Relations of PC indices to further geophysical activity parameters

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PC Indices

- The PC indices represent polar cap magnetic variations associated with the transpolar part of the polar forward double vortex current system driven mainly by the merging electric field of the solar wind-magnetosphere dynamo.

- The indices are derived from ground based geomagnetic measurements in the northern and southern Polar Caps. The PCN index is based on data from Thule (Qaanaaq) in northern Greenland while the PCS index is based on data from Vostok in Antarctica.
The PC indices and further parameters

- The PC indices characterize solar wind energy input to the magnetosphere, which is the driver of most other disturbance parameters.
- Thus, PC indices can be used to monitor auroral and mid-latitude magnetic activities characterized by the AE and Kp indices.
- PC indices can also be used to derive Polar Cap potentials, as well as Joule and particle heating of the upper atmosphere.
- The PC indices can be used to derive the asymmetric ring current index ASY-H.
- The PC index can also predict the development of the symmetric ring current flowing in the equatorial regions of the magnetosphere at distances between 4 and 6 Re.
- The ring current characterized by the 1-min SYM-H or the hourly Dst indices is assumed to represent the energy stored within the magnetosphere during the course of magnetic storms. Its intensity is a balance between source and losses.
Basics.
A high degree of correlation exists between polar cap horizontal magnetic field variations $F$ and the "Merging Electric Field" (or "Geo-effective Electric Field") $E_M$ (=MEF) that controls the global energy input (Kan and Lee, 1979):

$$E_M = V_{SW} \cdot B_T \cdot \sin^2(\theta/2)$$

where:

- $V_{SW}$: solar wind velocity,
- $B_T = (B_y^2 + B_z^2)^{1/2}$: IMF transverse magnetic field component, and
- $\theta = \arctan(B_y/B_z)$: IMF polar angle with respect to GSM Z-axis. Thus:

$$\Delta F_{PROJ} = E_M \cdot \alpha + \beta$$

Where $\Delta F_{PROJ}$ (in units of nT) is the magnetic variation projected to the "optimum direction" in a polar cap coordinate system fixed with respect to the Sun-Earth direction. The proportionality constant $\alpha$ is the "slope" (e.g. in units of nT/(mV/m)) and the baseline shift $\beta$ (nT) is the "intercept".

The dimensionless Polar Cap Index PC is derived from the magnetic variations calibrated to statistically equal the merging electric field:

$$PC = (\Delta F_{PROJ} - \beta)/\alpha = E_M$$

The scaling parameters, i.e. projection angle, slope and intercept, are found from statistical analyses of corresponding polar geomagnetic observations and interplanetary satellite measurements to make PC and $E_M$ values statistically equal. The parameters vary with local time and season but are invariant through the solar cycle.

Relations between PCN and Merging Electric Field

$E_M$ is always positive while the PCN (and PCS) indices could be strongly negative when IMF Bz is strong and positive.

Negative index values are inconsistent with PC indices representing energy input.
The combined PCC index

During strong northward oriented interplanetary magnetic fields (NBZ cases) the pattern in the central polar cap may change to “reverse” convection, which gives large negative values of the PC index. Now the close correlation between the PC index and the merging electric field is lost since \( E_M \) by definition is always positive, although numerically small in cases of northward IMF.

In NBZ cases reverse convection and associated negative PC index values occurs predominantly in the summer polar cap. The corresponding convection in the opposite (winter) polar cap is usually forward but weak such that the associated PC index here is positive but numerically small like the merging electric field.

Hence we expect better correlation between the merging electric field and a combined PCC index defined through:

\[
PCC = \frac{PCN \text{ if } >0 \text{ or else } 0 + PCS \text{ if } >0 \text{ or else } 0}{2}
\]

The use of a combined PC index also solves the ambiguity problem involved in having two separate PC index series to characterize the interplanetary merging electric field and global geomagnetic activity.

In general:

- **PCN** is used for Northern Hemisphere topics
- **PCS** is used for Southern Hemisphere topics
- **PCC** is used for Global topics

Thus they complement each other!
Relations between PCC and Merging Electric Field

\[ \text{PCC} = \frac{E_m}{\sqrt{1 + (E_m/E_0)^2}} \]
\[ E_0 = 10.5 \text{ mV/m}. \]

Relations between PCC and Auroral Electrojet Indices

\[ \text{AE} = 110 \text{ PCC} + 60 \text{ [nT]} \]
Cross-Polar-Cap Potential
The cross polar cap potential data shown in Fig. 10 of Hairston et al. (2005) could well be represented by an expression involving the PCC index (Stauning, 2012) by:

\[ \Phi_{PC} \approx 20 \text{ PCC} + 15 \text{ [kV]} \]

Joule Heating Northern Hemisphere
From the study by Chun et al. (1999), the total Joule heating power for the northern hemisphere (JHN) was estimated and compared to the corresponding values of the polar cap index, PCN. Their result for all data is:

\[ JHN = 4.03 \text{ PCN}^2 + 27.3 \text{ PCN} + 7.7 \text{ [GW]} \]

NB Just consider the trend. PCN data might not be final.
Relations between PCN and Auroral Power Indices

15-min PCN indices and total northern hemisphere auroral power

Note the close average relation.

\[
\text{APN} = \begin{cases} 
-2 \text{ PCN} + 10 & \text{For PCN<0} \\
13 \text{ PCC} + 10 \text{ [GW]} & \text{For PCN>0}
\end{cases}
\]

Relations between PCC and Kp Indices

The PC index has been averaged over the 3-hr Kp interval with a small shift.
Relations between PCC and Ring Current ASY-H Indices

Note the linear relation up to high PCC values

Relations between PCC and Ring Current Dst Source Function

The merging electric field, EM, or, equivalently, the polar cap PC indices should be considered to represent a source function for the Dst index rather than being related to its current value. Following Burton et al. (1975) the change in the Dst index with time could be written:

$$\frac{d\text{Dst}^*}{dt} = Q - \frac{\text{Dst}^*}{\tau} \ [\text{nT/hr}]$$

Q is the source term while the last term is the ring current loss function controlled by the decay time constant $\tau$ here measured in hours. For the small actual MPC corrections, the Dst dependent statistical values provided in Joergensen et al. (2004) are used while the decay function given in Feldstein et al., (1984) is used for the loss term.
Relations between PCC and Ring Current Source Function

Note the linear relation up to high PCC values

\[ Q = 4.6 \text{ PCC} + 1.2 \text{ [nT/hr]} \]

Relations between PCC and Ring Current Index Dst

Example of Dst Index values calculated from \( E_{\text{M}} \), PCC, and ASY-H

The Dst(source) index has been constructed by integration of the source function through 4 days using the real Dst as start value
Relations between PCC and Ring Current Index Dst

A few further examples

Comparison of different Ring Current Source Functions

<table>
<thead>
<tr>
<th>Source Parameter</th>
<th>$E_M$ field</th>
<th>PCC index</th>
<th>PCN index</th>
<th>AL index</th>
<th>ASY-H index</th>
</tr>
</thead>
<tbody>
<tr>
<td>No. hourly samples</td>
<td>3992</td>
<td>7776</td>
<td>8640</td>
<td>7968</td>
<td>8640</td>
</tr>
<tr>
<td>Avr. deviation</td>
<td>-7.6</td>
<td>1.8</td>
<td>2.7</td>
<td>11.5</td>
<td>-4.9 nT</td>
</tr>
<tr>
<td>Std. deviation</td>
<td>27.6</td>
<td>30.6</td>
<td>31.4</td>
<td>34.2</td>
<td>24.7 nT</td>
</tr>
</tbody>
</table>

The statistics have been built on all major magnetic storms during cycle 23 from 1995 to 2006.
Summary and Conclusions

- The Polar Cap (PC) indices are derived from polar magnetic variations scaled to equal the merging electric field (in mV/m) in the solar wind. They represent the conditions that dominate the solar wind interaction with the magnetosphere.

- The PC indices, PCN based on Thule magnetic data and PCS based on Vostok data, are the firsts among the ground-based indices to respond to changes in the solar wind forcing of the magnetosphere.

- Most other ground-based indices, e.g., the auroral electrojet index AE (or AL), the Kp index, and the ASY-H index could be derived directly from the PC index with time shifts of around 5-15 min.

- The ring current index, Dst, can be derived by integration of the PC index.

- Further indices or parameters like the Auroral Power index, the Electrojet Joule heating, and the Cross Polar Cap Potential could be associated statistically with the PC indices.

References


