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POLAR CAP INDEX VERSUS POLAR CAP POTENTIAL VARIATIONS AS A SUBJECT OF THE SOLAR WIND-MAGNETOSPHERE INTERACTIONS

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ABSTRACT

Polar Cap Index (**PCI**) had been suggested as an opportunity to estimate geomagnetic activity level from a single ground based magnetometer measurements close to the magnetic pole. It was shown that PCI is an approximate manifestation of the convection electric field at high latitudes under assumption that magnetic disturbances are mainly due to the Hall currents. In the present paper, cross polar cap potential ($\mathbf{\Phi}_{pc}$) data from 549 North pole passes around spring equinox 1998, taken from Special Sensor-Ions, Electrons and Scintillation (**SSIES)** instrument on **DMSP**-**F**13 satellite, under Defense Meteorological Satellite Program (**DMSP**) are used. For the same period, Thule North Pole PCI data were taken in conjunction with SSIES polar cap potential (**PCP**) data under various IMF conditions as observed from Advanced Composition Explorer (**ACE**) satellite. It was found relatively good correlation of about R=0.88 between SSIES $\mathbf{\Phi}_{pc}$ and Thule PCI data within the whole period of observation. While the satellite observations of PCP are an integral characteristic during almost 20min at high latitude part of the orbit, we suggest that PCI could be used under various purposes when higher time resolution is needed.

INTRODUCTION

Single point ground based magnetometer measurements closely located to the magnetic pole, have been proposed by Troshichev et al. (1979, 1985) as an index of geomagnetic activity which represents solar wind-magnetosphere interaction processes over polar cap. Near to magnetic pole, variations of the horizontal component of Earth's magnetic field as a subject of the IMF B_z behavior have been studied by Friis-Christensen et al.(1975), Maezawa (1976), Kuznetsov and Troshichev (1977), Rezenov et al. (1979). It was shown by Papitashvili et al. (1981) that almost linear behavior exists between IMF B_z values and magnetic disturbances observed close to the magnetic pole caused by DP_2 current system at $B_z<0$ for all universal time sectors. Similar linear relationship between IMF Bz values and corresponding disturbances of horizontal component caused by DP_3 system, but with slightly different slopes for the same UT intervals was observed for $B_z>0$. Troshichev and Andrezen (1985) pointed out, if summer polar cap conductivity could be assumed homogeneous, thus the observed horizontal magnetic disturbance vector has to represent cross-polar convection electric field. Troshichev et al. (1988) emphasized on the high correlation between horizontal magnetic disturbances and "half wave rectifier" model for solar wind electric field component suggested by Burton et al. (1975). Largest correlation had been found for suggested by Kan and Lee (1979 “merging” electric field E_m calculated from corresponding IMF data. An average correlation coefficient of about R=0.66 during UT 24 hours dial had been reported over three years (1978-1980) of observations from Thule and Vostok stations closely located at North and South magnetic poles respectively. As a result, authors used E_m calculated from IMF data in normalization procedure for the proposed in the paper Polar Cap Index. By means of DMSP Polar Cap Potential data, Troshichev et al. 2000 discussed relationship between observed electric field and Polar Cap index as a proxy of the ionospheric convection at high latitudes. Recently, Lukianova 2004 emphasized on the existence of the close connection between sudden pulses in the Solar Wind pressure and PC index variations.

In the present paper we compare DMSP-F13 polar cap potential data taken ±20 days of the spring equinox 1998 and simultaneous PCI data from Thule North pole station. We show that relatively good correlation exists between PCP and PCI during this period. Under certain restrictions, the observed correlation could be a reason PCI to be used as well as PCP in cases where shorter time scales become important.

EXPERIMENTAL DATA

Polar cap index data from Thule station at 85.4^o corrected geomagnetic (**CGM**) latitude are collected in a 1min and 15min time resolution files at Internet site of Danish Meteorological Institute (Copenhagen, Denmark). In the present paper, we use 15min **PCI** observations during 40 days from March 01 to April 10 of 1998. Largest geomagnetic storm for this period reaches $D_{st} < -120$ on March 10. In parallel to the PCI data set, polar cap potential data in the dawn-dusk meridian taken from SSIES instrument onboard DMSP-F13 are used. SSIES instrument package has flown on DMSP satellites since DMSP-F8 launched in 1987. DMSP-F13 mission started in 1994 at Sun synchronous circular orbit with local time of nodes 1711-0511 and orbital height of ~840km. Thermal ion drift measurements were continuously performed since the beginning of mission. As it was shown by Banks et al. (1981), ion drift velocity component transverse to the satellite track, i.e. the parallel electric field component $\mathbf{E}_{\|}=\mathbf{V}_{\perp}\mathrm{x}\mathbf{B}$, could be used in calculation of the polar cap potential. Generally, this electric field component integrated along the satellite orbit at high latitude locates potential minima and maxima along the orbit. If the satellite passes through the main extrema, the observed potential difference is proportional to the polar cap potential drop. During integration procedure, it is assumed that relatively small changes in **PCP** occur with time scale less than ~20min, which is approximate time for low Earth orbiting satellite to pass over the polar cap region. Otherwise, to avoid the effect of the accumulated offset in the integration due to instrument errors and/or short time changes in **PCP,** potential data have to be re-zeroed at certain magnetic latitude (usually ~55^o).

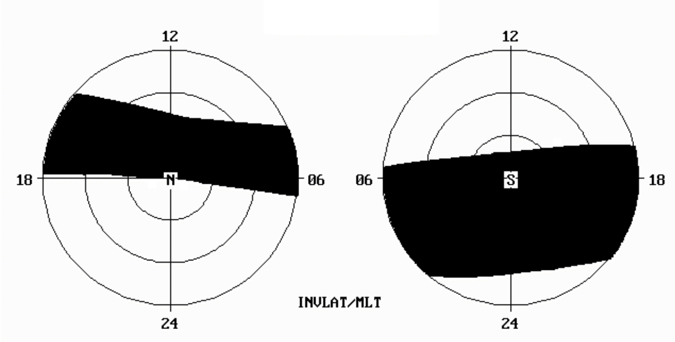

Fig.1. North and South Polar Cap zones covered by DMSP-F13 satellite during the period March 01 1998 to April 10 1998 (see the text)

On the Fig.1, using magnetic local time (**MLT**) versus invariant latitude (**INVLAT>**60^{o}**)** coordinate system, we show the summarized picture of the polar zones crossed by DMSP-F13 for whole 40 days period. Over North polar cap (left panel), DMSP-F13 passes predominately at the dayside MLT, while at South polar cap passes are located in a broader zone at night-time side. This asymmetry is a combined result of the magnetic poles offset position from North and South geographic poles and the chosen orbital parameters of the sun synchronous DMSP-F13 orbit. During the day, satellite passes at different distances from the magnetic pole almost in dawn-dusk meridian plane. If one can assume a non-skewed distribution of the polar cap potential (small IMF B_y component), similar to the Heppner and Maynard's "model A" (1978), thus the optimal orbital position to observe main potential difference is closest to the magnetic pole. While this happens almost once a day, it could be expected some modulation in PCP values, due to the current satellite track position in respect to the magnetic pole and electric field potential extrema. Basic problems of the PCP observations from the satellites had been discussed in details by Reiff et al. (1981), Wygant et al.(1983), Lockwood (1991),Boyle et al. (1997), Feshchenko and Maltsev (2003). As an illustration, on the top panel of Fig.2 we show relative changes of the smallest distances between North magnetic pole and orbital plane position during the whole period of 40 days from day 60 to day 100 of the year 1998 (**DOY**).

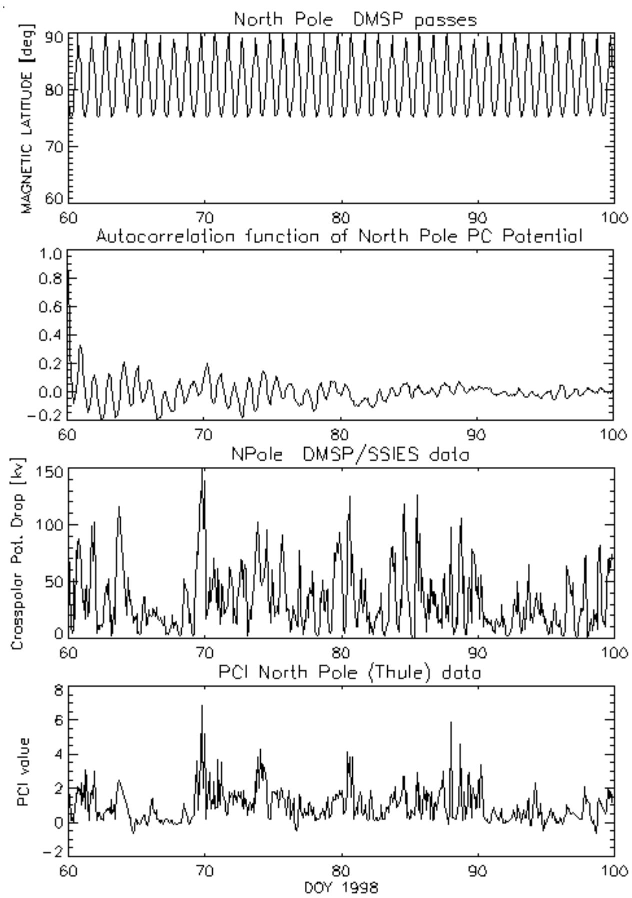

Fig.2. Combined plot of the (i) north magnetic pole closest DMSP-F13 position variations during the period of observations (top panel), (ii) autocorrelation function variations of the observed north

polar cap potentials, (iii) the observed north polar cap potentials from SSIES DMSP-F13 instrument, (iiii) north pole THULE PCI values (bottom panel)

Oscillations in the satellite position with 24-hour characteristic UT period in the range 75°-90° CGM latitude (top panel) correspond to the same period that is well pronounced in the autocorrelation function of DMSP-F13 PCP data chain. On the bottom two panels, DMSP-F13 PCP and Thule North magnetic pole PCI data taken over the specified period of 40 days are shown. While PCI observations have higher time resolution, they are averaged over every central UT of the PCP integration period for every North Pole DMSP-F13 pass (generally this is UT moment of the closest to magnetic pole DMSP-F13 orbital position). To minimize the sparse influence of the orbital plane position in respect to the magnetic pole, we imposed search window over the PCP data set, which cover only the geomagnetic latitudes greater than 82° CGM, together with their corresponding PCI values. This CGM limit had been chosen as a certain compromise between the observed correlation between PCI and PCP values and almost statistically sufficient number of 259 data points that remain after selection. Scattered plot of the resulted 259 observations of PCI/PCP pairs is shown on Fig.3.

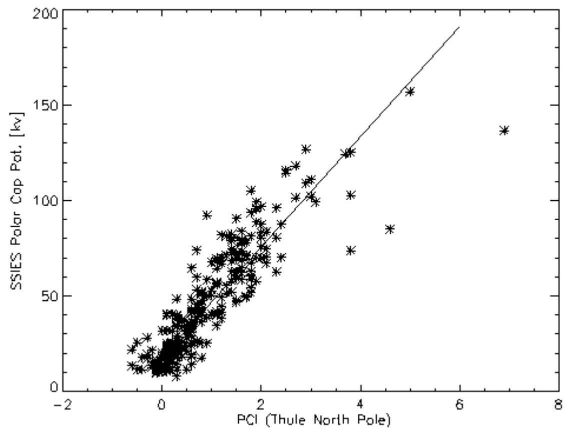

Fig.3. Scattered plot of the PCI and DMSP-F13 PCP Data (Orbital plane CGM>82°)

Correlation for the selected set of PCP/PCI measurements is R=0.88. At zero PCI we have 17.9kV residual polar cap potential. Linear fitting shown by solid line gives:

$$\Phi pc = 17.9 + 28.9 * PCI \qquad (1)$$

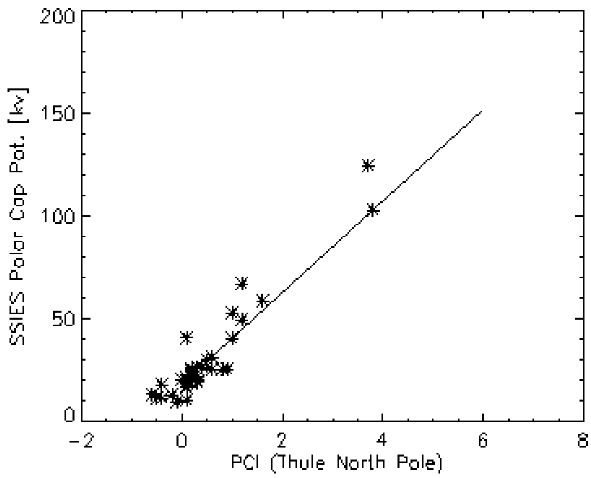

Fig.4 Same as Fig.3 but with an additional condition for IMF By component (1<By<3)

As it was mentioned above, optimal conditions for PCP observation appear when DMSP-F13 satellite passes close to the potential extrema in dawn-dusk frame of reference. For a given DMSP-f13 orbital parameters at North Polar Cap, as though to be optimal "non-skewed" potential distribution. We observe higher correlation R=0.95 between selected PCP/PCI values, when additional search window for By (1nT <By< 3nT) is imposed over data set (Fig.4). Linear fitting for the data presented on Fig.4 gives a residual potential drop of 18.1kV over polar cap at zero PCI:

$$\Phi pc = 18.1 + 22.2 * PCI \qquad (2)$$

Summarized, three different cases of relative variations in the correlation between PCP and PCI data as a consequence of the imposed search window over entire data set are shown on Fig.5. Vertical Y-axis represents correlation coefficients changes, while the CGM bottom limit varies from 75^{o} to 85^{o} with 1^{o} step (X-axis of both panels). On the bottom panel of Fig.5 corresponding number of PCP and PCI data points used in the statistics after each search procedure is shown.

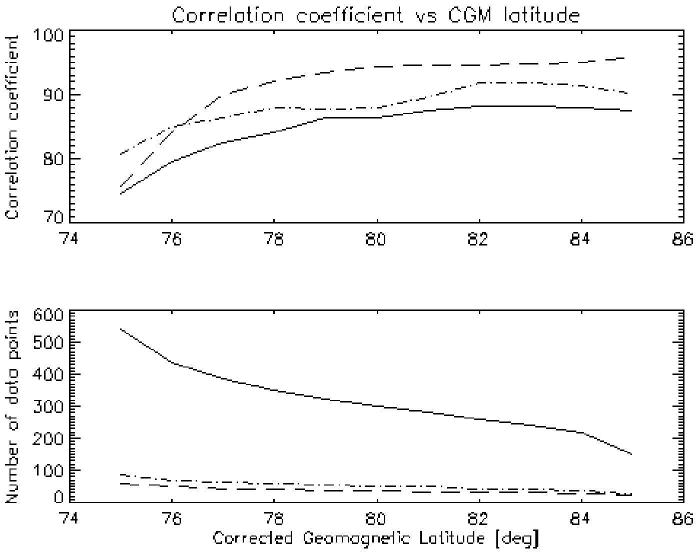

Fig.5. Correlation coefficient changes versus CGM bottom limit (top panel) and relative number of orbits used in the statistics for different CGM limits (bottom panel)

On the top panel of Fig.5, solid line represents changes in PCP/PCI correlation as a result of the applied CGM latitude bottom limit. As it was shown, maximum of R was found when IMF By component varies within the range 1nT-3nT (dash line on Fig.5), thus dash-doted line show the corresponding correlation to the selected "near by" cases with IMF By component in the range ±1nT around By=0. Correlation coefficients denoted to the "small" By cases are larger than the observed one without restrictions for IMF By over whole amount of data within the range of CGM latitudinal limits (top panel). At CGM latitude grater than 82^{o}, relative difference in R between different cases becomes 0.04. Observational chain of PCP and PCI data, filtered by simple running average with length of 15 points (one day period) is shown on Fig.6. On the top panel autocorrelation function of the PCP data show a good filtering effect over diurnal period of modulation from the orbital position of DMSP-F13. PCI data were filtered in the same way to sustain the same spectrum changes as in the PCP after filtering. It is well seen a relatively high similarity in

PCP and PCI behavior. Observed correlation coefficient for this set of 549 data points is R=0.92. However, smoothing cuts the higher frequency part of the spectrum of PCI and PCP variations.

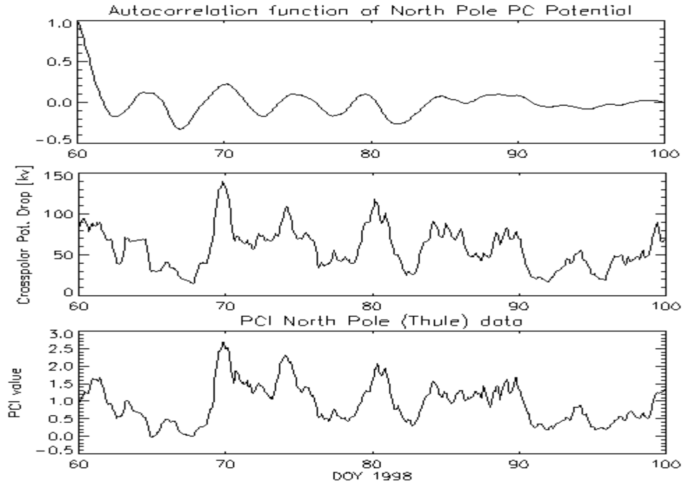

Fig.6 Autocorrelation function (top panel) of the smoothed (PCP) and both PCP/PCI data (bottom two panels)

In parallel, by running average we reduce the real amplitudes of PCP in a quite ambiguous way, which makes them unusable for evaluation of quantitative relationship between both PCP/PCI values. Thus, the observed relatively high R value is an indication that PCI and PCP have rather similar behavior for the periods greater than few hours.

CONCLUSIONS

The main task of the here presented work is to examine relative behavior of the PCI and PCP for Spring Equinox 1998. We observe maximum of correlation R=0.95 between Thule PC Index and DMSP-F13 Polar Cap Potential when IMF By from simultaneous ACE data (corrected with one hour for the distance of sub-solar magnetosphere interaction region) varies in the range 1nT÷3nT. It is important to be pointed out here, that we are using Polar Cap Potential drop data as a potential difference between observed extrema in SSIES data. No any pre-selection of data hade been used over specified period. As it was shown by Troshichev et al. (2000) Polar Cap electric field at 840km height seems to saturate at high PCI values. Here used PCP values were not normalized for the size of polar cap, but similar behavior could be noted from fig.3. Under the same reason, further work to improve this data set have to be done to exclude the effect on PCI caused by sudden Solar Wind pressure changes shown by Lukianova R.U. (2004).

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