

ON THE "CONVECTIVE" MODEL OF IPDP GENERATION

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Abstract. We present the Pc1-IPDP succession registered at midlatitude Mondy observatory during the recovery phase of the great magnetic storm on April 7, 2000. The succession possesses just the same properties as those following from the "convective" model of IPDP for the waves generated in the vicinity of the inner edge of the plasma sheet. We have made sure of the "convective" nature of Pc1-IPDP by way of model calculations and by analysing ground-based and satellites data.

Introduction

Intervals of pulsations of diminishing period (IPDP) are geoelectromagnetic waves in the period range 0.2-10 s. Since the IPDP discovery it has been generally agreed that IPDP type plasma events are caused by the resonant instability of the energetic ions delivered from the plasma sheet into the ring current (RC) during magnetospheric disturbances but the causes of IPDP frequency modulation are still debated. Two processes are presumed to be primarily responsible for the frequency rise. The first is azimuthal drift of particles injected into the inner magnetosphere during the substorm expansive phase. The second is radial displacement of the IPDP source toward the Earth in the course of wave generation. The former process is regarded as the cause of frequency modulation in the "injective" model of IPDP [Guglielmi and Zolotukhina, 1978]. The latter is responsible for rising wave frequency in a "convective" IPDP model [Zolotukhina, 1982]. The "injective" model of IPDP generation has a good experimental support [Kangas *et al.*, 1998 and references therein]. In contrast, in this paper we provide the first evidence of the "convective" IPDP nature.

"Convective" IPDP

Dynamic spectrum of a would-be "convective" IPDP event is presented in Fig. 1. This wave phenomenon was registered near the local midnight and was too long-lived to be interpreted as an "injective" phenomenon. It was observed for almost 3 hours whereas an injection in the midnight sector lasts only a few minutes. We can see that there is no short-lived vertical structure which could be identified as Pi1 burst usually associated with substorm injection. Instead, there is a narrow-band structure merging more or less continuously into IPDP. This narrow-band structure can be identified as structured Pc1,2 geomagnetic pulsations.

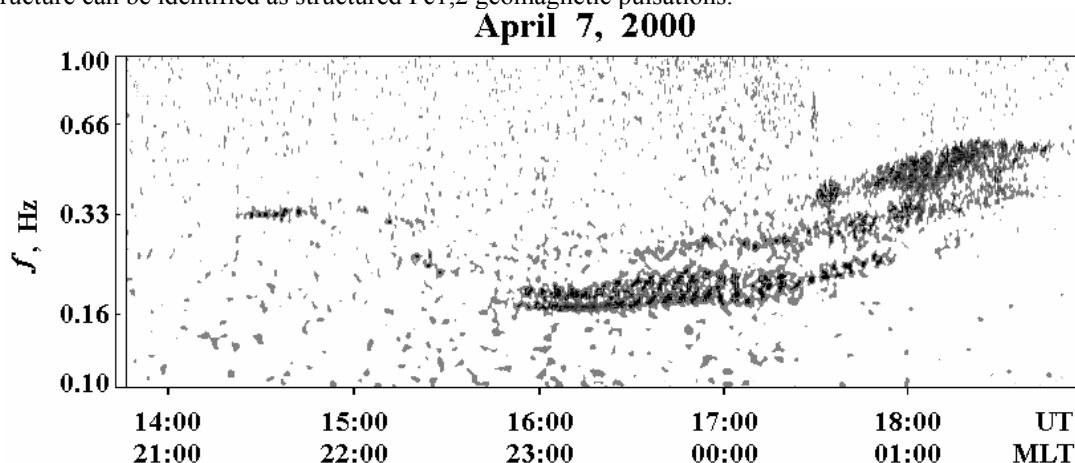


Fig. 1. Dynamic spectrum of magnetic pulsation recorded at Mondy (corrected geomagnetic coordinates $\varphi' = 47^\circ$, $\lambda' = 174^\circ$).

To interpret phenomena similar to the one in Fig. 1 a "convective" model of IPDP generation was constructed by [Zolotukhina, 1982] on the basis of the "injective" one. When modifying the model, it was taken into account that plasma sheet particles are not only delivered into the RC during the substorm expansive phase, but during enhanced magnetospheric convection as well. The enhancement of magnetospheric convection shifts the trajectories of the

plasma sheet particles toward the Earth and forms a “nose shaped” or “wedge-shaped”, as it is called, structure of ion spectrum in the inner magnetosphere [Burke et al., 1998; Kangas et al., 1998].

Zolotukhina (1982) showed that enhanced convection creates conditions for “convective” IPDP generation in the vicinity of the inner edge of the plasma sheet. In the frame of the “convective” model an IPDP source position is determined by the electric field E of magnetospheric convection as $L_{ps} \sim E^{-1/2}$ and the resonant particle energy changes as $\varepsilon \sim E^{1/2}$. Here L_{ps} is the McIlwain parameter of the inner edge of the plasma sheet. From the resonant equation $f \approx \Omega C_a / 2\pi U_z$ it follows that the frequency f of the waves rises with E as $f \sim E^2$ or as $f \sim L_{ps}^{-4}$. Here Ω is ion gyrofrequency, $U_z \sim \varepsilon^{1/2}$ - ion velocity and C_a – Alfvén velocity. A similar model was presented as the WPB (wave-particle boiler) model by [Kangas et al., 1998].

Model calculations

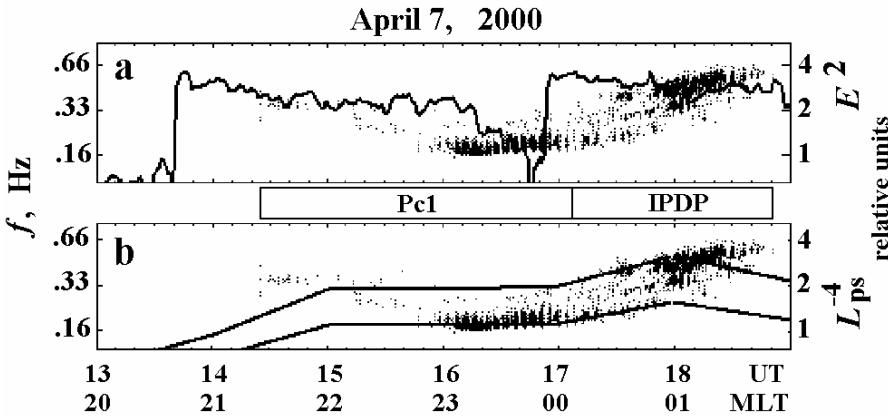


Fig.2. Superposition of the dynamic spectrum of Pc1-IPDP and the time variations of: **a** - E^2 and **b**- L_{ps}^{-4} .

The dynamic spectrum from Fig. 1, superimposed on $E(UT)^2$ and $L_{ps}(UT)^{-4}$ dependences, is depicted in Fig. 2. The E (UT) dependence was calculated from the WIND satellite data. The L_{ps} values were computed from the IMF Bz- component values according to the empirical model by [Kamide and Winningham, 1977]. The scales of f , E^2 and L_{ps}^{-4} showed in Fig. 2 are proportional. From Fig. 1, 2a it follows that the waves started as weak narrowband Pc1-like oscillations with period $T=3$ s forty minutes after the first enhancement of magnetospheric

convection and merged into IPDP twenty minutes after the next enhancement of E . From Fig. 2b we can see that the rise of the Pc1-IPDP frequency is similar to the rise of L_{ps}^{-4} value, as follows from the “convective” model of IPDP generation. So in the case under study the waves could be generated in the vicinity of the plasma sheet inner edge and IPDP frequency modulation could be the result of a progressive radial displacement of the plasma sheet toward the Earth caused by the enhanced magnetospheric convection.

Magnetospheric conditions

In the previous section we supposed that Pc1-IPDP succession registered in Mondy on April 7, 2000 can be the pure case of “convective” phenomenon generated without substorm injection. To verify this supposition we analyzed the physical processes that were developing in the magnetosphere and in the solar wind during the Pc1-IPDP registration. An analysis of the geomagnetic indices showed that the waves were registered at the end of the early recovery phase of the great magnetic storm at $Dst=-130$ nT and $Kp=4$ after four hours of very low auroral activity ($AU \approx 40$ nT, $AL \approx -60$ nT). Some of the results obtained in studies of geomagnetic indices, low-latitude geomagnetic disturbances, Pi2 activity data and the data from geosynchronous satellites, i.e. the most commonly used data to identify a substorm, are illustrated in Figs. 3-5. For convenience, one of two dependencies ($f(UT)$ or $A(UT)$) is given in Figs. 3-5. Here f is the frequency and A is the largest amplitude of the Pc1-IPDP spectral peaks determined from the Mondy data.

From Fig. 3 we notice that two increases of E

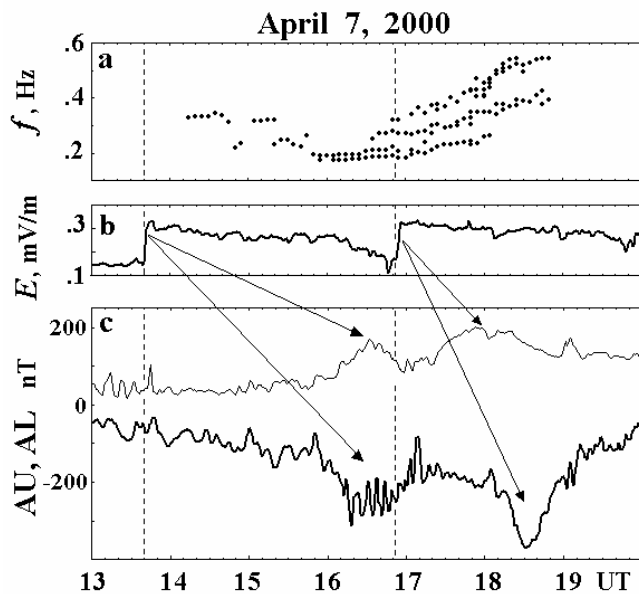


Fig. 3. The a- $f(UT)$, b- $E(UT)$, c- $AU(UT)$ and $AL(UT)$ dependencies.

produced two intensifications of the magnetospheric convection current system which manifested themselves in two bay-like AU and AL disturbances. The moments of sharp E increase in this and other pictures are shown with dashed lines. The mentioned disturbances are marked in Fig. 3 with arrows directed from E (UT) to AU(UT) and AL(UT). It is seen from Fig. 3 that there is not any one-to-one correspondence between spectral Pc1-IPDP composition and short-term variations of the auroral indices. From the IMAGE and 190°-210° magnetic meridian data it follows that the eastward and westward electrojets moved gradually to the equator while the Pc1-IPDP evolved.

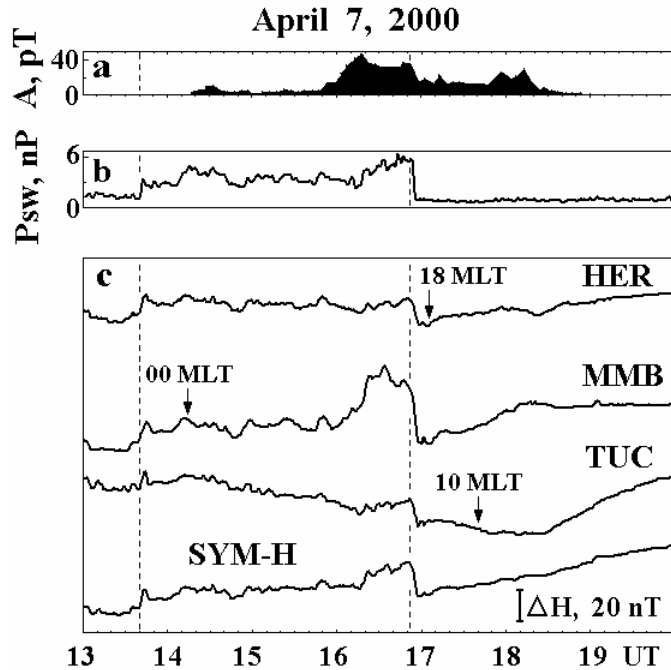


Fig. 4. Variations of: **a-** the maximum of Pc1-IPDP amplitude spectrum; **b-** solar wind dynamic pressure; **c-** H- component of the geomagnetic field in the low latitudes and SYM-H index.

geosynchronous satellite to Mondy (100.8° E). From Fig.5 c,d we notice that at 15:12 UT the LANL 1994 intersected a very spatially-limited and well defined surface characterized by sharply increased electrons density (N_e) and temperature (T_e) and entered into the nonadiabatic part of the plasma sheet typified by antiphased density and temperature fluctuations. Some antiphase fluctuations are marked in Fig.5 by the arrows. Phenomena of this type are usually observed in the distant plasma sheet [Sergeev and Tsyganenko, 1980].

We believe, based on the comparison of the Fig.5 data with Pi2 pulsations and geomagnetic disturbances (Fig. 3,4), that the sharp N_e and T_e increases as well as a fast growth in an electron flux J_e registered two hours later were caused by a disturbed plasma sheet displacement - not by substorm injection. This conclusion is confirmed by the data of other geosynchronous satellites.

It should be noted that at the time of Pc1-IPDP generation a negative bay-like disturbance which is commonly interpreted as the northwestward substorm expansion was registered at BJN (corrected geomagnetic coordinates $\varphi^2=71.4^\circ$, $\lambda^2=108.1^\circ$). The BJN magnetogram is shown in

The A (UT) dependency is shown in Fig. 4a as compared to variations of solar wind dynamic pressure P_{sw} (Fig. 4b), H-component of the midlatitude geomagnetic field and SYM-H index (Fig. 4c). It follows from Fig.4 data that the bay-like H-component variations registered at 13 - 17 UT in the afternoon (HER), at night (MMB) and in the morning (TUC) as well as SYM-H variations, are similar to P_{sw} fluctuations. Of special notice are the simultaneous Pc1-IPDP amplitude reduction and P_{sw} depletion, which latter is concurrent with the second E enhancement. By analogy with high-latitude Pc1,2 pulsations it can be supposed that in the case under study the fluctuations of P_{sw} made a significant contribution to the modulation of Pc1-IPDP activity.

It is significant for our investigation that the Pc1-IPDP succession was registered on April 7, 2000 near midnight i.e. in the region where the detection of the substorm injection based on Pi2 and geosynchronous satellite data are the most probable [Lee and Min, 2002]. From the Mondy data it follows that there were no clear Pi2 trains before or during the Pc1-IPDP succession.

As can be judged from geosynchronous satellite data the Pc1-IPDP waves were generated during the progress of the plasma sheet toward the Earth. It is illustrated in Fig. 5 by the example of LANL 1994_084 (103.7° E) satellite data. It is the nearest

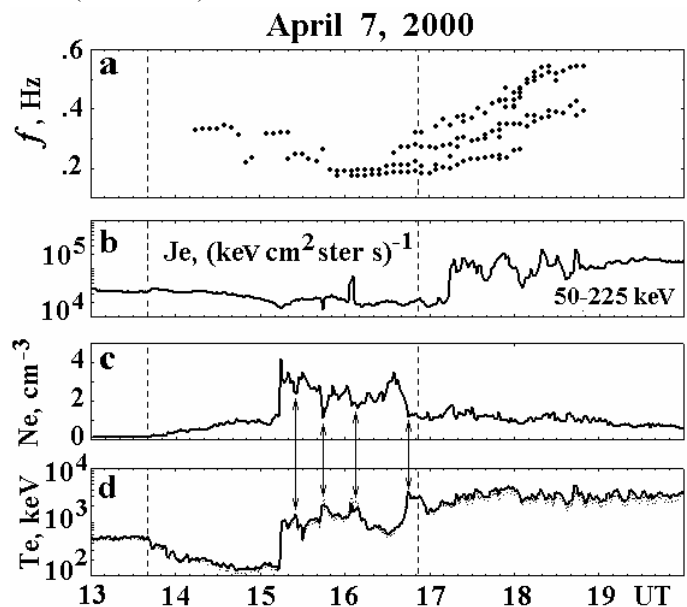


Fig. 5. Variations of: **a-** frequency of Pc1-IPDP; **b-** electron flux in 50 - 225 keV energy band; **c-** partial density and **d-** parallel (dotted line) and perpendicular (solid line) temperatures of 0.03-45 keV electrons.

Fig.6 together with the $f(UT)$ dependency and the variations of ASY-D and ASY-H indices. Data analysis showed that the negative bay was much localized and was not registered at the other IMAGE observatories. It should be particularly emphasized that the negative H disturbance was not accompanied by ASY-D or ASY-H bay-like disturbances as would be the case during a substorm [Iyemori and Rao, 1996]. In any case the mentioned negative H disturbance was not accompanied by changes in the Pc1-IPDP properties.

Discussion and conclusions

Ideally the “convective” IPDP should appear as an extension of Pc1,2 waves without any burst-like wave phenomena. But in reality the substorm injections and short-term auroral activations occur during all levels of geomagnetic activity and superimpose on the global slow-mode convection activity. Each of the mentioned magnetospheric disturbances stimulates the generation of geomagnetic pulsations. Because of this, more often than not, it is impossible to separate the convective component of the geomagnetic pulsations from the other components registered in the high latitudes during the periods of enhanced magnetospheric convection. Our study has shown that this separation is the easiest for waves registered in the middle latitudes where the effects of the short-term auroral activations are weakened.

We have shown that:

1. Pc1-IPDP succession of geomagnetic pulsations registered on April 7, 2000 at midlatitude Mondy observatory is a pure “convective” phenomenon resulting from magnetospheric convection enhancement.
2. In the case under study the source of the waves could be localized in the vicinity of the inner edge of the plasma sheet.
3. The “convective” model gives a fully satisfactory explanation for generation of the Pc1,2 frequency range geomagnetic pulsations happening during the enhanced magnetospheric convection.

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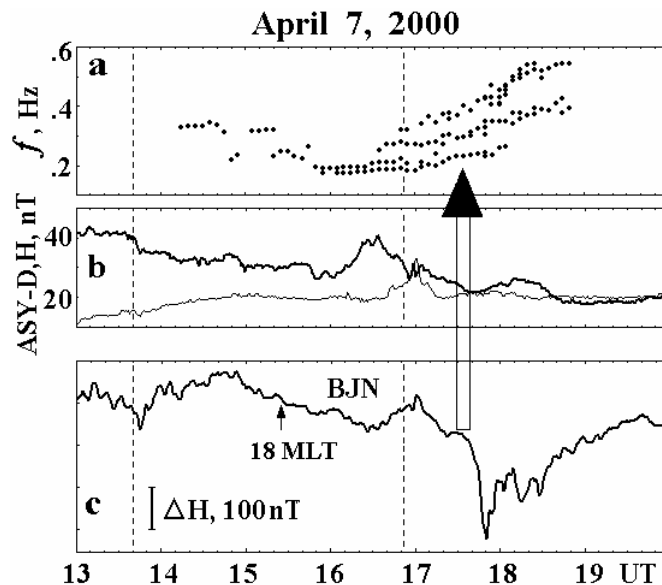


Fig. 6. Variations of: **a-** the frequency of Pc1-IPDP; **b-** ASY-D (thin line) and ASY-H (thick line) indices; **c-** H-component of the geomagnetic field at BJN.