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Mid-Latitude Pc1, 2 Pulsations Induced by Magnetospheric Compression in the Maximum and Early Recovery Phase of Geomagnetic Storms*

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Abstract We investigate the properties of interplanetary inhomogeneities generating long-lasting mid-latitude Pc1, 2 geomagnetic pulsations. The data from the Wind and IMP 8 spacecrafts, and from the Mondy and Borok midlatitude magnetic observatories are used in this study. The pulsations under investigation develop in the maximum and early recovery phase of magnetic storms. The pulsations have amplitudes from a few tens to several hundred pT and last more than seven hours. A close association of the increase (decrease) in solar wind dynamic pressure (P_{SW}) with the onset or enhancement (attenuation or decay) of these pulsations has been established. Contrary to high-latitude phenomena, there is a distinctive feature of the interplanetary inhomogeneities that are responsible for generation of long-lasting mid-latitude Pc1, 2. It is essential that the effect of the quasi-stationary negative B_z-component of the interplanetary magnetic field on the magnetosphere extends over 4 hours. Only then are the P_{SW} pulses able to excite the above-mentioned type of mid-latitude geomagnetic pulsations. Model calculations show that in the cases under study the plasmapause can form in the vicinity of the magnetic observatory. This implies that the existence of an intense ring current resulting from the enhanced magnetospheric convection is necessary for the Pc1, 2 excitation. Further, the existence of the plasmapause above the observation point (as a waveguide) is necessary for long-lasting Pc1 waves to arrive at the ground.

Key words Magnetic storm, Geomagnetic Pulsations, Solar wind dynamic pressure, Interplanetary magnetic field

1 Introduction

The effect of increased activity of Pc1, 2 geomagnetic pulsations during compression of the magnetosphere is one of the most known manifestations of the solar-terrestrial coupling in the midlatitude dayside magnetosphere. A detailed agreement between the variations in the Pc1, 2 intensity and the geomagnetic field magnitude, measured at the same spatial point[1], is sometimes observed in the outer magnetosphere. Anderson *et al*[1] indicated the relation between the Pc1, 2 amplitude and compressions of the magnetosphere, which were observed when the CCE spacecraft entered the low-latitude boundary layer and the magnetosheath.

The dependence of high-latitude Pc1, 2 activity on the IMF B_z component was referred to in Ref.[3], according to which all Pc1, 2 pulsations registered on OGO-5 at L of 7—14 are related to the regions of increased P_{SW}, and IMF is directed southward 2 h before the beginning of the variations.

In contrast to the outer magnetosphere, the probability of recording Pc1, 2 in the inner magnetosphere depends on the level of magnetic disturbance and is maximal during magnetic storms[4],[5]. According to Ref.[6], the region of generation of ion cyclotron waves in the Pc1, 2 range moves toward the Earth with the development of a storm disturbance and reaches minimal distances, corresponding to corrected geomagnetic latitudes $< 50°$, at a maximum and in the early recovery phase of magnetic storm.

In the present work, we will consider the long series of Pc1, 2 pulsations registered at Mondy (51.62°N, 100.75°E, L = 2.1, MLT = UT+7) and

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Borok (58.03°N, 38.97°E, L = 2.9, MLT = UT+3) midlatitude observatories. We will consider the processes in the interplanetary space (based on the Wind data*), which cause generation of midlatitude Pc1, 2 and their amplitude modulation.

2 Oscillation Character and Corresponding Geomagnetic Conditions

This work is aimed at studying the conditions in the interplanetary space resulting in the appearance of long series of midlatitude Pc1, 2 oscillations whose activity is regulated by changes in the solar wind. For the first time two such series were detected by us during the storms of October 18—19, 1995 and April 6—7, 2000[7],[8]. An analysis of the dynamic spectra of Pc1, 2 oscillations, accompanying 57 magnetic storms of 1997—1998, also revealed six similar events. Data of synchronous observations of geomagnetic pulsations, IMF, and the solar wind were the only criterion used to select storm disturbances.

The time variations in the *Dst* and *Kp* indices, based on data**, are presented in panels of Fig.1 for 4 storms accompanied by Pc1, 2. Filled rectangles mark the intervals of recording the Pc1, 2 series. Two left panels in bottom show for comparison the *Dst* (UT) and *Kp* (UT) variations for two magnetic storms with close conditions in the interplanetary space. These are the storms of May 15—16, 1997, and September 24—25, 1998, during which the oscillations Pc1, 2 were not observed.

The large magnetic storm of October 18—19, 1995 develops against a quiet background. The long

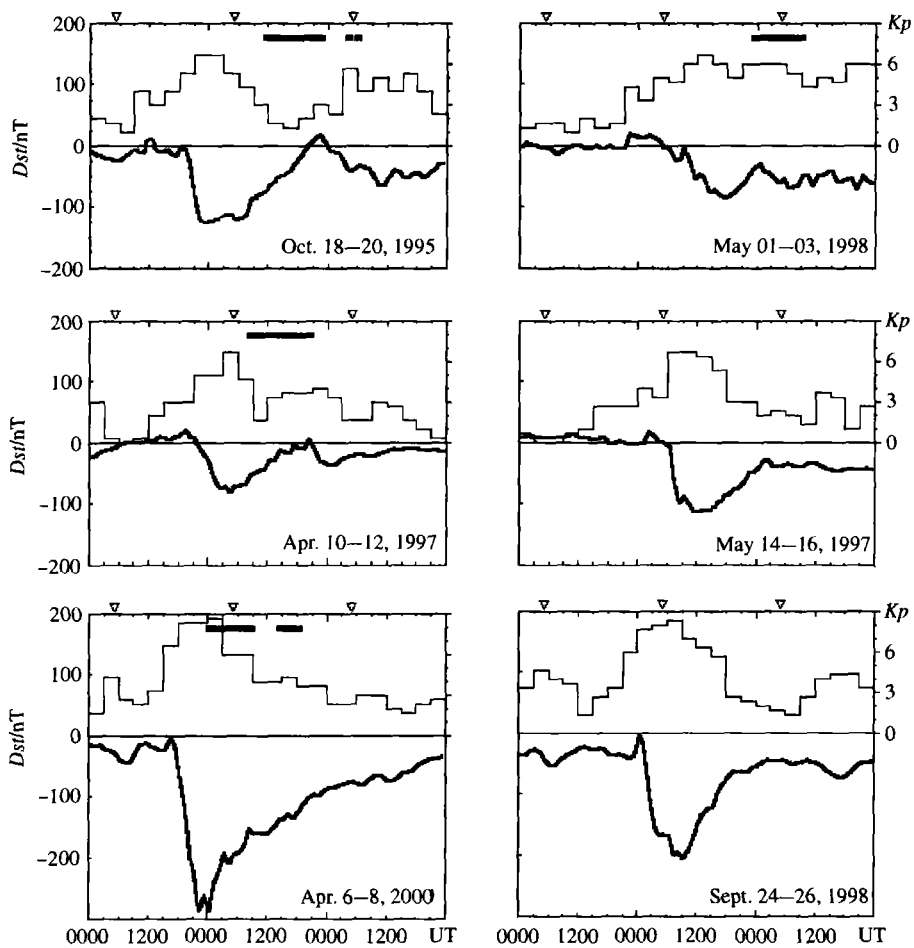

Fig.1 Time variations in the *Kp* and *Dst* indices during 3 days including the periods of the magnetic storms. Local geomagnetic noon at Mondy observatory is marked by triangles

*http://cdaweb.gsfc.nasa.gov/cgi-bin/cdaweb/evall.cgi

**http://swdcwww.kugi.kyoto-u.ac.jp/index.html

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series of oscillations with frequencies f of 0.8—1.5 Hz and amplitudes A in the range of 10—60 pT begins at 1100 UT on October 19, 11 h after the *Dst* minimum and 3 h after the beginning of a monotonous increase in *Dst*, determined in Ref.[7] as the beginning of the storm recovery phase. Pc1, 2 are registered until the end of the recovery phase (2300 UT on October 19).

Pc1, 2 pulsations, registered at the recovery phase of the moderate storm of April 10—11, 1997, begin 2.5 h after the storm maximum. At Mondy, the pulsation frequency is 0.55—0.65 Hz at amplitude of about 4 pT. At Borok, the amplitude is approximately twice as large and the frequency is by about 0.15 Hz lower than at Mondy. Despite these differences, the form of the dynamic spectra at the two observatories, spaced in latitude and longitude, is similar.

The event of April 6—7, 2000 is the strongest storm among 8 events. Accompanying pulsations are also very intense. The oscillation amplitudes are 20—170 pT and 5—500 pT at Mondy and Borok, respectively.

The moderate storm of May 1—3, 1998, is not isolated. It is the third event in the series of the magnetic storms registered after April 23, 1998. The most intense oscillations are clearly defined in the Mondy dynamic spectra at $f \approx 0.15$ Hz (the Pc2 range). Weak Pc1 geomagnetic pulsations at $f \approx 1.8$ Hz are observed simultaneously. The oscillations begin about 4.5 h after a *Dst* minimum and continue for about 11.5 h with certain interruptions.

So the Pc1, 2 series of duration > 4.5 h, beginning at the storm main phase or during the first 2—6.5 h of the storm recovery phase, can be observed in any MLT sector during both moderate and large storms. At the same time, these series were not registered during other storms of 1997—1998, two of which are also presented in Fig.1. Consequently, the storm intensity and the level of magnetic activity do not evidently indicate that the series of midlatitude Pc1, 2 are present or absent at a maximum and at the early stage of the ring current breakup.

3 Interplanetary Space Conditions

The time variations in the two most geoeffective parameters of the interplanetary medium, the solar wind dynamic pressure and the IMF B_z component, are shown in 6 panels of Fig.2.

The Pc1, 2 series are marked with rectangles in the upper part of the panels. The beginning and end of the pulsation observation intervals shown in Fig.2 correspond to discrete fragments of the solar wind plasma, which reach the magnetosphere at the beginning and end of oscillation registration, determined from Wind data.

An analysis of the P_{SW} (UT) dependences indicates that the prolonged series of midlatitude Pc1, 2 correspond to the regions of increased dynamic pressure of the solar wind. The regions with high P_{SW} were also registered during the storms that were not accompanied by Pc1, 2 series. Consequently, the compression of the magnetosphere not always stimulates the appearance of midlatitude Pc1, 2 series.

An analysis of the B_z (UT) dependences (shown in the lower part of the panels) indicates that the extensive regions with the quasistationary, slightly fluctuating, negative IMF B_z component represent the main feature of geoeffective inhomogeneities of the interplanetary medium. These regions are marked in Fig.2 with horizontal bars at the base of the B_z (UT) dependences. The storms of May 14—16, 1997 (Fig.2) also develop under the conditions of large negative B_z observed for a quite long time (> 6 h). However, during these storms, as well as during the most storms in 1997—1998, the regions with quasistationary negative B_z are much less extensive than during the storms accompanied by midlatitude Pc1, 2.

According to data presented by us, the interplanetary plasma inhomogeneities (responsible for the generation of midlatitude Pc1, 2) at a maximum and during the first hours of the storm recovery phase include two characteristic structures: the region of slightly fluctuating quasistationary southward IMF (registered on Wind for not less than 4 h) and the region with increased dynamic pressure of the solar wind following the first region.

4 Amplitude Modulation Effects

We will study the effect of P_{SW} variations on a pulsation amplitude by comparing the times of the be-

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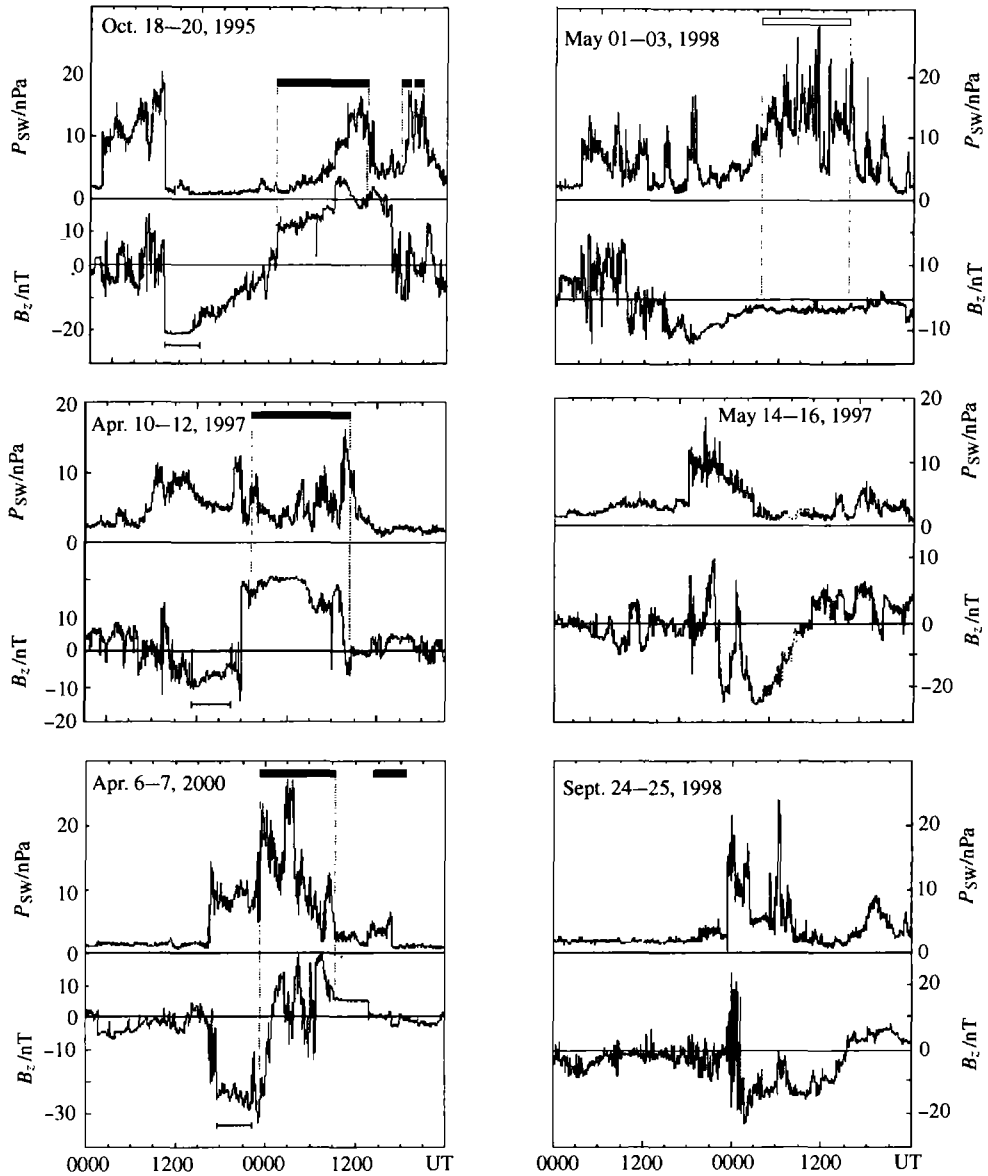

Fig.2 Variations in the solar wind dynamic pressure (P_{SW}, top of panels) and in the IMF B_z component (bottom of panels)

ginning and end of registration of the characteristic elements observed on the P_{SW} (UT) curves with similar characteristics of the individual structures present in the A (UT) amplitude envelopes which were constructed based on the digital records of oscillations in the frequency range of 0.1—5 Hz. The methods used by us to construct the amplitude envelope of pulsations provide a time resolution of 1 min in UT equal to the time resolution of Wind data.

The fragments of the P_{SW} (UT) and A(UT) dependences, used to study the effects of amplitude modulation, are illustrated in Fig.3. We present Wind and Borok data for the storm recovery phase of April 10—11, 1997 and Wind and Mondy for 1—3 May, 1998 (bottom). It is evident that the variations in P_{SW} and A have similar forms. A sharp pressure fall at 0833 UT April 11, 1997 results in an almost complete cessation of oscillations, which are observed again after a pressure growth at 0846 UT. The time delay between the onsets of a decrease in P_{SW} and A is 7 min, whereas the delay between a pressure growth and recommencement of oscillations is 4 min. A sharp pressure fall by a factor of 2.7 at 1447 UT, April 11 1997 leads (with time delay about 4 min) to

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a considerable decrease in A. Pulsations are not observed at 1554 UT, i.e., 11 min after the next decrease in P_{SW} by a factor of 1.8. We can similar forms of time variations of the pulsation amplitude envelope (A) and solar wind dynamic pressure (P_{SW}) for the May 1—3, 1998 storm.

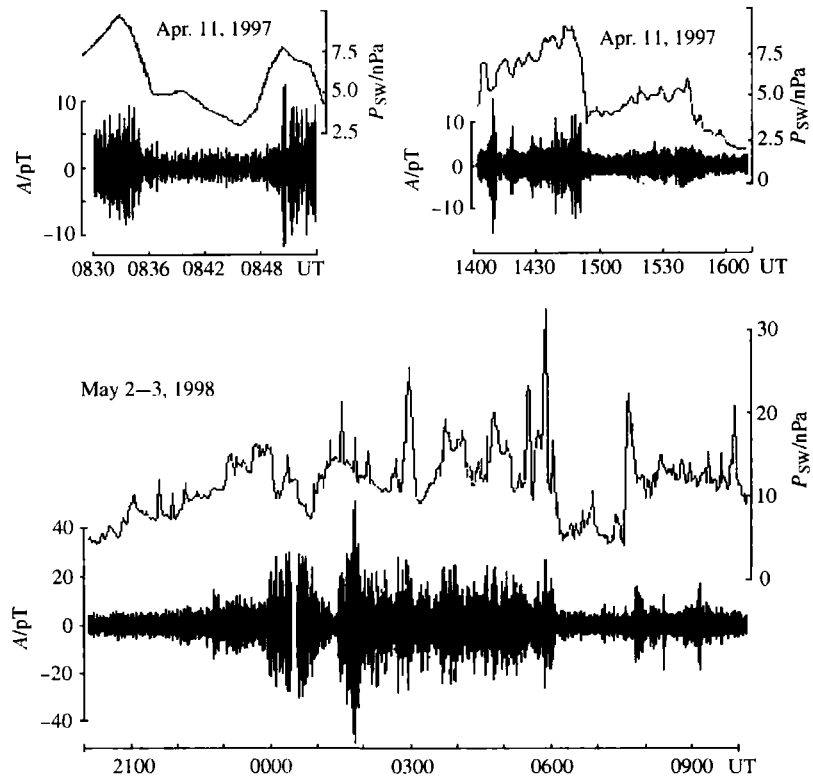

Fig.3 Variations in the amplitude (A) of Pc1, 2 geomagnetic pulsations and in the solar wind pressure (P_{SW}) during the storms

The relation between the variations in the solar wind dynamic pressure and the Pc1, 2 oscillation amplitude (illustrated at two previous events) is typical of all events considered by us. When performing a comparative analysis, we distinguished 98 similar elements on the A (UT) and P_{SW} (UT) curves. In these elements, the duration of the intervals of increased and decreased oscillations coincides within several minutes with the duration of registration of the corresponding regions of increased or decreased P_{SW} (UT).

5 Discussion

The study performed by us indicates that the evident relation exists between prolonged series of Pc1, 2 midlatitude geomagnetic pulsations and changes in the solar wind dynamic pressure, which is shown at a maximum and at the early stage of the magnetic storm recovery. The pulsations appear (disappear) after the beginning of an increase (decrease) in the pressure, and the amplitude of the oscillations registered in the dayside sector of the magnetosphere is modulated by changes in P_{SW}.

The mechanism of Pc1, 2 intensification during compressions of the magnetosphere was considered in Ref.[1] and [4]. These works indicated that compression of the magnetosphere leads to an increase in the magnetic field and, then, to an increase in the particle energy of the magnetospheric plasma and in increments of ion cyclotron and Cherenkov instabilities.

In contrast to high-latitude Pc1, 2, sporadically originated in the dayside high-latitude magnetosphere, midlatitude Pc1, 2 series appear only after the interval of increased magnetospheric convection, which develops in the Earth's magnetosphere at a quasistationary southward IMF. The duration of the

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interval of increased convection should be sufficient for the oscillation sources (energetic ions of the ring current with a nonmonotonic and anisotropic distribution of particle velocities) and the waveguide (plasmapause) responsible for the earthward propagation of pulsations generated in the magnetosphere to be formed in the inner magnetosphere[4]. According to the results obtained, the process of reconfiguration of these permanently existing magnetospheric structures, which consists in the displacement of these structures to midlatitude L shells, requires a high level of quasistationary convection for at least 4 h. Under the conditions indicated above, long series of midlatitude Pc1, 2 can be generated during the compression of the magnetosphere at a maximum and at the early stage of the magnetic storm recovery.

6 Results

We have presented results of a direct comparison between the time variations in the solar wind parameters and Pc1, 2 geomagnetic pulsations registered at midlatitudes during geomagnetic storms of different intensities. We have indicated the following.

(1) Long series of midlatitude Pc1, 2 pulsations are observed at a maximum and the early stage of magnetic storm recovery during the interaction between the Earth's magnetosphere and the region of increased dynamic pressure of the solar wind.

(2) The Pc1, 2 series are generated when the zones of increasing P_{SW} follows the solar wind region with the quasistationary negative B_z component, interacting with the Earth's magnetosphere for not less than 4 h.

(3) In the dayside sector of the magnetosphere, the changes in the oscillation amplitude envelope within the series are similar to the registered variations in P_{SW} and follow these variations with delays of several minutes to several tens of minutes.

The conclusion has been made that wave activity of midlatitude Pc1, 2 during the considered events increases as a result of the compression of the dayside magnetosphere by the regions with increased solar wind dynamic pressure. The compression leads to an increase in the particle energy in the ring current dayside sector and stimulates the development of kinetic plasma instabilities in the Pc1, 2 frequency range. The following azimuthally drift of the Pc1, 2 sources results in the penetration of the oscillations into the night side sector of the magnetosphere.

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