Comment on “Unified PCN and PCS indices: Method of calculation, physical sense, dependence on the IMF azimuthal and northward components” by O. Troshichev, A. Janzhura, and P. Stauning

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1. Introduction

[1] Troshichev et al. [2006, hereinafter referred to as T06] presented newly calculated unified PC indices from both hemispheres that are “well consistent one with another in their value and behavior and linearly correlate with the solar wind merging electric field (MEF)” (p.1 of T06). Significant differences in the magnitude between the northern (PCN) and southern (PCS) indices produced by the Danish Meteorological Institute (DMI) and the Arctic and Antarctic Research Institute (AARI), respectively, were revealed after transition to the 1-min values [Lukianova et al., 2002]. Since the technique traditionally applied for calculation of the PCN and PCS is different to some degree, elaboration of the consensus between two institutions, the producers of the indices, is quite appreciated. However, careful examination of the changes introduced by T06 to the procedure and the results of these changes reveals some contradictions. T06 alleged that the newly applied smoothing of the coefficients and the choice of quiet daily variation (QD) as the level of reference for magnetic disturbances have eliminated the systematic exceeding of the PCS over the PCN. The similarity of two indices was achieved in such a manner that the PCS became smaller while the PCN became larger.

[2] The AARI technique always took into account deviation of the magnetic field from the QD curve. In the DMI technique an appropriate daily quiet level (QWL) was deduced from interpolation between the magnetic field’s absolute values determined at midnight hours of quiet winter days in 2 consecutive years [Vennerstrøm et al., 1991]. The analysis performed in preparation of the paper [Lukianova et al., 2002] revealed that the exceeding of PCS over PCN quickly increased with the growth of magnetic activity and mostly during the northern summer months. In order to check if the discrepancy in the indices arises from the different procedure, the AARI technique was applied to the magnetic data from Thule. The calculations by AARI method showed that the northern PCN_AARI became larger and closer to PCS than published PCN from DMI. The increase of PCN_AARI accelerated with the growth of magnetic activity. The similarity of PCN_AARI to PCS was achieved solely due to an increase of the former. An example of the 1-min PC time series for 1998 is presented in Figure 1. In this figure, the former published PCN and PCS are presented along with the northern PCN_AARI.

[3] T06 did not mention the specific character of the discrepancy between PCN and PCS. T06 stated that the former PCN was an “underestimate,” whereas the PCS was an “overestimate.” These authors argued that the main reason for the discrepancy was “too high” and “extremely weak” of a smoothing applying to the normalization coefficients (p. 4 of T06). The first goal of present comment is to demonstrate that the choice of the level of reference, namely replacing the QWL line by the QD curve, is crucial for increasing the magnitude of PCN in response to the solar wind (SW) and IMF forcing. Other factors (better capture of the UT variation of fitting parameters as well as the procedure for derivation of the QD curve) are of secondary order with respect to the leveling of PCN and PCS amplitude especially during disturbed periods. As is shown in this comment, for the unified index, T06 followed the AARI technique and used the QD in both hemispheres. Consequently, a question of why does the amplitude of the unified PCS turn out smaller than that of former PCS arises. Also, a larger increase should be expected from the unified PCN. It particularly concerns the extreme values of the index. The appearance of many new negative values is troubling.

[4] At the present time, there is no doubt that the polar cap electrodynamics during the disturbed periods is complicated and nonlinear. The transpolar part of the DP2 ionospheric current associated with the two-cell convection system which determines the behavior of the PC index is controlled by different factors, not only by the interplanetary merging electric field (MEF or Em). The second goal of the Comment is to caution against a simplification of the PC response to the MEF. T06 stated that the new “indices ensure the best linear correlation” with MEF under conditions of southward IMF (p. 10 of T06). They ignored the fact that during magnetic storms, convection bays, SW...
pressure events and substorms the linear correlation is often violated.

2. Data and Calculation Techniques

[5] In this section the question of how the QD choice or the smoothing of fitted parameters affects the magnitudes of PCN and PCS is addressed. The influence of each modification proposed by T06 on the final value of the PC index is briefly considered.

2.1. Level of Reference for Magnetic Variations

[6] Figure 2 gives an example of the QD curve and the QWL line for the horizontal geomagnetic components from Thule and Vostok in 1998–2000. Both components show the same regularities before 1998 and after 2000. The presented 3-year time series exhibits the well-known seasonal and diurnal variations of the QD. The right panels give the QDs used for routine day-to-day calculation of PCS at AARI. Straight lines in the left panels represent the QWL which were used for routine calculation of PCN at DMI. Sine-like curves in the same panel show the QDs used for the PCN_AARI from our earlier paper [Lukianova et al., 2002]. All QDs were averaged from the 5 quietest days of each month taking into account three (D, H, Z) components of geomagnetic field measured at Thule and at Vostok. Arbitrary fluctuations were removed to obtain the smoothed wave-like variation. Following the AARI technique, T06 rejected the QWL and adopted the QD for calculation of the unified PC. T06 introduced a construction of the QD curve for H and D components by 1-min quiet intervals snapped up from the previous 30 days. The advantage of the

Figure 1. Example of the PC indices for 1998: published (former) PCS and PCN, and the northern PCN_AARI calculated by former AARI method.

Figure 2. Level of reference for disturbances in horizontal geomagnetic components for (left) Thule and (right) Vostok. Thin and thick lines represent the behavior of QD curve and QWL line, respectively.
proposed method is sliding of the days, but an artificial

\[ PC = \zeta \cdot (\delta F - \beta) / \alpha \]

\( \zeta = 1 \) mV/m is a scale coefficient and \( \alpha \) and \( \beta \) are

fitted parameters. We first collect statistics for several years

of the linear regression between the signal and response at

each UT moment of the year. These statistics are mainly

represented by the coefficients of slope (\( \alpha \)) and intercept

(\( \beta \)), where \( \alpha \) is of the major influence on PC. For simplicity

in the following discussion we will neglect \( \beta \) and ignore the

angle \( \phi \) contained in \( \delta F \). Having a set of coefficients, we are

able to reconstruct the signal at any time based solely on the

actually measured response. This sequence of steps is

shown in Figure 3. The horizontal and sine-like thick solid

lines represent QWL and QD, respectively. Note that this is

not the actual D or H component but a representation of the

geomagnetic disturbance \( \delta F \). First, we calculate the

coefficients. In the sketch, the thin solid line indicates a

statistical response to a statistical signal for a given interval

time \( t_1 t_2 \). The signal is not shown because its actual value

is not important for the present discussion. Assuming the

signal equals unity at \( t = t_0 \), the distances \( (ac) \) and \( (bc) \) correspond to the coefficients (or to the slope \( \alpha \) if \( \beta \) is

neglected) in the case of QWL and QD, respectively. It is clear that \( (ac) \) exceeds \( (bc) \). That is because the former

includes both the response to solar illumination and the

response to MEF while the latter includes the pure response

to MEF. The effect is clearly seen in the amplitude of \( \alpha \) given below in the top of Figure 4.

[8] As a second step, we apply the coefficient to the

actually measured response in order to obtain the PC. If for

e.g., the magnetic activity increases a factor of two, the

response reaches point \( (d) \). In the sketch the dashed line

indicates the corresponding behavior of the horizontal

geomagnetic field \( \delta F \). It is easy to see that the value of \( \alpha \)

PC is different in the QD case from the QWL case. Taking

\( ab = bc = cd \) for simplicity and following the equation (1),

we obtain PC \( \sim (ad)/(ac) = 1.5 \) and PC \( \sim (bd)/(bc) = 2 \),

respectively. Further, if the magnetic activity increases, for

e.g., by a factor of 6 (point \( e \)), than the ratio \( (ae)/(ac) \) = \( \frac{3}{5} \) and the ratio \( (be)/(bc) \) = 6. The difference in the first and

second ratios increases progressively with the growth of

activity. This simple illustration gives the explanation of

why the PCS exceeded PCN and why the discrepancy

increased with the growth of activity and mostly in northern

summer months when \( ab \) is larger. That can also explain

why the PCN from the unified technique of the T06

becomes larger than former PCN. However, it is harder to

explain the reported decrease of unified PCS.

2.2. Smoothing of the Coefficients

[8] T06 said “mainly the unified smoothing procedure

(for the coefficients) has led to similarity of the newly

unified PCN and PCS indices” (p. 4). It is difficult to agree

with this statement. Figure 4 shows a time series of

coefficients obtained by Vennerstrøm \textit{et al.} [1994] (available

at http://web.dmi.dk/projects/wdcc1/pcn/coef24g3.txt)

and used for routine calculation of the PCN at DMI (Figure 4,

left), the coefficients obtained for calculation of the northern

PCN AARI by the AARI technique [Lukianova \textit{et al.},

2002] (Figure 4, middle), and the coefficients used for

routine calculation of the PCS at AARI (Figure 4, right).

The coefficients are given in series for each month of the

year. The diurnal variation is seen within each month. In the

AARI technique, the original data sets of coefficients were

obtained by correlating the 5-min averaged values of \( \delta F \)

with 5-min values of MEF over 1977–1980 from IMP-8/9

and combined monthly to increase statistics. The DMI

technique used the 15-min values of the same parameters.

The original coefficients were then smoothed through the

entire year. In Figure 4, gray and black lines represent the

original and smoothed datasets, correspondingly. We were

unable to locate the original 15-min data sets from DMI. At

AARI, FFT filtering was used to eliminate high harmonics

from the time series. A similarity in rhythm of yearlong

curves of the slope \( \alpha \) (i.e., the main part of the \( \delta F \) response)

has been selected as a criteria for the degree of smoothing

applying to the southern coefficients. That was merely

...
because the sets of coefficients at AARI were calculated later than at DMI. Additional difficulty in the appropriate choice of the smoothing degree applied to the entire yearlong time series arose from the fact that southern coefficients showed more frequent variations than northern ones. That is mostly caused by the difference in location of the stations. A unified degree of smoothing applied to both sets of coefficients therefore may not answer properly to its real behavior. The fitting parameters $a$, $b$, and $f$ once obtained were used to calculate the index for each current year.

[10] At p. 4 T06 wrote “when deriving the former 1-min PC indices, too high of a smoothing was applied in case of the PCN index, and extremely weak of a smoothing was applied in case of the PCS index. As a result, the amplitudes of the former PCN index turned out to be underestimated, whereas the former PCS index was overestimated.” What does this mean mathematically in terms of the former calculation methods? Figure 4 of this comment demonstrates that there were no “arbitrary fluctuations of the coefficients” (p. 10 of T06). Because smoothing is a nonlinear procedure applied to the original curve, some points of the resulting curve are located above the original curve whereas other points are below. Better capture of seasonal and UT variation is undoubtedly the important issue for more precise calculation of the PC. How can the proposed change in the coefficients affect the general magnitude of PC compared to the former one?

[11] We use the formula (1) to answer the question. We simply substitute the coefficients from the former and newly calculated sets then roughly estimate the result. Figure 5 visualizes (1) for winter and summer at both polar caps. From the two-dimensional plots given in Figure 3 of T06 and from the time series given in Figure 4 of the comment, one can see that both $a$ and $b$ reach their extremes at about 0400 and 1600 UT (except the Antarctic summer when the UT variation is more complicated). The peaks are likely the combined effect of the local noon at each station and the UT variation of ionospheric conductivity due to the largest interhemispheric asymmetry in solar illumination at 0440 and 1640 UT. The extremes would be affected first by the applied smoothing. Thus it seems reasonable to compare the dependence of PC on $dF$ obtained from the former and new calculations at 0400 and 1600 UT. The values of the corresponding $a$ and $b$ are given in Table 1. Figure 5a gives the result for the northern polar cap. Note that only the northern PCN_AARI, for which the QD curve were used as the level of reference, can be explicitly compared with the unified PCN because of approximately the same value of $dF$. Four lines in each plot depict the equation (1) using $a$ and $b$ from Table 1. Thin and thick lines indicate the former and unified method, respectively. Black and gray colors...
indicate UT = 0400 and UT = 1600, respectively. Figure 5a

Figure 5. (a) Dependence of PCN on $\delta F$ obtained from the former and newly calculated coefficients for January and July; (b) the same but for PCS. Lines in each plot depict the equation (1) with corresponding $\alpha$ and $\beta$ from Table 1. Thin and thick lines indicate the former and unified method, respectively. Black and gray colors indicate UT = 0400 and UT = 1600, respectively.

Table 1. Values of the Winter, w, and Summer, s, PC for $\delta F = 100$ nT and the Ratio Between Them

<table>
<thead>
<tr>
<th>Index</th>
<th>PCN_AARI Former</th>
<th>PCN Unified</th>
<th>PCS Former</th>
<th>PCS Unified</th>
</tr>
</thead>
<tbody>
<tr>
<td>UT = 0400, January</td>
<td>5.0 (w)</td>
<td>5.5 (w)</td>
<td>3.7 (s)</td>
<td>3.1 (s)</td>
</tr>
<tr>
<td>UT = 0400, July</td>
<td>2.5 (s)</td>
<td>3.2 (s)</td>
<td>2.0 (w)</td>
<td>2.4 (w)</td>
</tr>
<tr>
<td>UT = 1600, January</td>
<td>3.3 (w)</td>
<td>3.4 (w)</td>
<td>4.9 (s)</td>
<td>3.8 (s)</td>
</tr>
<tr>
<td>UT = 1600, July</td>
<td>1.9 (s)</td>
<td>2.4 (s)</td>
<td>2.9 (w)</td>
<td>3.1 (w)</td>
</tr>
<tr>
<td>UT = 0400</td>
<td>2.00</td>
<td>1.72</td>
<td>1.85</td>
<td>1.29</td>
</tr>
<tr>
<td>UT = 1600</td>
<td>1.73</td>
<td>1.42</td>
<td>1.69</td>
<td>1.22</td>
</tr>
<tr>
<td>Averaged over UT</td>
<td>1.9</td>
<td>1.6</td>
<td>1.8</td>
<td>1.3</td>
</tr>
</tbody>
</table>

*Ratio between the winter (w) and summer (s) PC for $\delta F = 100$ nT.

The second doubt arises from the comparison of the lines representing different seasons in Figure 5. If we want PC about the same in each hemisphere, the coefficients $\alpha$, $\beta$ must provide approximately the same value of PC in response to a given level of SW forcing irrespective of the season. Indeed, in Figure 5 in both polar caps the lines are more vertical in local winter, when the geomagnetic effect ($\delta F$) to MEF is minimal, and more horizontal in local summer, when the effect of MEF is maximal. We can easily calculate the ratio between the winter and summer PC for fixed $\delta F$, for example $\delta F = 20$ and 100 nT, respectively. On p. 5, T06 wrote “Figure 4 shows as an example the run of the PCN and PCS indices during 1998–2001. One can see the remarkable agreement in behavior of the positive PC indices in the northern and southern hemispheres, with the index reaching as large value as 20 at both the Thule and Vostok stations.” However, simple arithmetic shows that if the former PCS exceeds 25 (for example, the former PCS reached the upper level of 35 on 25-09-1998 or 15-07-2000), the expected value of the new PCS exceeds 20.

The seasonal difference in PC in 1998–2001 for fixed $\delta F = 100$ nT. (The same can be done for fixed PC, but Figure 5 is visually easier when using a fixed $\delta F$.) The results are given in Table 2. One can see that for the former indices the ratios are 1.9 and 1.8 for PCN_AARI and PCS, respectively. It implies that the amplitude of geomagnetic variations decrease by a factor of 1.8–1.9 going from summer to winter in both hemispheres to provide generally no seasonal difference in PC in response to a given MEF. For the unified indices we obtain the smaller values: 1.5 (PCN) and 1.3 (PCS). Why is the seasonal difference, especially in the southern $\delta F$, so small? The geomagnetic records show larger differences. Figure 6 gives an example. Figure 6a shows the 1-hour time series of D and H components from Vostok for January and July 1998. Figure 6b shows the quiet daily variations for the corresponding month (shown above in Figure 2 with lower resolution). We now estimate the seasonal change of the amplitude of D and H taking into account only the response...
We choose the approximate zero level and then calculate the mean value of positive (PA) and negative (NA) deviations. The sum of PA and NA gives us the mean amplitude of the original geomagnetic variation (from Figure 6a) and the mean amplitude of the QD curve (from Figure 6b). In order to remove the effect of solar illumination we subtract the latter from the former. The values of PA and NA are given in Figure 6. We obtain the following estimates for the amplitude of D and H components: for January $dD = (133 + 112) - (30 + 20) = 195$ nT and $dH = (54 + 62) - (21 + 32) = 63$ nT, for July $dD = (57 + 60) - (6 + 3) = 108$ nT and $dH = (23 + 18) - (3 + 3) = 35$ nT. One can see that for both $dD$ and $dH$ the ratio between the southern summer and winter variations is 1.8. This value is in good agreement with what we have from the former PCS. However, the new PCS implies that the summer variations of $dD$ and $dH$ exceed the winter ones only by a factor of 1.3, which is smaller than the actually measured geomagnetic field.

2.3. Correspondence Between the MEF and PC

Comparing the ground magnetic data with space data from the ACE satellite for 4 years free of gaps, T06 used the 5-min time resolution from the AARI technique. Before, the periods with $Dst < -50$ nT were excluded from IMP data. The use of ACE instead the IMP, although it brings more statistics, gives rise to confusion with the arrival time of the SW structures and corresponding ground response. Unlike...
IMP, ACE is located much farther from the magnetopause
(at L1 point) and the arrival time can vary from 20 min to
100 min depending on the SW speed and the precise
position of the satellite. T06 did not use any specific tracing
technique. Without appropriate tracing, the utilization of
ACE data can give rise to uncertainties in statistics, espe-
cially of the upper values.

[15] Another concern is many large negative values
appeared in the newly calculated PC. Even visual exami-
nation of Figure 4 of T06 reveals more negative PC values
than those from the former time series (compare with Figure
1 of the comment). An appearance of many PC < 0 can
mean that the regression relationship between MEF and δF
was found inaccurately. Equation (1) shows that the slope α
is equally effective for both large and small values of δF,
whereas any change in the intercept β would affect mostly
the lowest values of PC. Just β is responsible for zero or
positive PC under northward IMF conditions where δF is
small or even negative. Indeed, when the geomagnetic data
are compared with space data to lay the statistical back-
ground for the calculation of PC, the situation of δF < 0
(antisunward ionospheric transpolar current) while MEF ≈
0 (IMF Bz ≈ 0) occurs sometimes. This forms a statistical
threshold ensuring PC ≥ 0. At a given UT/day this
threshold determines the magnitude of β. The PC remains
positive until the actual measured δF exceeds β during the
events of very strong northward IMF. Since β is more
negative for the unified PCN compared to β for the former
PCN_AARI (e.g., β is −120 and −30, respectively, for July
at 1600 UT in Table 1), one might expect less negative new
PCN values. However, instead, from Figure 4 of T06, more
negative PC values occur in the local summer at both
stations.

3. Response of PCN/PCS to Variations of MEF
and Other SW Parameters

[16] T06 alleged that differences in values of the previous
1-min PCN and PCS indices gave rise to discrepancies in
results of various analyses and to “quite dissimilar” or even
“erroneous” physical conclusions of previous works utiliz-
ing the PC index. T06 suggested the replacement of the
existing sets by newly calculated unified PCN and PCS. In
particular, T06 said that they planned “to revise the PCN/
PCS relationship with the solar wind dynamic pressure and
auroral substorms” using newly calculated “unified PCN
and PCS” which “under conditions of southward IMF
linearly correlate with the MEF.” In general, the linear
correlation exists. Since the algorithm for the derivation of
the PC index is based on the regression analysis of an
assumed linear relationship between MEF and δF observed
near the geomagnetic pole [Trosichiev et al., 1988;
Vennerstrom et al., 1991], with large statistics under quiet
and moderate conditions the index does linearly correlate
with MEF. T06 showed correlation coefficients of PCS and
PCN with MEF in Figure 10 for all conditions to be about
0.63–0.66, while Trosichiev and Andrezen [1985] found
better correlation coefficients of r > 0.8.

[17] Since PC originates in ground magnetic variations, it
responds not to the MEF itself but to the overhead electric
currents which are not solely controlled by the MEF. It has
recently been demonstrated that the linear correlation is
often violated during disturbed periods. For example, there
is a loss of correlation between the PC and MEF during
magnetic storms [Trosichiev and Lukianova, 2002], sub-
storms [Huang, 2005], and SW pressure pulses [Lukianova,
2003; Lee et al., 2004]. The SW pressure pulses are much
more geoeffective under conditions of intense southward
IMF [Boudaridis et al., 2005] with poleward and equator-
ward expansion the polar cap as well as the intensification
of the nightside aurora [Liou et al., 1998]. Under extreme
conditions the PC reflects a strengthening of convection and
a nonlinear magnetospheric response to SW forcing. Refer-
ing to Nagatsuma [2002], T06 wrote “the use of the former
underestimated PCN index provides effect of the PC index
saturation.” Trosichiev et al. [2000] reported the effect of
saturation of the ionospheric electric field based on the PCS
statistics. These various results reflect a nonlinear behavior
of the magnetosphere/ionosphere system under very dis-
turbed conditions and further investigation is needed, so the
linearization of the PCN and PCS may not be the best way
to resolve the problem.

4. Conclusion

[18] The unified technique proposed by T06 seems to be
similar to the former AARI technique in the choice of the
quiet day curve which governs the magnitude of the PC
index. With the same technique it is difficult to see how the
different smoothing in the slope, intercept and angle can
can level up and down the former “underestimate” PCN and
“overestimate” PCS, respectively. Examination of the coef-
ficients presented by T06 shows that the former northern
PCN_AARI, the new unified PCN, and the unified PCS are
relatively close to the former PCS in January. In July, the
larger α in the unified PCS results in smaller values, while
the more negative β in the unified PCN results in larger
values as shown in Figure 5. However, these coefficient
changes lead to smaller summer to winter seasonal changes
in the assumed geomagnetic variations with ratios of 1.5
(unified PCN) and 1.3 (unified PCS). The observed geo-
magnetic records require a summer to winter ratio of 1.8 at
Vostok, not 1.3, whereas the former PCS coefficients have a
seasonal variation of about 1.8.

[19] How does the different smoothing lead to a better
linear correlation between PC and MEF, including the
disturbed periods when linear dependence between PC
and MEF is often violated? Further explanation would be
helpful for the solution of the long-standing problem of the
discrepancy between the PCN and PCS. The agreement
between two institutions, DMI and AARI, about the usage
of the same basic technique for both indices is very
important, but clearer understanding of the procedure and
more accurate analysis is needed.

reviewer for their assistance in evaluating this paper.

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