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Effective area for the northern polar cap magnetic activity index

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Abstract. In this letter, we report for the first time a study of an effective area where the polar cap (PC) magnetic activity index stably preserves a value. The 1998 data from three Greenlandic magnetic stations Qaanaaq (formerly Thule), Savissivik, and Kullorsuaq are utilized for derivation of 15-min PC indices using normalization coefficients defined earlier for Thule. The results obtained show that Qaanaaq and Savissivik produce almost identical PCI through the year; however, the index from Kullorsuaq correlates poorly with the other two stations. Therefore, as defined only by the Thule coefficients, the effective area for PC index is estimated to be ~15° in diameter centered at the north corrected geomagnetic pole.

1. Introduction

A number of geomagnetic activity indices are currently in use for various purposes. For example, the 3-hr Kp index indicates planetary geomagnetic activity; the hourly Dst index follows the dynamics of the magnetospheric ring current, particularly during magnetic storms; and the 1-min AE, AL, and AU indices show the auroral eletrojets development and activities in the northern auroral region.

Fairfield [1968] has found that a polar cap magnitude (defined as the maximum perturbation in the horizontal magnetic field components measured at the stations Alert, Mould Bay, and Resolute Bay) sometimes increases slightly before changes in the AE index. He suggested that the former might be a better indicator of high-latitude geomagnetic activity since it is less likely to be affected by spatial variations. This approach has been used in some studies [e.g., *Kokubun et al.,* 1972], but the index has never been derived routinely. Later *Saroso et al.* [1992], *Maclennan et al.* [1997], and *Ballatore et al.* [1998] introduced the AE-like index derived from magnetic disturbances occurring near 80° of corrected geomagnetic (CGM) latitude.

Troshichev et al. [1979, 1988] introduced the polar cap (PC) magnetic activity index widely used today, which is derived from geomagnetic data at a single near-pole station. A major motivation in this introduction was to quantify magnetic disturbances caused by a sunward, transpolar portion of the standard two-cell ionospheric current system, in other words, the ionospheric DP2 nonsubstorm current system. Therefore, the PC index can be regarded as a measure of high-latitude, transpolar convection electric fields generated by coupling of the solar wind and interplanetary magnetic field (IMF) with the Earth's magnetosphere.

Vennerstrøm et al. [1991] suggested two possible sources of the near-pole magnetic disturbances: (1) a transpolar ionospheric Hall current, and (2) a distant effect of field-aligned currents (FAC) located at the poleward boundary of the auroral oval. Since ionospheric conductivity in the sunlit, near-pole area is mainly produced by the solar ultraviolet radiation, a dominant source of magnetic disturbances here would be the ionospheric Hall current. However, the magnetic effects from distant field-aligned currents can dominate in the dark, winter hemisphere because conductivity becomes too low to support any substantial ionospheric current. *Vassiliadis et al.* [1996] and *Chun et al.* [1999] also refer to such additional contributions to the PC index.

Two stations, Thule (now Qaanaaq) in Greenland and Vostok in Antarctica, were selected for simultaneous derivation of the PC index because of differences in ionospheric conductivities in the winter and summer polar caps [*Vennerstrøm et al.,* 1994]. Time resolution was initially proposed to be 15-minutes; the index from Qaanaaq is routinely available from the Danish Meteorological Institute (DMI, Copenhagen, http://www.dmi.dk/projects/wdcc1/). The Russian Arctic and Antarctic Research Institute (AARI, St. Petersburg, http://www.aari.nw.ru) recently increased resolution of the PC index from Vostok to 1-minute. In 1999, the International Association of Geomagnetism and Aeronomy adopted the PC index as the official IAGA index for measuring of magnetic activity in the polar caps and recommended continuing its derivation separately for the northern and southern polar regions.

However, since the first introduction of the PC index, geomagnetic data from more stations in the near-pole regions have become available. Table 1 lists magnetic stations that are located above 80° corrected geomagnetic (CGM) latitudes over both the northern and southern polar caps (note that the most near-pole stations Eureka and Concordia are not yet fully operational). Geomagnetic data from all these stations can be utilized to investigate the morphology and dynamics of the near-pole ionospheric currents, as well as in validating the PC indices derived from different stations. Thus, a thorough study of the effective area within the polar cap, where the PC index would stably preserve a value, becomes important, especially in the light of recently introduced national and international "space weather" initiatives. Though our study is limited in longitudinal scope, it might be helpful in defining the reliability of the PC index for the immediate benefits of various practical applications.

2. Method

An algorithm to derive the PC index is based on a statistical analysis of relationships between the interplanetary pa-

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Table 1. Northern and Southern Near-Geomagnetic-Pole Stations

Epoch 1999.0	IAGA	CGM		MLT	Epoch 1999.0	IAGA	CGM		MLT
Station name	Code	Lat.°	Long.°	Noon	Station name	Code	Lat.°	Long.°	Noon
Eureka	EUR	88.61	326.29	18:54	Concordia	CRD	−88.63	54.46	01:02
Alert	ALE	87.01	102.31	09:33	U. S. AGO P5	AP5	−86.64	30.89	14:48
Qaanaaq (Thule)	THL	85.39	33.51	14:55	U. S. AGO P6	AP6	−84.98	215.17	02:29
Savissivik	SVS	83.64	35.91	14:44	Vostok	VOS	−83.37	54.91	13:02
Resolute Bay	RES	83.50	318.97	19:18	Casey	CSY	−80.84	155.91	06:31
Kullorsuaq	KUV	81.22	44.51	14:06	Dumont d'Urville	DRV	−80.59	236.05	00:54
Mould Bay	MBC	80.96	273.01	22:23	U. S. AGO P1	AP1	−80.07	17.68	15:43
Nord	NRD	80.93	105.80	09:17	Terra Nova	TNB	−80.04	307.86	20:07

rameter(s) and magnetic disturbances observed at the near-pole station. Because the DP2 transpolar ionospheric current is somewhat skewed with respect to the magnetic noon-midnight meridian, the observed magnetic perturbation vectors point duskward in general [e.g., *Troshichev et al.*, 1988; *Vennerstrøm et al.*, 1991; *Papitashvili et al.*, 1994].

The "true" direction of this DP2 current is defined through a correlation analysis relating the interplanetary parameter(s) and ground horizontal magnetic perturbations projected on various directions duskward. According to *Troshichev and Andrezen* [1985], the "merging electric field" by *Kan and Lee* [1979]:

$$E_m = v \cdot B_T \sin^2(\theta/2) = v \cdot (B_y{}^2 + B_z{}^2)^{1/2} \sin^2(\theta/2)$$

is best for that correlation (v here is the solar wind velocity, B_y and B_z are the IMF azimuthal and vertical components, and θ is the angle between the Earth's magnetic field and the IMF total "clock-angle" vector). Such a direction that shows maximum correlation with E_m is then used for derivation of the PC index during a given UT hour. However, this optimal direction varies with UT and therefore, to consider these variations, a properly projected horizontal magnetic perturbation should be normalized with respect to E_m. These normalization coefficients have independently been determined for Thule and Vostok for periods with good IMF coverage [e.g., *Vennerstrøm et al.*, 1991].

Troshichev et al. [1988] and *Vennerstrøm et al.* [1991] have shown that near-pole magnetic disturbances correlate better with E_m in summer; however, there is higher correlation between the PC index and AE index in winter and equinox. During summer, the daytime "reverse" ionospheric convection caused by northward IMF can significantly affect the PC index, reducing its capabilities in estimating variations of E_m. That was a reason for suggesting the derivation of the PC index simultaneously from the Thule and Vostok data.

3. Results

In this study, we utilized the same set of pre-defined normalization coefficients obtained for Thule in calculating the standard, 15-min PC indices through 1998 from geomagnetic data obtained at Qaanaaq, Savissivik, and Kullorsuaq. According to Table 1, these stations are located approximately along the same geomagnetic meridian and they span geomagnetic latitudes from 85.4° to 81.2°; Savissivik is in the middle of this chain.

Figure 1 shows the PC-index time series derived from THL, SVS, and KUV for May 1–15, 1998. As seen, all three series show similar behavior, though some differences are recognizable when the PC indices experience sharp negative excursions. Nevertheless, it seems that all three stations can produce a PC_{THL}–like index.

We calculated and then correlated the PC-index times series from THL and SVS for January–December 1998. Figure 2 shows these results plotted separately for winter, equinox, and summer. The dashed lines indicate 45° slopes, the solid lines (plotted within a range of fitted ~11,000 points for every season) represent regression equations shown in the left, top corner of each plot. As seen, the correlation coefficient between the two PC-index series is 0.96 in average and the slope of solid straight lines is almost 45°. The best correlation is achieved during winter; the points increasingly scatter through equinox and summer. These re-

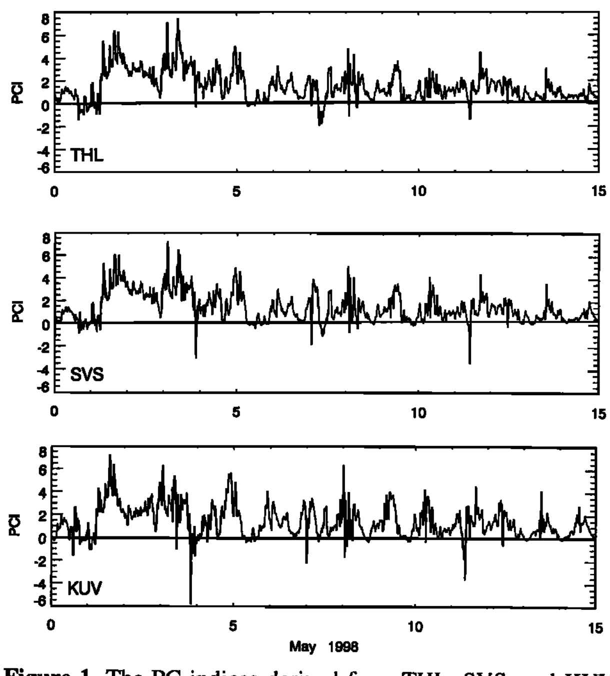

Figure 1. The PC indices derived from THL, SVS, and KUV for May 1–15, 1998.

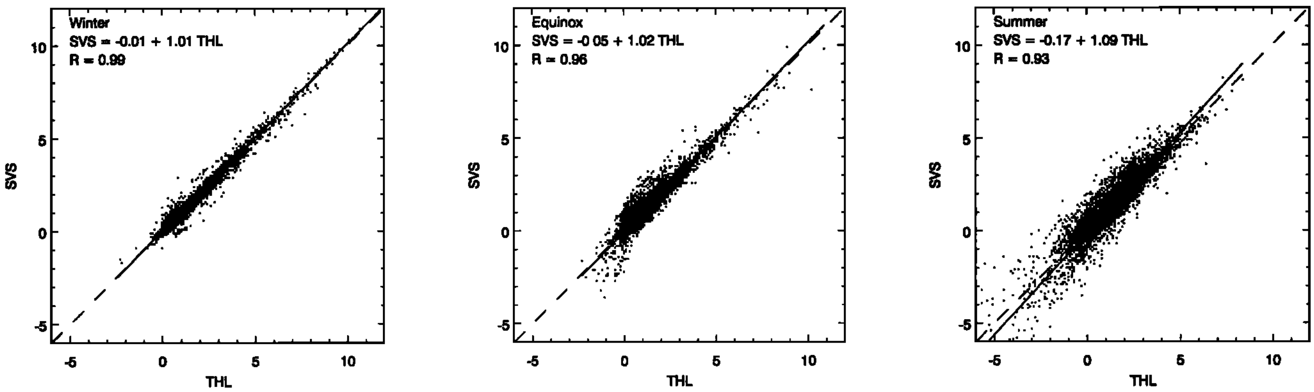

Figure 2. Correlation of the PC indices obtained from THL and SVS for winter, equinox, and summer of 1998.

sults clearly show that the PC index is stable between THL and SVS; therefore, almost identical PC indices can be produced using geomagnetic data from these two stations.

Figure 3 shows results of similar correlations between THL, SVS, and KUV, plotted for three months (April–June 1998) in transition from equinox to summer (this interval was limited by the available data from KUV). The top row shows correlation between THL and SVS, the middle row – between THL and KUV, and the bottom row – between SVS and KUV.

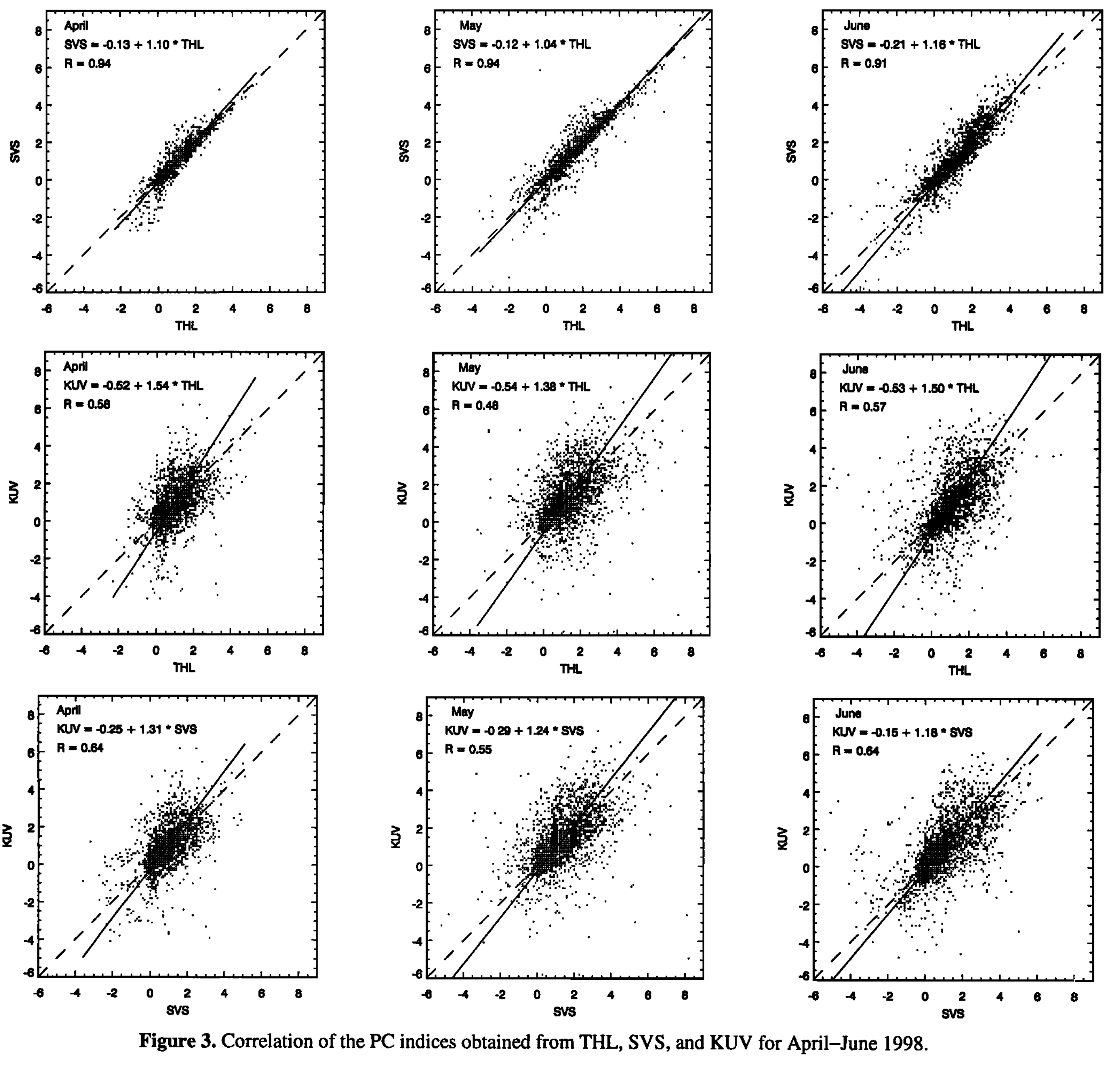

Figure 3. Correlation of the PC indices obtained from THL, SVS, and KUV for April–June 1998.

The correlation between THL and SVS for these three months almost repeats the results shown on Figure 2 in the distribution of the points (~2,800 for each month), as well as for the obtained numbers. However, correlation becomes poorer (R ~ 0.5) as we compare THL and KUV: the slope of the linear regression fit increases suggesting that PC_{KUV} could differ up to 50% from PC_{THL}. The same conclusion can be made from comparisons between SVS and KUV: the correlation also becomes poorer (R ~ 0.6), though it is slightly better than that between THL and KUV. According to the slope and intercept values, PC_{KUV} could also differ up to 30% from PC_{SVS}.

4. Discussion and Conclusion

The standard PC index is normalized to be positive in estimating variations in the transpolar electric fields through sensing magnetic perturbations caused by the ionospheric DP2 current system developed over the polar region during southward IMF. During summer, this DP2 system maintains stable, sunward transpolar current. In winter, the Region 1 FAC system would add the sunward magnetic perturbations to the DP2 magnetic disturbances [e.g., *Vennerstrøm et al.*, 1991].

It is known that the background convection (caused by the solar wind "quasi-viscous" interaction with the Earth's magnetosphere) is a two-cell system and the IMF B_y-related ionospheric convection is generally circular around the magnetic pole [e.g., *Papitashvili et al.*, 1994]. As $B_z \rightarrow 0$, the DP2 current system becomes asymmetric (shifted towards dawn or dusk) depending on the B_y-component direction and hemisphere. Therefore, the transpolar current of a combined convection system will be sunward in general, and one can expect that the PC index will also be positive.

As the IMF turns northward and $B_z > B_y$, the dayside near-pole ionospheric electric field is reversed (from dusk to dawn) causing a reversal of the transpolar ionospheric current in the antisunward direction. In this case, the PC index would be negative while the station (used for derivation) rotates under that current; however, negative PC-index values are usually limited to the near-noon MLT hours.

Shue and Weimer [1994] have shown that the near-pole region (where the antisunward convection holds during southward IMF) is almost unaffected (at least, statistically) by geomagnetic activity and changes in the IMF azimuthal component. They estimate that the width of the sunward, transpolar current (i.e., the dusk-dawn distance between the foci of the DP2 system) could reach 30° during enhanced convection caused by moderate magnetic activity.

From the results of this study, we can conclude that the index-effective area definitely includes Qaanaaq and Savissivik, but excludes Kullorsuaq. Therefore, taking into account the magnetometer "field-of-view" at SVS, the effective area for the northern PC index can be estimated as being ~15° in diameter centering at the geomagnetic pole. This area roughly corresponds to the lower estimates of the transpolar current width in the standard, two-cell convection pattern developed over the polar cap during southward IMF [e.g., *Papitashvili et al.*, 1994]. This effective area can be larger if new coefficients (similar to those we utilized from Thule) are determined for every new station. However, an ultimate criterion here should be preservation of PC_{THL}–index over the area, for example, within 10% of a value.

In conclusion, we note that the approach used in this study is applicable only for stations located along the same geomagnetic meridian. One can see from Table 1 that five stations in the north (EUR, ALE, THL, SVS, and RES) and four stations in the south (CRD, AP5, AP6, and VOS) are good candidates for validation of the PC-index effective area. However, subsurface magnetic anomalies in northeastern Canada make data from Alert (and possibly from Eureka) suspect in that validation. We believe that data from all stations listed in Table 1 should be utilized in determining the spatial extent of the transpolar ionospheric currents in both hemispheres. That would help in studying the coherence of geophysical information transmitted to the polar regions from the magnetosphere during different seasons and various solar wind and IMF conditions.

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