The polar cap magnetic activity indices in the southern (PCS) and northern (PCN) polar caps: Consistency and discrepancy

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1. Introduction

There are some systematic differences between the 1-min Polar Cap (PC) indices of magnetic activity derived from data from the southern hemispheric station, Vostok, and the northern hemispheric station, Thule. First of all, differences in sign of the PC index are observed when $B_z$ is northward: negative values of the PC index are common in the summer polar cap. Secondly, predominance of larger PC index values is seen in winter hemisphere for extremely high levels of magnetic activity ($PC > 12$) when the ionospheric electric field in summer and winter polar caps tends to approach an asymptotic value of $E = 40–45$ mV/m. It is suggested that ionospheric conductivity in the winter polar cap can be significantly increased owing to bombardment of the ionosphere by solar protons ($E = 1–10$ MeV) in association with polar cap absorption events.


2. Distinctions in PC Indices as Determined by Different Methods

Currently the 1-min PC index is derived using magnetic data from Vostok in Antarctica (PCS) and Thule in Greenland (PCN). These indices are calculated in the Arctic and Antarctic Research Institute (AARI) and Danish Meteorological Institute (DMI). These two sets of PC indices systematically differ in value: the PCS index exceeds $PN_{DMI}$ index, and the excess increases with growth of magnetic activity. Figure 1 (left column) shows statistical relationships between full sets of the 1-min PCS and $PN_{DMI}$ indices for the years of decay (1992), minimum (1995), and rising (1998–1999) in the last cycle solar activity. We see that the PCS and $PN_{DMI}$ indices are linearly related, but the PC indices provided by DMI are essentially smaller in value (statistic ratio $PCN_{DMI}/PCS = 0.65$).

The difference in techniques utilized in AARI and DMI for calculation of the 1-min PC index seems to be the main reason of this discrepancy. The first difference concerns the level of reference for magnetic disturbances in the polar cap. The AARI technique takes into account deviations of magnetic field from the quiet daily variation determined independently for each month of every year, the DMI technique uses the winter midnight quiet level, interpolated to the date between two consecutive years (to take into account the secular variation). The second difference concerns the coefficients determining the relationship between the interplanetary electric field and the polar cap magnetic activity. All coefficients in the AARI technique were determined with 5-min resolution and then were interpolated for 1-minute values, the DMI technique used the hourly coefficients to interpolate the 1-minute values.

In order to compare the PCN and PCS indices in a meaningful way, we calculated the Thule derived PCN index following the methodology developed at AARI and...
used to calculate the Vostok PCS index. Results of comparison of PCS and PCN indices obtained by the AARI techniques are shown also in Figure 1 (right column). One can see that use of the unified technique removes the regular discrepancy between values of the PCS and PCNAARI indices (PCS/PCNAARI = 1.0). In our subsequent analysis we shall examine exclusively the PC indices calculated by the technique utilized in AARI.

3. Regular Discrepancies Between PCN and PCS Indices

[6] Regular differences in the magnitude of the PCN and PCS indices are typical of very high levels of magnetic activity. Figure 2 shows differences between monthly values of PCS and PCN indices in course of six years (1992, 1995, 1997–2000) for quiet (0 < PC < 2), disturbed (2 < PC < 12), and extremely disturbed (12 < PC) periods.

PCN indices increases up to 5, and seasonal variation becomes noticeable: the PC index reaches higher values in the winter polar cap.

[7] Another discrepancy concerns the discordance in signs of the PC indices observed sometimes in the opposite hemispheres. Analysis [B. Emery, Private communication, 2001] has shown that negative PC indices are observed predominantly when BY > 0 and |BY/BZ| > 1. Figure 3a, b shows two examples when the PC index was essentially negative in summer polar cap, and close to zero or positive in the winter polar cap. In both cases the IMF BZ and BY components were positive. Figure 3c shows a rather rare event when both PCN and PCS indices were strongly negative (about −5) in the course of a severe storm of July 15/16, 2000. The IMF BZ component was strongly positive (about +10nT) from 13.00 to 17.00 UT on 16 July, whereas the BY component was close to zero.

[8] Figure 4 shows the monthly frequency and the extreme value of the negative PC indices observed at Vostok and Thule for 1998 and 1999. One can see that the negative PC are more common in the summer polar cap (October–March for Vostok, May–August for Thule) when their
frequency can be more than 10%. Occurrence of the negative PC index as a signature of reverse convection in the summer polar cap had been noted by Vennerstrom et al. [1991]. Nevertheless, our analysis demonstrates that negative PC indices can be observed in the winter cap as well. Examination of the IMF orientation for these periods shows that the negative PC indices are associated, irrespective of season, with the northward IMF component.

4. Discussion

[9] We see frequent differences in sign of the PCN and PCS indices observed under conditions of northward IMF, and seasonal differences in values of PCS and PCN indices observed during extremely high magnetic activity. We believe that both differences are due to peculiarities of the ionospheric conductance in the summer and winter polar caps. Indeed, the negative values of the PC index are most often in the summer polar cap. It implies that formation of a current system with the anti-sunward currents over the polar cap (DP-3 system [Troshichev, 1982]) is strongly regulated by ionospheric conductivity that is maximum in the sunlit summer polar cap. In the usual scenario, only the sunlit ionosphere ensures conditions for closing of the NBZ field-aligned currents [Iijima and Shibaji, 1987] and formation of reverse convection pattern. As a result, the negative PC indices are observed only in the summer polar cap. Nevertheless, the similar current systems can be observed in the winter polar cap as well. As an example, Figure 5 shows the convection patterns, constructed by the AMIE procedure for 15.30 UT on July 16, 2000 (Bastille storm). One can see that the intense vortices with reverse convection are formed in the morning sector in both, summer and winter, polar caps. These vortices maintain the unusual dusk-dawn oriented magnetic disturbances at stations Vostok and Thule, which are located just in the morning sector during this period. The relevant PCN and PCS indices will be negative in this time (Figure 3c).

[10] There are grounds to assume that ionospheric conductance in the winter polar cap was strongly enhanced during the Bastille storm in association with the polar cap absorption (PCA) following the very intense solar flare. Indeed, the absorption registered by the 30 MHz riometer at Vostok station exceeded the quiet level by the factor 5–30 during July 15–16, 2000. PCAs associated with bombardment of the ionosphere by solar flare-accelerated protons with energies $E_p = 1–10$ MeV result in increased ionization at ionospheric D and E layers, with duration ranging from tens of hours to several days [Hultqvist, 1969]. As a result of the enhanced conductivity, the conditions for closing of the appropriate field-aligned currents should be arisen in the winter ionosphere, and corresponding current systems (DP-3 or DP-2) determined by the polarity of the IMF will be developed. Indeed, the PC index at Vostok station varied in range from $-20$ to $+35$ on July 15, when absorption reached extremely high value of 20 decibels.

[11] To demonstrate the efficiency of ionospheric conductivity for the polar cap magnetic disturbances we examined the relation between PC index and ionospheric electric field under conditions of extremely high magnetic activity. Twelve magnetic disturbances have been chosen as the test cases. Figure 6 shows the southern polar cap electric field versus the PCS index from Vostok (upper panel) and the northern polar cap electric field versus the PCN$_{AARI}$ index from Thule (lower panel). Data sets are for 12 strongest magnetic storms in 2000. Points within circles are for storms with the intense polar cap absorption (June 8 and July 15, 2000).
cases, as follows: February 12, March 1, April 06, May 24, June 08, June 23, July 14–16, August 12, September 18, October 28, November 10, and November 27, 2000. Using the measurements on board of the DMSP spacecraft we selected the orbits that crossed the near-pole region in approximately the dawn-dusk direction, in so doing the potential reverses its sign. The average electric fields over the near-pole region have been calculated for 166 trajectories of the DMSP crossings of the northern and southern near-pole regions following the technique adopted in [Troshichev et al., 2000]. The mean values of PCS and PCN for intervals of the appropriate DMSP crossing have been taken as the PC indices corresponding to the calculated electric field.

[12] Figure 6 shows the relationships between the ionospheric electric fields observed in the southern and northern polar caps and the appropriate PCS and PCN indices. The positive values of the electric field are for the dusk-dawn direction, the negative values are for the dusk-dawn direction. The correlation results presented in Figure 6 show that the relationships between the PC index and ionospheric electric field are very similar in the northern and southern polar caps and may be described for PC < 15 by the following rough expression:

\[
E(\text{mV/m}) = 6.0 + 3.0(\text{PC}) - 0.06(\text{PC})^2
\]

[13] For PC > 15 the electric field approaches to asymptotic value \(\approx 40–45\) mV/m.

[14] The extreme growth of the polar cap magnetic activity under condition of saturated electric field implies occurrence of extraordinarily high ionospheric conductance. Indeed, all cases of saturated electric field for PC > 18 were observed exclusively on June 8 and July 15, 2000 (points within circles in Figure 6) when the powerful polar cap absorption took place. Both polar ionospheres, northern and southern, were bombarded by flare-accelerated protons in the course of these events, and the increased conductivity should be manifested in summer and winter polar caps. Thus, in association with severe polar cap absorption we see the growth of PC indices with saturated electric field, on the one hand, and occurrence of the negative PC index (reverse convection) in the winter polar cap, on the other hand. Both these uncommon phenomena can be explained by extraordinary growth of conductivity in the winter cap.

5. Conclusions

- The PC indices published by AARI and DMI are essentially different in value: the PC\text{AARI} indices are regularly higher than the corresponding PC\text{DMI} indices and this discrepancy increases as magnetic activity increases.
- The PCN and PCS indices calculated by the unified technique, demonstrate two types of regular discrepancies: (1) differences in sign of the PCN and PCS indices, observed under conditions of northward IMF, and (2) larger PC indices in the winter polar cap in periods of extremely high magnetic activity. Both these effects seem to be connected with peculiarities of conductance in the winter and summer polar regions.

- Statistical relationships between the PC index and ionospheric electric field can be described as the quadratic polynomial in both, northern and southern polar caps, the polar cap electric field being tended to asymptote to levels of \(E \approx 40–45\) mV/m, for high magnetic activity (PC >12).
- The great growth of the polar cap magnetic activity under condition of saturated electric field was observed in association with PCA events. It implies the uncommon enhancement of the ionospheric conductance in response to bombardment of polar caps by the solar flare-accelerated protons. As a result, the negative as well as extraordinarily high positive PC indices can be observed in the winter polar cap.
- The positive IMF B\text{Z} component is a necessary condition for the negative PC index occurrence provided by the high ionospheric conductivity in the polar caps.

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References


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