind velocity corresponding to these Pc periods ([4]), one can try to determine the mean size of these inhomogeneities of the interplanetary magnetic field. In the case of using the mean values of the fading time of Pc3, $t_{\text{cp}} = 10-20$ min, and $v_{\text{cp}} = 6 \cdot 10^7$ cm/sec, the mean dimensions of the inhomogeneities are $l_{\text{cp}} = v_{\text{cp}} t_{\text{cp}} = 17 \times 60 \times 6 \cdot 10^7$ cm, while in the case of maximum values $l_{\max} = 1.4 \cdot 10^{11}$ cm, which is in agreement with estimates of the sizes of inhomogeneities of the interplanetary field made from cosmic-ray anisotropy ([7]) and with theoretical estimates of the sizes of expansions and bends of flux tubes given in ([8]).

Thus, the excitation of sustained Pc oscillations of different groups is associated with a definite orientation of the interplanetary magnetic field. Modulation of the Pc amplitude is determined by a change in the direction of the field, and the amplitude decreases to zero in the case where the field direction is perpendicular to the Sun–Earth line.

The data obtained have for the first time made it possible to establish one of the fundamental facts necessary for understanding the mechanism of Pc excitation, namely the nature of the agent responsible for their sudden onsets and disappearances on a planetary scale.

The established relationships make it possible to outline the following ways of using ground-based observations of the regime of sustained oscillations for the diagnosis of a number of the most important parameters of the solar-wind structure.

1. The fact of excitation of sustained oscillations of various types indicates the existence of a definite orientation of the interplanetary magnetic field; the absence of the Pc regime is an indicator of a sharp change in the predominant direction of the interplanetary field from a direction close to the Parker spiral to a direction perpendicular to the Sun–Earth direction.
2. The observed correspondence of prolonged Pc "fadings" to the moments of reversal of the interplanetary field can be used to estimate the regularity of the sector structure of the interplanetary field in various phases of the solar-activity cycle.
3. The spectrum of individual Pc "fadings" can be used to estimate the mean sizes of inhomogeneities of the interplanetary magnetic field.

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Note: Figure translations are in progress. See original paper for figures.