"Physics of Auroral Phenomena", Proc. XXXVII Annual Seminar, Apatity, pp. 63-66, 2014

Polar Geophysical Institute

GEOMAGNETIC Pc1 PULSATIONS IN THE SOLAR ACTIVITY MINIMUM

N.G. Kleimenova, F.Z. Feygin, Yu.G. Khabazin, L.M. Malysheva
(Schmidt Institute of the Physics of the Earth RAS, Moscow, Russia)

Abstract. We studied the long-lasting (more 2 hours) series of Pc1 geomagnetic pulsations occurrence during the minimum of the solar activity (2006-2010) based on the ground-based induction magnetometer network at Scandinavia. It is known, that the Pc1 occurrence maximum is observed in the declining phase of the solar activity. Really, in the declining phase of the 23-th cycle of the solar activity (2006), the number of the hours with long-lasting Pc1 series was ~270. In the minimum between 23-th and 24-th cycle, the lowest value of the Wolf number (Wp) ~ 3 was observed in 2008 and 2009. However, in 2008 there were two sequences of recurrent magnetic storms with 13-14 storms in each, i.e. an overall about 30 moderate magnetic storms, but in 2009 there were only 5 small magnetic storms. Correspondingly, the number of the hours with long-lasting Pc1 series was ~100 in 2008 and it was~20 in 2009. It supports the relationship of long-lasting Pc1 generation with magnetic storms development. We found that, generally, during the solar activity minimum, the shape of the dynamic Pc1 spectra looked like a very monochromatic emissions of not more 3-5 hours duration with a low central frequency (less than 1 Hz) and a narrow width of the dynamic spectra. However, during the declining (2006) and increasing (2010) phases of the solar activity, the spectral structure of Pc1 became more complicated and the duration of the Pc1 series increased up to 10-12 hours. The central frequency of the Pc1 series and the width of the wave dynamic spectra significantly increased. Sometimes it consisted of several varying frequency bands. The theoretical interpretation showed the width of the Pc1 spectra is controlled by an important magnetospheric parameter $(V_A / U_{\|})$, where V_A is the Alfven speed in the top of the magnetic field line, and $U_{\|}$ is the average field-along speed of the anisotropic protons.

Introduction

The Pc1 geomagnetic pulsations are the repeated wave packets of Alfven waves in the frequency range 0.2-5.0 Hz travelling between the conjugated hemispheres. Their theory of generation and the morphological properties are widely discussed in the literature list time, e.g. in several revues [*Gulielmi and Pokhotelov, 1994; Kangas et al., 1998; Demekhov, 2007*]. The results of the last 10-years satellites (THEMIS, CHAMP, Cluster spacecrafts) measurements are presented in some papers, e.g. [*Min et al., 2012; Park et al., 2013; Lin et al., 2014*].

It is no doubt that Pc1 pulsations ("pearls") are generated via the cyclotron instability of radiation belt protons with anisotropic velocity distribution [*Cornwell, 1965; Kennel and Petchek, 1966; Feygin and Yakimenko, 1971; and many others*].

The ground-based data demonstrated the maximum of the mid-latitude (obs. Borok) Pc1 activity in the anti-phase with the solar activity [*Matveeva, 1987*], and the Pc1 activity in California, USA was strongest during the declining phase of a solar cycle [*Fraser-Smith, 1970*]. The rather similar results was obtained in the auroral latitudes (obs. Sodankylä, Finland), where the Pc1 occurrence rate appeared inversely correlated with solar activity with the phase delay of about two or one year [*Mursula et al., 1991*], which was explained in terms of magnetospheric ion composition [*Guglielmi and Kangas, 2007*].

Here we continue to study the Pc1 activity and their spectral properties using the wave spectrograms obtained from the ground-based induction magnetometer network at Scandinavia during the minimum of the solar activity (2006-2010).

Results

Here we present the results of the analyzing the ground-based data of the magnetometer chain of Sodankylä Geophysical observatory, stored at (*http://sgo.fi/Data/Pulsation/pulArchive.php).* Fig. 1 demonstrated the solar activity during the discussed period**.**

It is seen that in the minimum between 23-th and 24-th cycle (Fig. 1) of the solar activity, with the lowest value of the Sunspot number (Wp ~ 2-3) was observed in 2008 and 2009. The geomagnetic activity variation in 2008 and 2009 geomagnetic Pc1 pulsations occurrence is shown in Fig. 2. The magnetically quiets year was 2009. In 2008 there were two recurrent magnetic storm sequences with 13-14 storms in each (Fig. 2), i.e. an overall about 30 moderate magnetic storms. However, in 2009 there were only 5 small magnetic storms. It is seen, that in 2008 there were observed much more number of long-lasting Pc1 events than that in 2009. Most of Pc1 events were associated with magnetic storms and magnetic disturbances development. The long-lasting Pc1 pulsation series were observed mostly during the late recovery phase of magnetic storms and disturbances.

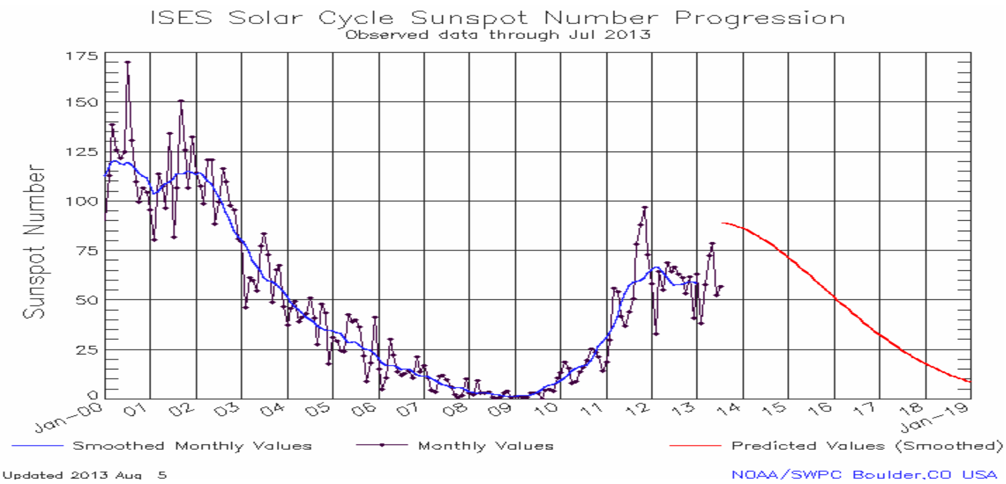

Figure 1. The solar activity (measured the Sunspot number) in 2001-2013 (blue line) and its prediction (red line).

The common yearly Pc1 duration (the number of the hours with long-lasting Pc1 series during one year) in the declining phase of the 23-th cycle of the solar activity (2006), was rather high ~270, but in 2008, this number was ~100 and in 2009 it was only ~20**.**

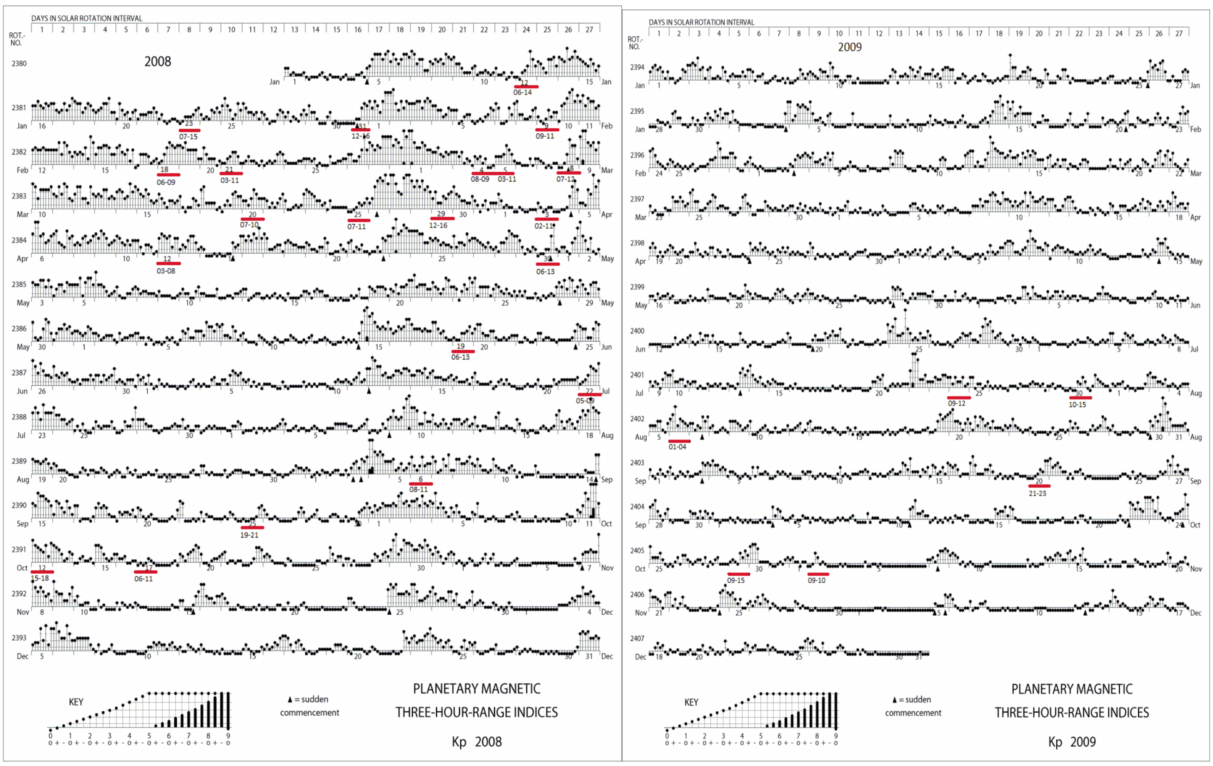

Figure 2. The geomagnetic activity and long-lasting Pc1 occurrence (red bars) in 2008 and 2009

The spectral structure of the Pc1 pulsations was different in quiet and disturbed magnetic conditions. It was much more complicated under the latest (see some examples in Fig. 3).

As a rule, during the solar activity minimum, the shape of the frequency-temporal Pc1 spectra looked like a very monochromatic emission of not more 3-5 hours duration with a narrow of the width of the dynamic spectra. An example of such event is presented at the right panel of Fig. 3 (on 30.07.2009 under Kp~0-1). The central frequency of the Pc1 emissions was less 1 Hz with the spectral width in the order of 0.2-0.3 Hz.

During the declining (2006) and increasing (2010) phases of the solar activity, the spectral structure of Pc1 pulsations became more complicated and the duration of the Pc1 series increased up to 10-12 hours. Sometimes it consisted of several varying frequency bands as it was demonstrated at the left panel of Fig. 3. The central frequency of Pc1 waves and the spectral width significantly increased.

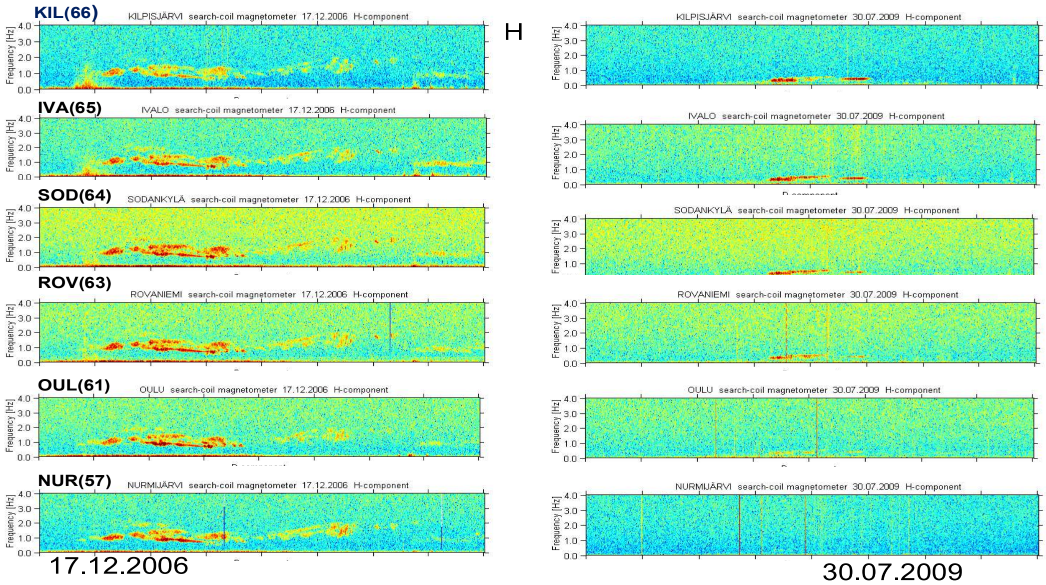

Figure 3. The spectral structure of Pc1 pulsations under magnetically disturbed period (left panel) and under very quiet condition (right panel). The geomagnetic latitude of stations is shown behind the station cod.

Discussion

According to [*Feygin and Yakimenko, 1971; Gendrin at al., 1971*], the frequency band of a Pc1 wave packet could be determined by the expression: $\Delta\omega \propto \dfrac{\beta V_{g0}}{\alpha^{1/2}\left(\alpha^2+\beta^2\right)^{1/2} t_n^{1/2}}$, where n - the number of the equator wave crossing, $\beta = \dfrac{d^2\omega}{dk^2}|_{k=k_0}, \alpha = \dfrac{d^2\gamma}{dk^2}|_{k=k_0}$ are the terms of the expansion of the frequency (ω) and grow rate (γ) by the wave number (k); $V_{g0} = \dfrac{d\omega}{dk}|_{k=k_0}$. The growth rate ($\gamma$) depends on the very important magnetospheric parameter $\left(V_A/U_{\|}\right)$, where V_A - the Alfven speed in the top of the magnetic field line, and $U_{\|}$ is the average field-along speed of the anisotropic protons. The numeric calculations showed that under small values of the $\left(V_A/U_{\|}\right)$, the frequency Pc1 band could be small as well as the width of the wave spectra. However, under large values of this parameter, the frequency Pc1 band could become large. The result of this calculation is shown in Fig. 4

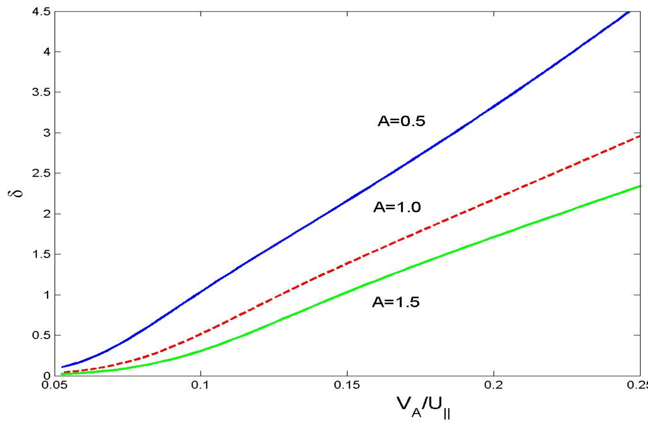

Figure 4. The wave spectral width dependence on the parameter $\left(V_A/U_{\|}\right)$

It is seen that the relative width of the Pc1 wave spectra $\delta = \left[\Delta\omega / \left(\Omega_i / t_n \right)^{1/2} \right]$ increases with the $\left(V_A / U_{\|} \right)$ increasing. The anisotropy also controls the wave spectral width - with increasing anisotropy A, for fixed the value of parameter $\left(V_A / U_{\|} \right)$, the spectral width decreases.

Conclusion

During the minimum of the solar activity (2006-2009) and the beginning of the new cycle (2009- 2012), the common annual duration of the long-lasting series (more 2 hours) of the Pc1 geomagnetic pulsation was controlled by the cycle variations of the solar and geomagnetic activity.

The long-lasting Pc1 pulsation series were observed mostly during a late recovery phase of magnetic storms and disturbances.

In the solar activity minimum, the shape of the dynamic Pc1 spectra looked like a very monochromatic emission of a rather short (not more 3-5 hours) duration with a low central frequency (less than 1 Hz) and a narrow width (~0.2-0.3 Hz) of the dynamic spectra.

However, during the declining (2006) and increasing (2010) phases of the solar activity, the spectral structure of Pc1 became more complicated and the duration of the Pc1 series increased up to 10-12 hours. The central frequency of the Pc1 series and the width of the wave dynamic spectra significantly increased. Sometimes it consisted of several varying frequency bands.

The theoretical interpretation showed the width of the Pc1 spectra is controlled by an important magnetospheric parameters $\left(V_A / U_{\|} \right)$ and anisotropy A, where V_A is the Alfven speed in the top of the magnetic field line, and $U_{\|}$ is the average field-along speed of the anisotropic protons.

Acknowledgements. The paper was supported by the Program No 4 of the Presidium of the Russian Academy of Sciences (RAS) and partly by the RFBR Grants № 14-05-00850.

References

Cornwall J. M. Cyclotron instabilities and electromagnetic emission in the ultra low frequency and very low frequency ranges // J. Geophys. Res., 70(1), 61–69, doi:10.1029/JZ070i001p00061 1965.

Demekhov A.G. Recent progress in understanding Pc1 pearl formation // J. Atm. Solar-Terr. Phys. V. 69. P. 1609-1622. 2007.

Feygin F.Z, Yakimenko V.L. Appearance and development of geomagnetic Pc1 type micropulsations ("pearls") due to cyclotron instability of proton belt // Ann. Geophys. V.27. P. 49–55. 1971

Fraser-Smith A.C. Some statistics on Pc 1 geomagnetic micropulsation occurrence at middle latitudes: Inverse relation with sunspot cycle and semi-annual period // J. Geophys. Res. V. 75. P. 4735–4745, doi:10.1029/JA075i025p04735, 1970.

Gendrin R., Lacourly S., Roux A., Solomon J., Feygin F.Z., Gokhberg M.B., Troitskaya V.A., Yakimenko V.L. Wave packet propagation in an amplifying medium and its application to the dispersion characteristics and to the generation mechanism of Pc1 events // Planet. Space Sci. V. 19. P. 165–194. 1971.

Guglielmi A., Kangas J. Pc1 waves in the system of solar–terrestrial relations: New reflections // J. Atmos. Solar-Terr. Phys. V.69. P. 1635–1643, doi:10.1016/j.jastp.2007.01.015, 2007.

Guglielmi A., Pokhotelov O. Nonlinear problems of physics of the geomagnetic pulsations // Space Sci. Rev. V. 65. P. 5-57. 1994.

Kangas J., Guglielmi A., Pokhotelov O. Morphology and physics of short-period magnetic pulsations // Space Sci. Rev. V.83. P. 435-512. 1998.

Kennel C.F., Petschek H.E.. Limit on stably trapped particle fluxes // J. Geophys. Res. V. 71(1). P. 1-28. doi:10.1029/JZ071i001p00001. 1966.

Lin R.-L., Zhang J.-C., Allen R.C., Kistler L.M., Mouikis C.G., Gong J.-C., Liu S.-Q., Shi L.-Q., Klecker B., Sauvaud J.-A., Dunlop M.W. //Testing linear theory of EMIC waves in the inner magnetosphere: Cluster observations // J. Geophys. Res. V. 119. P. 1004-1027. doi: 10.1002/2013JA01954. 2014.

Matveeva E.T. Cyclic variation of geomagnetic Pc1 activity // Geomagnetism and Aeronomy V. 27. No.3. P. 392-395. 1987.

Min K., Lee J., Keika K, Li W. Global distribution of EMIC waves derived from THEMIS observations // J. Geophys. Res. V. 117. A05219, doi:10.1029/2012JA017515. 2012.

Mursula K., Kangas J., Pikkarainen T., Kivinen M. Pc1 micropulsations at a high-latitude station: A study over nearly four solar cycles // J. Geophys. Res. V. 96. P. 17651–17661, doi:10.1029/91JA01374, 1991.

Park J., Lühr H., Rauberg J. Global characteristics of Pc1 magnetic pulsations during solar cycle 23 deduced from CHAMP data // Ann. Geophys. V. 31. P. 1507–1520. 2013.