https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Title: Comment on "Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field" by Troshichev et al. (2011).

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Abstract. In the publication Troshichev et al. (2006) on the Polar Cap (PC) indices, PCN (North) and PCS (South), an error was made by using components of the Interplanetary Magnetic Field (IMF) in their Geocentric Solar Ecliptic (GSE) representation instead of the prescribed Geocentric Solar Magnetosphere (GSM) representation for calculations of index scaling parameters in the version AARI_1998-2001 (named AARI#3) issued from the Arctic and Antarctic Research Institute (AARI) in St Petersburg, Russia. The mistake has caused a trail of incorrect relations and wrong conclusions extending since 2006 up to now (2020). For the publication commented here, Troshichev et al. (2011), the authors state that they have used scaling parameters of the (invalid) AARI#3 PC index version in their work but they have actually substituted parameters from the more recent AARI_1995-2005 (AARI#4) version instead. The mingling of PC index versions have resulted in erroneous illustrations in their Figs. 1, 2, 3, 6, 7, and 8 and the issuing of non-substantiated statements.

1. Introduction.

The publication Troshichev et al. (2006), hereinafter TJS2006, describes principles of a unified calculation procedure using polar magnetic observations to derive values of Polar Cap (PC) indices PCN (North) and PCS (South) agreed between the Arctic and Antarctic Research Institute (AARI) in St. Petersburg and the Danish Meteorological Institute (DMI). PCN indices are based on magnetic variations measured at Qaanaaq (THL) in Greenland while PCS indices are based on data from Vostok in Antarctica.

The polar cap indices reflect the magnetic variations caused by the electric current systems (Hall currents) associated with the transpolar convection of ionized plasma and embedded magnetic fields driven by polar electric fields induced by solar wind - magnetosphere interactions. The magnetic variations are scaled with respect to the merging electric field, E_M, in the impinging solar wind (Kan and Lee, 1979) in order to make the index independent of local ionospheric properties, in particular, the variable conductivities.

New analyses has disclosed that the use in TJS2006 of Interplanetary Magnetic Field (IMF) components IMF B_Y and IMF B_Z in their Geocentric Solar Ecliptic (GSE) representation instead of the prescribed Geocentric Solar Magnetosphere (GSM) representation have had grave consequences for the PC index scaling parameters and index values. The GSE and GSM components of IMF differ by a rotation around the common IMF B_X direction by ±11.4° (magnetic dipole offset) in the daily variation superimposed on the ±23.5° (eclipse angle) seasonal variation, that is, a total variation of ±34.9° throughout the year. These varying differences have strong impacts on the calculation of scaling parameters for the PC indices

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

The mistake is illustrated in Fig. 1 here where the IMF B_Y and B_Z components, displayed in TJS2006 without mentioning of their reference system, are reproduced from Fig. 7 of Troshichev et al. (2006) in Fig. 1a to be compared with their appearance in the GSE and GSM representation displayed in Fig. 1b. The differences between the GSE and GSM versions are most easily distinguishable between 12 and 14 UT where IMF B_Z(GSE) is positive while B_Z(GSM) is negative.

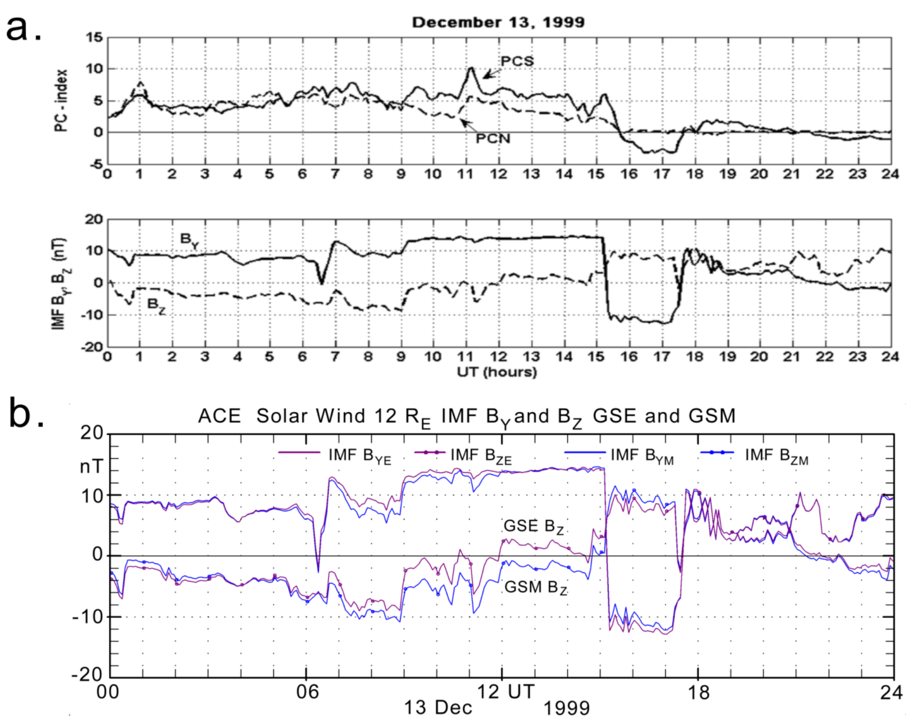

Figure 1. (**a**) IMF B_Y and B_Z components reproduced from Fig. 7 of Troshichev et al., 2006. (**b**) IMF B_Y and B_Z components in their GSE version (magenta line) and in their GSM version (blue line). The differences between GSE and GSM versions of IMF B_Z are clearly discernible between 12 and 14 UT.

The mistake had no strong impact on the remaining presentation of the PC index concept in TJS2006. Usually, such a mistake would not attract attention after the many years that have passed since the publishing in 2006. However, the incorrect feature drags a trail of erroneous relations and invalid statements presented in publications on polar cap indices issued since 2006 extending up to present (2020).

Thus, the scaling parameter sets presented in the colour-coded diagrams of Figure 3 of TJS2006 have been reproduced in Troshichev et al. (2011), in Troshichev and Janzhura (2012), and in Troshichev (2011) that all form part of the basis for the IAGA-recommended PC index versions (Matzka, 2014; Nielsen and Willer, 2019). Most recently, the TJS2006 publication and the incorrect results from the derived publication, Troshichev et al. (2011), have been referenced in Troshichev (2017) and in the technical report, ISO/TR 23989: 2020, issued by the International Standards Organization (ISO) in January 2020.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

2. Erroneous scaling parameters for the PCS indices.

In the agreed formulation, the PC indices are derived from the expression shown in Eq. 1 here (see, e.g., TJS2006; Stauning et al., 2006):

$$PC = (\Delta F_{PROJ} - \beta)/\alpha \quad (1)$$

where ΔF_{PROJ} is the projection to an optimal direction of the horizontal magnetic disturbance vector measured from a quiet reference level while α (slope) and β (intercept) are calibration parameters. With the magnetic components in their geographic (X,Y) representation and *UTh* the UT time in hours, the projection angle is defined by Eq. 2:

$$V_{PROJ} = \text{observatory longitude}(\lambda) + UTh \cdot 15° + \text{optimum direction angle}(\varphi) \quad (2)$$

The optimum direction is characterized by its angle (φ) with the dawn-dusk meridian and derived from seeking optimal correlation between ΔF_{PROJ} and the solar wind merging electric field, E_M, in the formulation of Kan and Lee (1979) based on using IMF components in their GSM representation.

In Troshichev et al. (2006), the derived PCN and PCS scaling parameters (φ, α, β) are presented in the colour coded diagrams in their Fig. 3, which is reproduced here (including caption) in Fig. 2 for convenience. This version from 2006 was named "AARI#3" by McCready and Menvielle (2010, 2011).

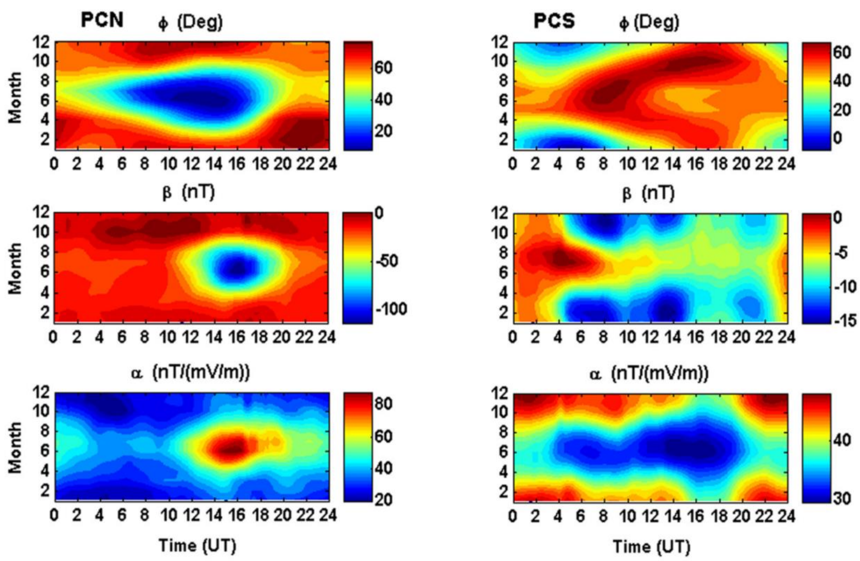

Figure 3. Angle ϕ and coefficients α and β used for calculation of the unified PCN and PCS indices derived on the basis of magnetic data from Thule and Vostok stations for 1998–2001.

Fig. 2. Reproduction of colour-coded displays of PC index scaling parameters from Fig. 3 of Troshichev et al. (2006).

In coarse terms the IMF B_Z component mainly affects the noon-midnight flow intensity while the IMF B_Y component mainly affects the dawn-dusk component of the transpolar flow of plasma and embedded magnetic fields that generate the polar magnetic variations represented in the Polar Cap (PC) indices,. Thus, the relation between the two IMF components affects the transpolar flow intensity and, in particular, its direction. Consequently, the main effect of the different GSE/GSM

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

IMF representations would be found in the optimum direction assumed perpendicular to the dominant flow direction.

In the derived publication, Troshichev, Podorozhkina, and Janzhura (2011) (hereinafter TPJ2011), the colour-coded diagrams for PCS scaling parameters in version AARI_1998-2001 (AARI#3) presented in the right column of Fig. 3 of TJS2006 (Fig. 2 here) are displayed in the left column of their Fig. 5 (here reproduced including caption in Fig. 3). These values are considered to represent PCS scaling parameters for a solar maximum epoch. The figure has also a column (left) for the scaling parameters in the later version AARI_1995-2005 (AARI#4) based on data from the epoch 1995-2005 spanning an entire solar cycle. The middle column in their Fig. 5 (Fig. 3 here) presents scaling parameters based on the solar minimum years 1997+2007-2009, here named version AARI_1997+2007-2008 taken to represent solar minimum scaling parameters.

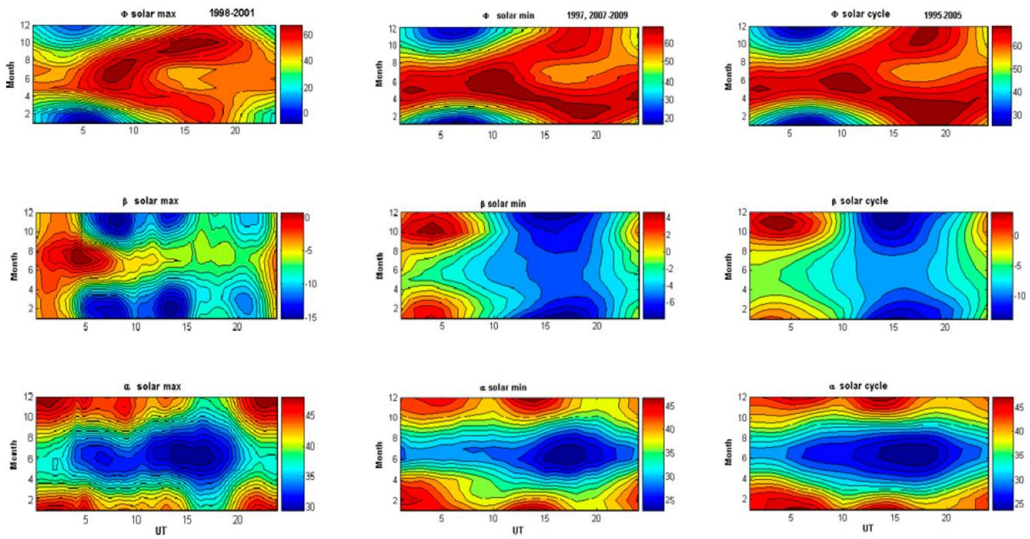

Fig. 5. Parameters ϕ, β, and α derived for Vostok station independently for epoch of solar maximum (1998–2001) [Troshichev et al., 2006], for epoch of solar minimum (1997, 2007–2008), and for complete cycle of solar activity (1995–2005) (AARI#3 version); the axis of abscises being for UT and axis of ordinates being for month.

Fig. 3. PCS scaling parameters in colour-coded formats for (left) solar max. version AARI_1998-2001, (middle) solar minimum version AARI_1997+2007-2009, and (right) average solar cycle version AARI_1995-2005. (Reproduced from Troshichev et al., 2011, note error 2008 instead of 2009 in caption).

A problem for the analysis of possible effects of the invalid PCS scaling parameters derived in TJS2006 by using IMF components in their GSE representation is the unavailability of numerical files of the parameters.

Instead, the colour-coded diagrams have been "manually" read-off to be converted to numerical files. Actually, the readings of PCS scaling parameters from the right column of Fig. 3 of TJS2006 (Fig. 2 here) have been consolidated by the readings of the corresponding diagrams in Fig. 5 of TPJ2011 (Fig. 3 here) where the colour coding has been supplemented by contour curves, which facilitates the reading of values. Using the colour coded scales to the right of each diagram, the parameter values have been read-off and converted from the graphical representation into the files of mean hourly values shown in Table 1 of the appendix.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

For the full cycle (1995-2005) the scaling parameters in version AARI_1995-2005 (AARI#4) have been provided in files (Angle_Fi.1M, Coeff_alpha.1M, Coeff_beta.1M) supplied from AARI at an earlier communication ("Parameter.rar", Janzhura 21-06-2011). The mean hourly values derived from these files are shown in Table 2 of the appendix.

The investigations reported in their Figs. 6, 7, and 8 seem to indicate that the PCS index values derived by using the "solar max" parameters of the AARI#3 version from 2006 are very close (in p.1488 declared to be "*within 10%*") to the PCS values derived with the "solar min" scaling parameters in the AARI_1997+2007-2009 version. Thus, it is concluded in TPJ2011 that scaling parameters derived using appropriate quiet day reference (QDC) handling are virtually independent of the solar cycle.

However, by some further mistake, the AARI#3 scaling parameters in version AARI_1998-2001 from TJS2006 are not at all used in the reported examinations. It appears that the scaling parameters from version AARI_1995-2005 (AARI#4) have been inserted (without mentioning) to substitute for the (erroneous) parameters of version AARI_1998-2001 (AARI#3) in the QDC analyses related to their Figs. 1, 2, and 3. It has not been possible to deduce the origin of the scaling parameters actually used for two PCS versions being compared in Figs. 6, 7, and 8 of TPJ2011.

Thus, it appears that the TPJ2011 publication fails to recognize the problems with the adverse scaling parameters in the version AARI_1998-2001 (AARI#3), which have been used by the authors for further publications throughout some years since it was developed in 2006. By stating to use version AARI#3 scaling parameters for calculations of PC indices and then demonstrate the small differences between PC index values derived by tacitly using scaling parameters of two slightly different AARI#4 versions, they avoid to demonstrate the failure of the AARI_1998-2001 (AARI#3) version from 2006. Instead, in the caption of their Fig. 5 (Fig.3 here) the authors make version AARI_1995-2005 become "AARI#3" which make the real AARI#3 version from 2006 vanish.

The substitute of versions is supported by incorrect quotations. In p. 1479 of TPJ2011 the authors write: "*The parameters α, β, φ derived for full cycle of solar activity (1995-2005) were used in the procedure adopted in the Arctic and Antarctic Research Institute for the unified PC index derivation (the procedure known as AARI#3 version, according to the nomenclature proposed by McCready and Menvielle, 2010).*"

However, McCready and Menvielle (2010) note in their summary Table 1 (pp. 1888-1889) on the different PC index versions that: "*AARI#3_2006, ACE 1998-2001, official PCS index*".

The mingling of scaling parameter versions in the discussion of the effects of using quiet day levels (QDC) or just base levels (without QDC) in the reference levels used for processing of magnetic data to derive PC index values has generated obviously incorrect results easily spotted in the "optimum angle" and "slope" scaling parameters displayed in their Fig. 1 as demonstrated in section 3 here.

3. Examination of the PCS scaling parameters used in Troshichev et al. (2011).

This section examines in detail the use of PCS scaling parameters in TPJ2011. One line of examinations concern identification of the PCS version actually used in the analyses. The other line of examinations regards the validity of the reported results assuming that the PCS version substituted for the erroneous AARI_1998-2001 version (AARI#3) has adequate properties.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

3.1. Identification of the PCS parameter version

The QDC issue is the question whether the polar magnetic variations used in Eq. 1 should be measured from the secularly varying base level or from the varying level (QDC) recorded during "*extremely quiescent days*" (TJS2006). (see Janzhura and Troshichev, 2008, for details)

Fig. 1 of TPJ2011 is meant to provide basis for a discussion of the importance of using QDC correction of the reference level for observed magnetic data at calculations of PC index scaling parameter and index values. The diagrams of their Figs. 1a, b, and c display daily variations in the optimum angle, φ, the slope of the regression line, α, and the intercept, β, derived without using QDC (thin blue lines) and with use of QDC (thick green lines) for the same local winter (15 June) and summer (15 November) days.

There are two essential problems with their Fig. 1. Against their statements, the "with QDC" curves are not derived as stated from the AARI_1998-2001 (AARI#3) version from TJS2006. They are taken from the more recent AARI_1995-2005 (AARI#4) scaling parameter version. Furthermore, the "without QDC" curves are not derived from calculations of scaling parameters from the "with QDC" version just without using QDCs but are of indefinable origin.

Figs. 4a,b here displays in green line the optimum angles read from the "with QDC" curves in Fig. 1a. The angle values derived from the parameter file, Angle_Fi.1M, derived for epoch 1995-2005 are displayed in blue dashed line, and the corresponding angles read from the left column (epoch 1998-2001) of their Fig. 5 (Fig.3 here) are displayed by the red line with dots.

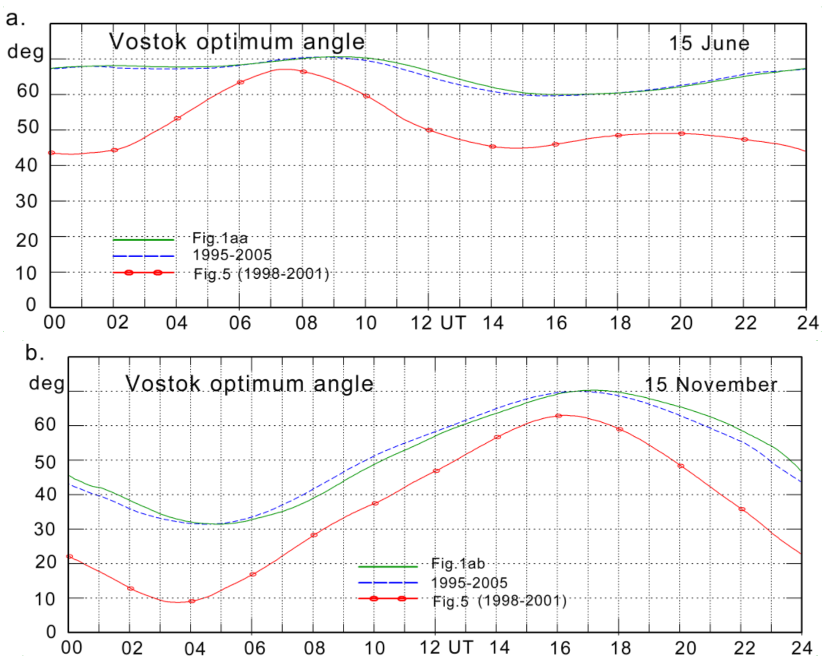

Fig. 4. (**a**) Vostok optimum angles on 15 June. Angles read from Fig. 1aa of Troshichev et al., 2011, in green line. Angles from AARI file (Coeff_Fi.1M, 21-06-2011), epoch 1995-2005, in blue, dashed line. Angles read from the left column of their Fig. 5 (epoch 1998-2001) in red line with dots. (**b**) The corresponding diagram for 15 November (Fig.1ab) using notation and line colours like those of Fig. 4a.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae
Discussions
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From the displays of optimum angles by the green lines in Figs. 4a and 4b here it is evident that the angles represented by the "with QDC" solid green lines in Fig. 1a of TPJ2011 for 15 June and 15 November represent the AARI_1995-2005 version presented in Fig. 4 here in blue, dashed line, and not the AARI_1998-2001 version (derived by Troshichev et al., 2006) represented here by the red line with dots. The optimum angles from the AARI_1998-2001 (AARI#3) version (red line, dots) differ by up to 25° (in June) from the other two optimum angle versions.

Concerning the PCS slope (α) coefficients, Figs. 5a,b here displays in green line the slope values displayed by the "with QDC" heavy green line in Fig. 1b (15 June and 15 November) of TPJ2011. The slope values defined in the AARI file Coeff_alpha.1M (21-06-2011) (epoch 1995-2005) are displayed in dashed blue line while the slope values from the AARI_1998-2001 version read from the left column of their Fig. 5 are displayed by the red line with dots.

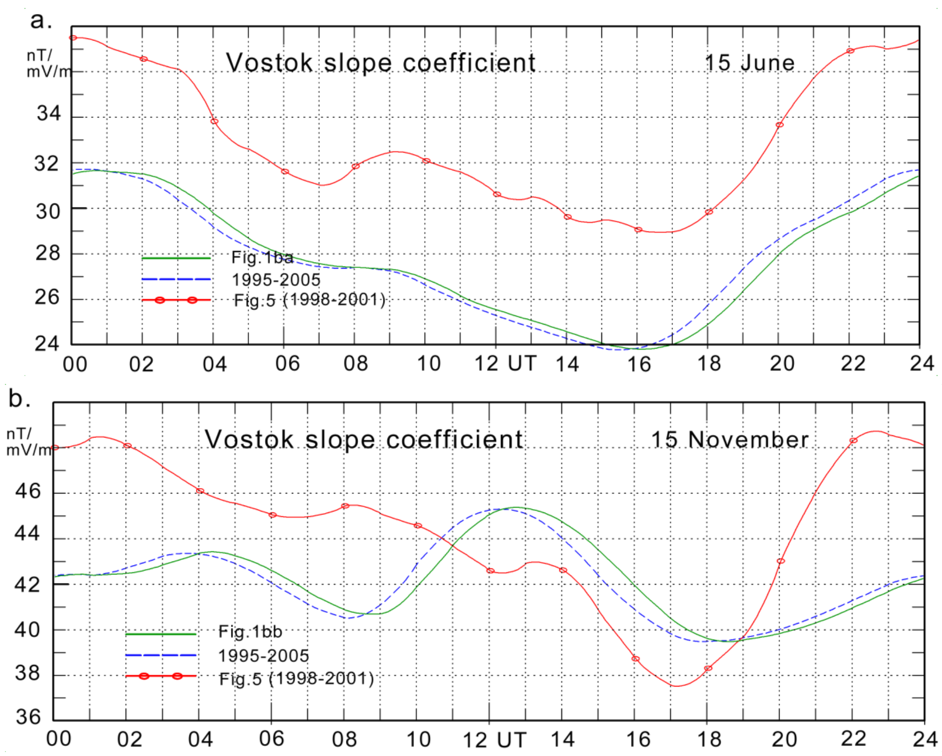


Fig. 5. **(a)** Vostok PCS slope coefficients 15 June (with QDC). Slope values read from Fig. 1ba of Troshichev et al., 2011 in green line. Slope values from AARI file (Coeff_alpha.1M, 21-06-2011), epoch 1995-2005, in blue dashed line. Slope values read from left column of their Fig. 5 (epoch 1998-2001) in red line with dots. **(b)** The corresponding diagram for 15 November (ref. Fig.1bb) using notation and line colours like those of Fig. 5a.

Again, like inferred from the displays of optimum angles, the "with-QDC" curves in heavy green lines in Fig. 1b of Troshichev et al. (2011) represent slope values from the AARI_1995-2005 version (AARI#4) and not the AARI_1998-2001 version (AARI#3) from Troshichev et al. (2006).

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

Concerning identification of the version used in TPJ2011 for the intercept (β) values in the diagrams displayed in their Fig. 1c, the "with QDC" curves (in heavy green line) provide again, as seen in Figs. 6a,b here, values derived from the AARI_1995-2005 version (AARI#4) and not the AARI_1998-2001 version (AARI#3) as claimed in their statements.

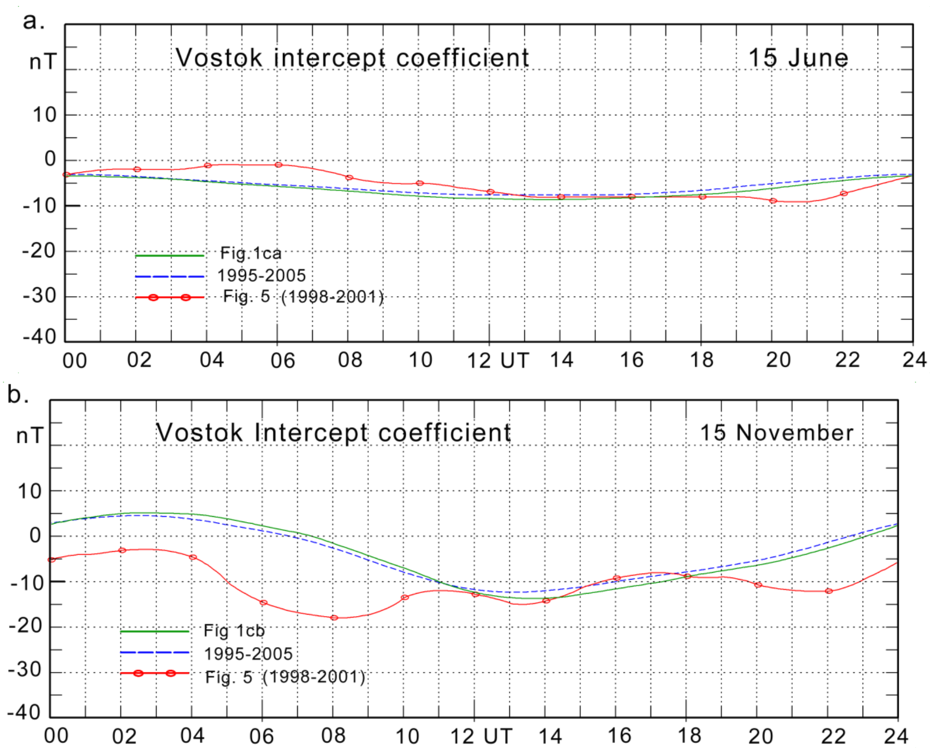


Fig. 6 (**a**) Vostok intercept coefficients 15 June (with QDC). Intercept values read from Fig. 1ca of Troshichev et al., 2011, in green line. Intercept values from AARI file (Coeff_beta.1M, 21-06-2011), epoch 1995-2005, in blue dashed line. Intercept values read from left column of their Fig. 5 (epoch 1998-2001) in red line with dots. (**b**) The corresponding diagram for 15 November (ref. Fig.1cb) using notation and line colours like those of Fig. 6a.

The close correspondence between values in the AARI files of scaling parameters derived for epoch 1995-2005 version (AARI#4) and the values read from the "with QDC" curves in Figs. 1a, b, c leaves no doubt that they are derived from the same scaling parameter version. In spite of possible inaccuracies in the reading of values from the colour-coded diagrams it is clear that the values represented by the red curves with dots in Figs. 4b, 5b, and 6b here are not displayed in Fig. 1 of TPJ2011. Thus, the statement in p. 1484 of TPJ2011, claiming that the scaling parameter values shown in their Fig. 5 based on epoch 1998-2001 have been used for the displays in their Fig. 1, is incorrect.

3.2. The QDC effects on PCS scaling parameters

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

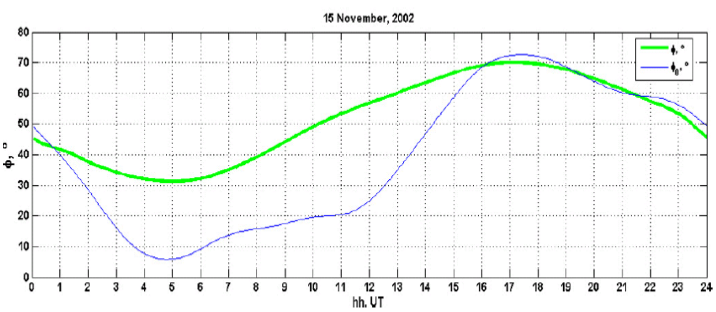
Like noted above, the text to the diagrams in Figs. 1a, b, and c of TPJ2011 claim they display daily variations in the optimum angle, φ, the slope of the regression line, α, and the regression intercept, β, derived without using QDC (thin blue lines) and with use of QDC (thick green lines) for the same local winter (15 June) and summer (15 November) days.

In p. 1484 the authors write: "*To demonstrate the QDC role in derivation of α, β, and φ parameters, the parameters derived with inclusion of the QDC and without QDC should be compared. To provide such comparison, in our analysis we used the same experimental data (Satellite measurements of EKL and magnetic data from Vostok for 1998-2001) to derive a set of parameters α_0, β_0, and φ_0 without including the QDC. Results of this calculation – angle φ_0, slope of regression β_0 and intersection β_0 - are shown in Fig. 1 for winter and summer days at the Vostok station (15 June and 15 November 2002, respectively) along with parameters φ, α, and β derived for the same days with inclusion of QDC.*"

For the data displayed in heavy green line in their Fig. 1a reproduced from Troshichev et al. (2011) in Fig. 7a here, it is stated in p. 1484 of TPJ2011, as quoted above, that they present PCS optimum angles derived from magnetic data from Vostok for 1998-2001 with QDC corrections of the reference levels. For the data displayed in thin blue line in their Fig. 1a reproduced in Fig. 7a, it is stated that they present PCS optimum angles derived from the same data but without using QDC reference level corrections.

However, it is seen at a glance that this could not be correct. Optimum angle values are derived by searching for optimum correlation between the merging electric field, E_M, (also denoted E_{KL}) in the solar wind and the projected value of the horizontal polar magnetic disturbance vector. The QDC represent the undisturbed variations on "*extremely quiescent days*" (quote from TJS2006) where $E_M \approx 0$ and could not possibly affect the correlation of ΔF_{PROJ} with E_M much. Thus, the optimum angles with QDC and without QDC should be (almost) the same. It has not been possible to obtain information on the real origin of the "without QDC" curves or to deduce their derivation by examining available data.

PCS scaling parameters have been derived with a DMI program (Stauning et al., 2006; Stauning, 2016) where the QDC involvement can be switched in and out without affecting other steps in the calculations. Another feature in the program is the possible adjustment of the averaging/smoothing of the derived optimum angles. For the example for 15 November, Fig. 7b (middle field) here presents the resulting optimum angles for the with/without-QDC cases for a light level of smoothing. Fig. 7c (bottom field) presents the optimum angles for the QDC/no QDC cases with a stronger level of averaging/smoothing. The differences between the re-calculated "with QDC" and "without QDC" values are very small in both cases.



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Preprint. Discussion started: 4 December 2020

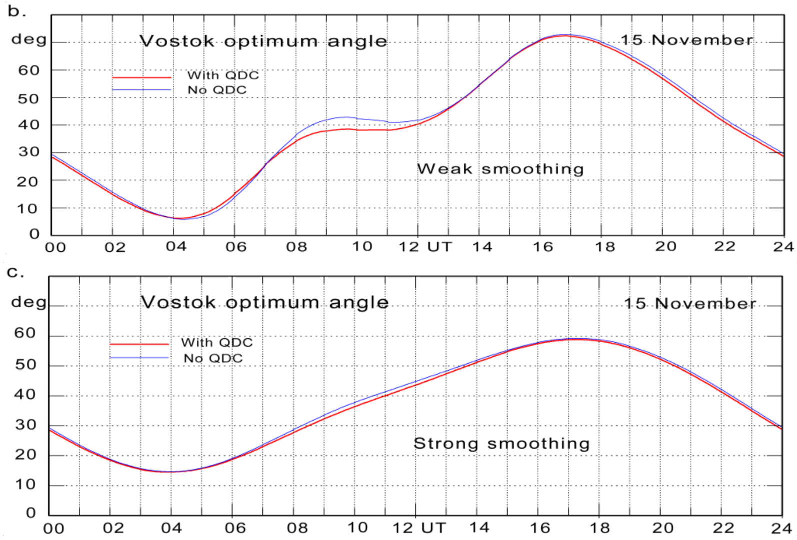
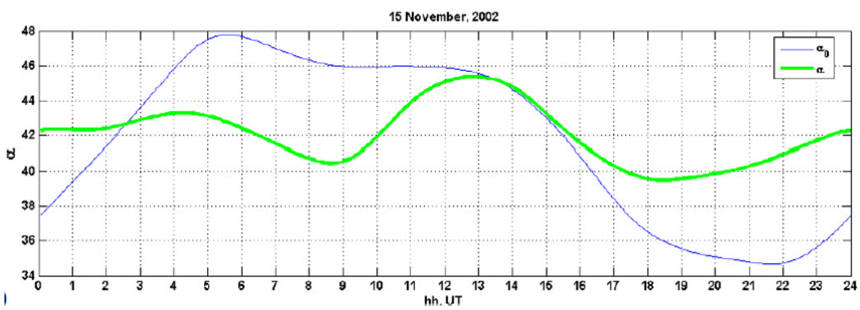


Fig. 7. Optimum angles for Vostok on 15 Nov. The top field (**a**) displays the with-QDC (heavy green line) and no-QDC (thin blue line) calculations of optimum angles by Troshichev et al. (2011) reproduced from their Fig. 1ab. Middle field (**b**) displays results from the re-calculation with and without QDC with light smoothing. Bottom field (**c**) displays the re-calculation of optimum angles with and without QDC with strong averaging/smoothing.

The slope values (α) for the “with QDC” and “without QDC” cases should also be nearly the same since the samples of magnetic disturbance data used for the regression line are all displaced (parallel-shifted) by the same QDC-related amount. The intercept values (β) will change by this amount (see Stauning, 2013). The relations between slope values in Fig. 1bb of TPJ2011 and re-calculated values are displayed in Fig. 8 while the relations between intercept values in Fig. 1cb of TPJ2011 and recalculated values are shown in Fig, 9



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Preprint. Discussion started: 4 December 2020

Annales Geophysicae
Discussions
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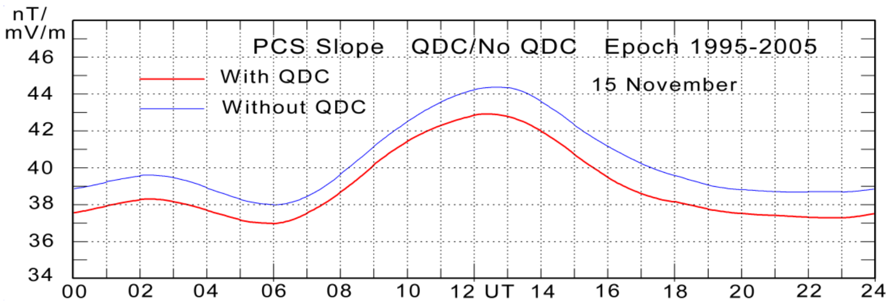

Fig. 8. Display of slope values, α, for 15 Nov to be used for derivation of PCS indices. Top field: slope values reproduced from Fig. 1bb of Troshichev et al., 2011. Bottom: re-calculation of slopes with QDC (red) and without QDC (blue)

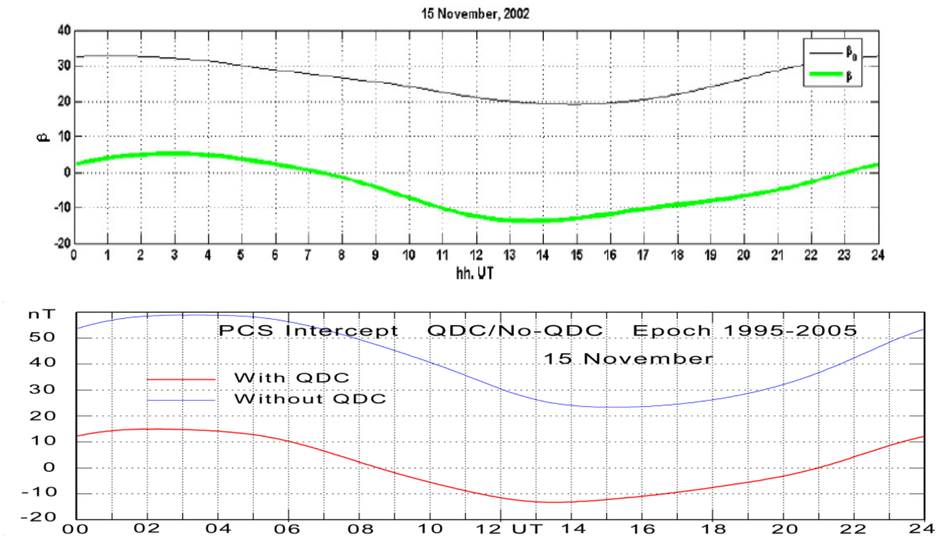

Fig. 9. Top field: PCS intercept values 15 Nov 2001 reproduced from Fig. 1cb of Troshichev et al., 2011. Intercept values derived with QDC in heavy green line. Without QDC in thin blue line. Bottom: Display of intercept values, β, for 15 Nov calculated with QDC (red) and without QDC (blue).

3.3. PCS values calculated with/without QDC.

Re-calculated values of the with-QDC/no-QDC coefficient sets α, β, and φ have been used to re-calculate PCS index values with and without QDC reduction of Vostok geomagnetic data. The re-calculated PCS values corresponding to those of Figs. 2a and 2b of TPJ2011 are displayed in Fig. 10.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions Open Access

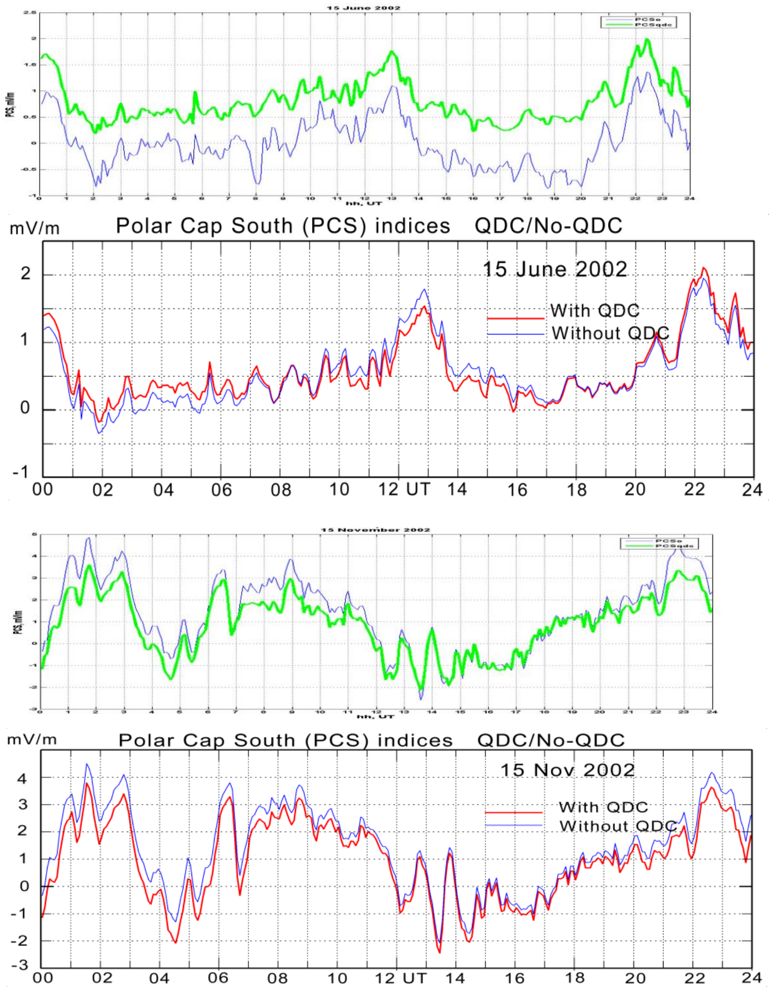

Fig. 10. PCS indices calculated with/without QDC. Top field: PCS index values for 15 June 2002 reproduced from Fig. 2a of Troshichev et al. (2011). Next lower field: Recalculation for 15 June 2002. Lower two fields present corresponding sets for 15 November 2002.

It is evident from the examples in Fig. 10 that the differences between the "with QDC" and the "without QDC" cases have been substantially reduced in the re-calculations. Actually, an epoch-average QDC correction is built into the intercept (β) scaling parameter as explained in Stauning (2013). When the same "with/without QDC" procedure is used for calculation of the scaling parameters as well as for the calculation of PC index values then the differences are rather small.

The overall results for 2002 are displayed in the bottom field of Fig. 11 here in the format of Fig. 3 from TPJ2011.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

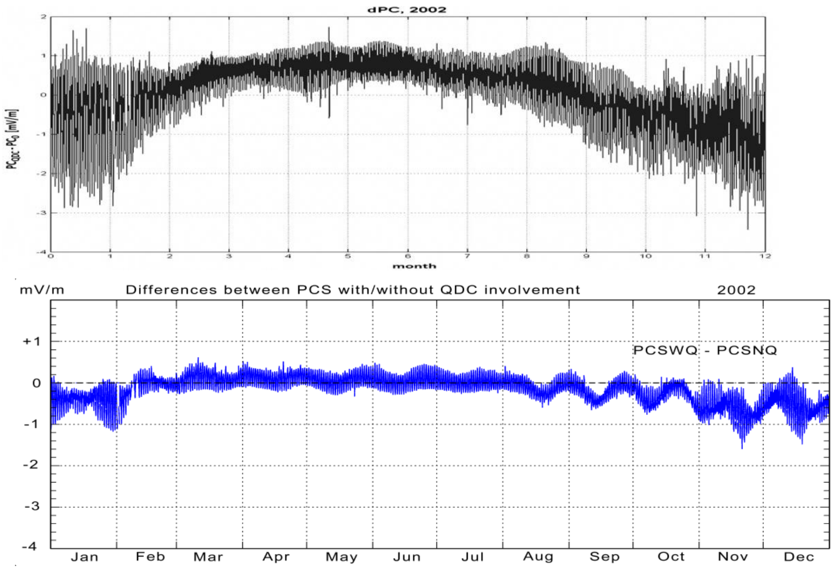

Fig. 11. Display of differences between PCS values calculated with and without QDC reductions of Vostok magnetic data for 2002. Top field: Reproduced from Fig. 3 of Troshichev et al., 2011. Bottom: Re-calculation of the PCS with-QDC/no-QDC index differences.

The top field of Fig. 11 presents the differences between the with-QDC/no-QDC PCS index values throughout 2002 displayed in Fig. 3, p.1483, of TPJ2011, while the diagram in the bottom field of Fig. 11 presents the corresponding re-calculated values using reference levels with and without QDC reduction. The plots in Figs. 10 and 11 indicate that the differences between PCS index values calculated with and without QDC reduction of Vostok data are 2-3 times larger in TPJ2011 publication than in the re-calculations. The main reason for the enhanced differences in the TPJ2011 version is the introduction of an incorrect "without QDC" scaling parameter version (of unknown origin) shown by the thin blue lines in their Fig. 1.

3.4. Differences in PC index values for different sets of scaling parameters.

According to the statements in TPJ2011, the PCS values and their differences displayed in Figs. 6, 7, and 8 have been derived from using the "solar max" scaling parameters (AARI_1998-2001) displayed in Fig. 3 of TJS2006 (or Fig. 5 of TPJ2011) and the "solar min" scaling parameters in version AARI_1997+2007-09 displayed in the middle column of the diagrams in their Fig. 5. The "solar max" and "solar min" PCS values are superimposed on each other in the top fields of Fig. 6 (December 2001), Fig. 7 (June 2001), and Fig. 8 (year 2001). Their current differences are displayed in the middle fields while the bottom fields display statistics on the distribution of difference samples. Fig 12a here displays the TPJ2011 results for December 2001. It is seen from the display of the statistics that the overwhelming majority of events are constrained within ± 0.2 mV/m.

With the index scaling parameters read from Fig. 5 of TPJ2011 for versions AARI_1998-2001 (AARI#3, solar max) and AARI_1997+2007-09 (solar min) and using Vostok magnetic data supplied from INTERMAGNET, the corresponding PCS index values have been calculated for the same cases. The results for December 2001 are displayed in Fig. 12b in the format of Fig. 12a.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions
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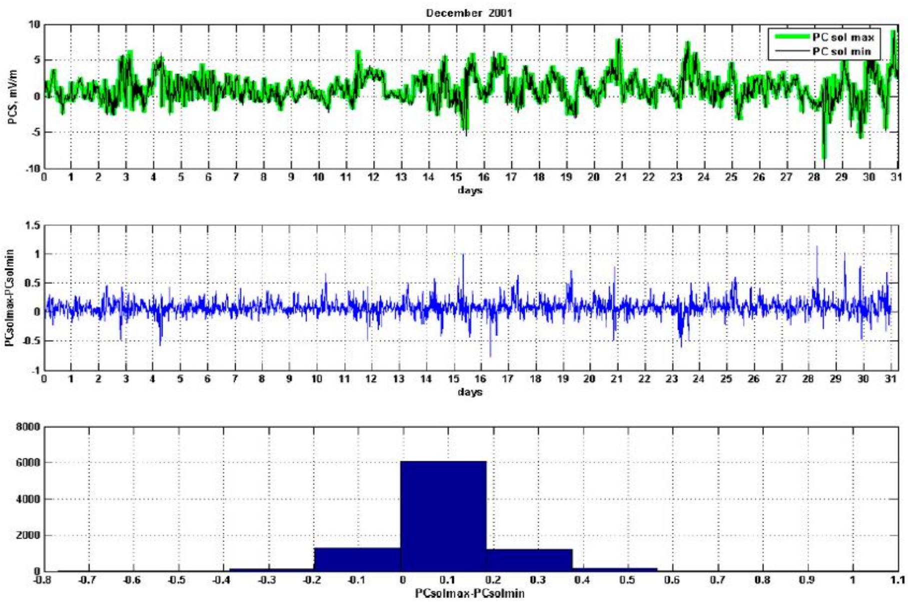
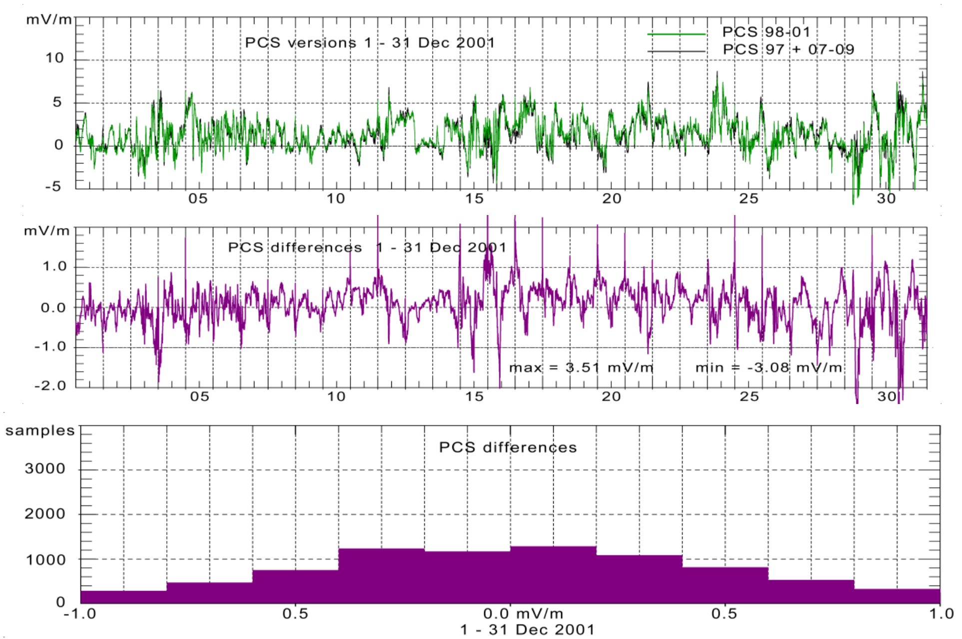
Now, the corresponding majority of events are held within about ± 1 mV/m with differences ranging up to 3.5 mV/m.

a.



b.



https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

Fig. 12. Display of differences between PCS index values for December 2001 calculated with epoch 1998-2001 scaling parameters and with epoch 1997+2007-2009 scaling parameters, respectively. (**a**) Reproduction of Fig. 6a from Troshichev et al. (2011). (**b**) Re-calculations using readings of scaling parameters from Fig. 5 of TPJ2011.

The scaling parameters for the displays in Fig. 12b were derived from readings of the erroneous version AARI_1998-2001 (AARI#3) from 2006. In order to see whether using proper versions throughout could give small differences like those of Fig. 12a, the PCS indices derived from using version AARI_1995-2005 (solar cycle) and AARI_1997+2007-09 (solar min) have been compared. The results are displayed in Fig. 13.

The differences derived for this case are smaller than those presented in the recalculations based on version AARI_1998-2001 (solar max) vs. version AARI_1997+2007-2009 (solar min) displayed in Fig. 12b. They are still considerably larger than the differences displayed in Fig. 6 of TPJ2011 (Fig. 12a here) although, in principle, spanning only half the range between max and min solar activity, they should be lower. Thus, the small differences displayed by the comparisons in Figs. 6, 7, and 8 are not based on PCS index values calculated with scaling parameters derived from different epochs among those in play.

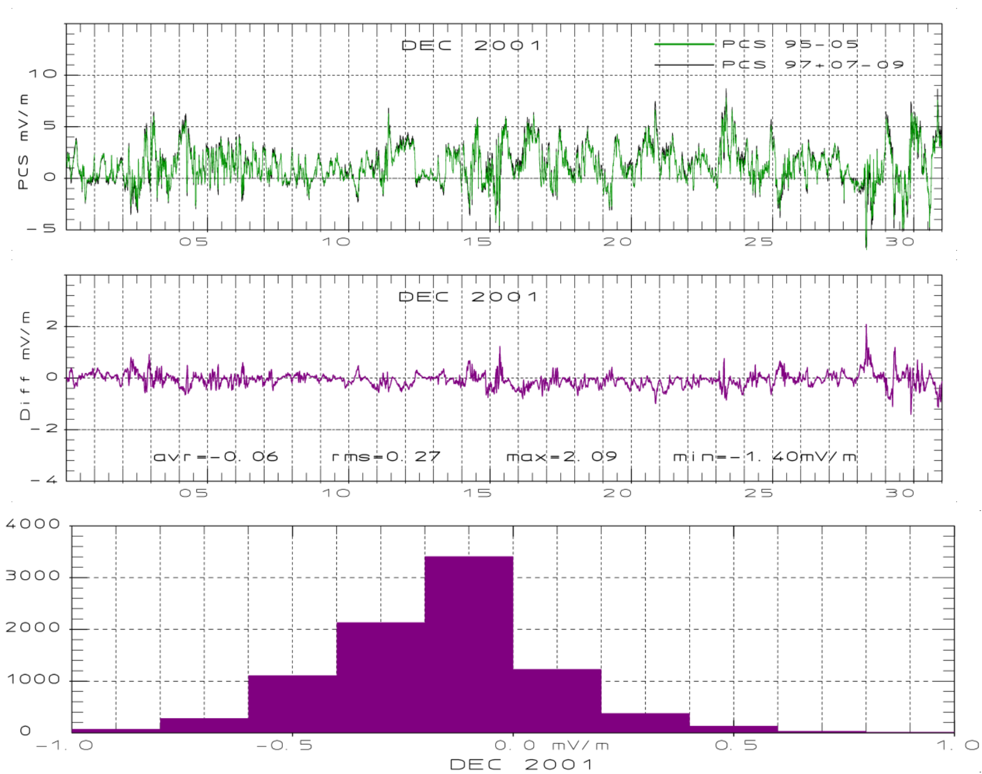


Figure 13. Calculation of PCS index values for December 2001 in versions 1995-2005 and 1997+2007-2009 and their differences in the format of Fig. 6 of Troshichev et al. (2011).

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions
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EGU

It has not been possible to deduce the origin of the scaling parameter sets used for calculations of the PCS index values presented in Figs. 6, 7, and 8 in TPJ2011. However, it is evident that the authors have not used the scaling parameters provided by the AARI#3 version from TJS2006.

The authors of TPJ2011 conclude (p. 1488) from their Figs. 6, 7, an 8 that the close consistency between PC indices calculated with scaling parameters derived from epochs of high solar activity (AARI_1998-2001) and from epochs of low solar activity (AARI_1997+2007-2009) indicates that the scaling parameters "*can be considered as invariant with respect to solar activity*". However, their conclusion rests on the erroneous substitute of another set of scaling parameters (presently not known) for the solar maximum-based AARI_1998-2001 (AARI#3) scaling parameter set derived on basis of the Troshichev et al. (2006) mistake in using IMF parameters in their GSE representation. Thus, the conclusion in TPJ2011 is not properly substantiated.

4. Differences in optimum angles and resulting PCS values between versions AARI#3 and #4.

Results from the double reading of the PCS scaling coefficients for the optimum angle (φ) from Fig. 3 of TJS2006 and Fig. 5 of TPJ2011 are displayed by the green and red curves in Fig. 14 here. The magenta curves in Fig. 14 presents PCS optimum angle values for version AARI_1995-2005 (AARI#4) provided in the file ("Parameter.rar", Janzhura 21-06-2011) from AARI.

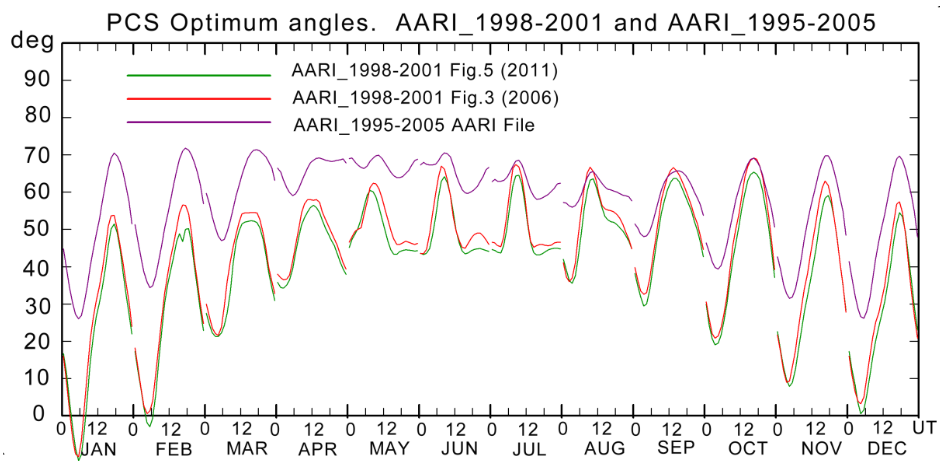

Fig. 14. Reading of the optimum angles for the PCS coefficients in version AARI_1998-2001 (AARI#3) from the upper left diagram in Fig. 5a of Troshichev et al. (2011) in green line and those from upper right diagram of Fig. 3 from Troshichev et al. (2006) in red line. Optimum angles in a numerical file for the PCS version AARI_1995-2005 (Angle_Fi.1M) are displayed by the uppermost magenta line.

For each of the 12 monthly sections of Fig. 14, the displayed curves present the monthly average daily variation from 00 to 24 UT. The differences between optimum angles in the AARI_1998-2001 (AARI#3) and the AARI_1995-2005 (AARI#4) versions vary with time of the day and season between 0° at appr. 10 UT in the southern winter season and up to almost 40° at appr. 06 UT in the southern summer season. These variations in the differences are coupled to the systematic variations in the angular differences between IMF components in the GSE vs. GSM representations.

The slope (α) and intercept (β) calibration parameters are also affected by the erroneous use of IMF components in the GSE representation in TJS2006. When applied to calculations of PC indices

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

there are considerable differences between results derived from using the AARI_1998-2001 GSE-based (AARI#3) and the AARI_1995-2005 GSM-based (AARI#4) scaling parameter versions. An example of differences in the PCS calculations throughout 2001 is presented in Fig. 15.

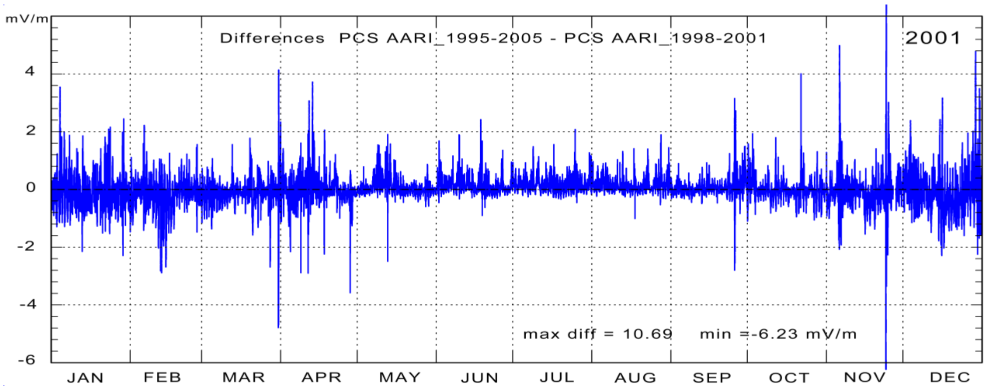

Fig. 15. Differences between PCS values derived with solar cycle average scaling parameters in the AARI_1995-2005 (AARI#4) GSM-based version and PCS values derived with GSE-based scaling parameters in the AARI_1998-2001 (AARI#3) version.

Generally, the differences range between ±1 mV/m during quiet or weakly disturbed conditions, but may rise to range between ±2 mV/m during intervals of disturbed conditions. During magnetic storm events the differences could be much larger to reach values in excess of 10 mV/m like noted in Fig. 15.

The erroneous PC index values might have affected individual cases used, for instance, in reported magnetic storm or substorm investigations. It should also be noted that the systematic nature of the errors in the PC indices related to systematic variations in the GSE vs. GSM transformations is expected to invalidate statistical investigations based on using PC indices derived with the erroneous scaling parameters in version AARI#3 resulting from the use of GSE-based IMF components in TJS2006.

5. Discussions

In a natural and acceptable development, geomagnetic indices may change as new basic data arrive or when the calculation methods are refined. Such changes should be revealed in the updated documentation. However, changes resulting from detection of errors in the calculations should also be reported to the scientific community. There is no question that the mistake in using GSE rather than GSM representation in Troshichev et al., 2006 (TJS2006) is an error that has resulted in incorrect values of the scaling parameters (φ, α, β) in the AARI_1998-2001 (AARI#3) version. The error was detected in 2009 but at that time considered of minor importance. The grave consequences of the mistake were not disclosed until the recent examination of the publication Troshichev et al., 2011 (TPJ2011).

The stated main purpose of TPJ2011 was to demonstrate the invariability of PC index scaling parameters derived on basis of data from epochs of high and low solar activity, respectively. A secondary mission was to prove that including specifically calculated quiet day values (QDCs) in the reference level was mandatory for obtaining proper PC index values. For both cases, reference was made to the work presented in TJS2006 which included calculation of PCS index scaling

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

parameters for version AARI_1998-2001 (AARI#3) displayed in their Fig. 5 in a copy of the right column of Fig. 3 of TJS2006.

However, in their Figs. 1, 2, and 3, against their statements, the scaling parameters in version AARI_1995-2005 (AARI#4) and not the version AARI1998-2001 (AARI#3) were used for the "with QDC" version, while the "without QDC" version displayed in their Fig. 1 and used for the results in Figs. 2 and 3 is of unknown origin. The "without QDC" versions are definitely not presenting scaling parameters obtained by just omitting the QDC involvement.

For their Figs. 6, 7, and 8 the authors state (p. 1486): "*To emphasize any differences in the behaviour of parameters α, β, and φ in course of solar maximum and minimum epochs, the coefficients presented in the left and middle columns of Fig. 5* (i.e., AARI_1998-2001 and AARI_1997+2007-2009, respectively) *have been applied to calculate the appropriate values* (PC_{solmax}) *and* PC_{solmin}) *for the same year 2001*." The small differences were taken to support their conclusion that "*once derived parameters of α, β, and φ can be regarded as valid forever, provided that the appropriate QDCs are used*"..

In both cases the authors, against their statements, fail to use the AARI_1998-2001 (AARI#3) scaling parameters derived by Troshichev et al. (2006). Thus, their Figs. 1, 2, 3 and 6, 7, and 8 are incorrect. It should be stressed that this judgement is not a matter of different opinions but a conclusion drawn from documented errors in TJS2006 and TPJ2011.

6. Importance of the commented publication, Troshichev, Podorozhkina, and Janzhura (2011)

The mistake in the use of IMF components in their GSE instead of GSM representation has no strong impact on the remaining presentation of the PC index concept in TJS2006. Usually, such a mistake would not attract attention after the many years that have passed since the publishing in 2006. However, the incorrect features drag a trail of erroneous relations and invalid statements presented in publications on polar cap indices issued since 2006 extending up to now (2020), among others, in the commented publication: Troshichev, O. A., Podorozhkina, N. A., and Janzhura, A. S.: Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field, Ann. Geophys., 29, 1479-1489, 2011.

Thus, the enlargement of the differences between PC index values derived with QDC vs. those derived without QDC involvement presented in Figs. 2a, b and Fig. 3 of TPJ2011 may deter Space Weather services from using the simple and reliable calculation of PC index values directly from the magnetic variations with respect to the secular baseline using "without-QDC" scaling parameters and accepting the implied small inaccuracies (less than ~1 mV/m).

The apparent small differences between the AARI_1998-2001 (AARI#3) and the AARI_1995-2005 (AARI#4) versions resulting from the hidden substitution of AARI#4 parameters might disguise inaccuracies in further publications that have used the erroneous AARI#3 version.

The publications Troshichev et al. (2006) and Troshichev et al. (2011) have affected the endorsement by IAGA of the present PC index versions. Basis for the endorsement is provided by the "*Criteria for endorsement of indices by IAGA*" adopted in 2009. Here, section 2 reads:

"2. *The derivation of the index will be clearly defined; the algorithm will be available through appropriate refereed and citeable publication(s); the algorithm must be shown to be independently reproducible.*"

The material submitted from DTU Space and AARI to IAGA in 2013 in the application for endorsement of their PC index versions (Matzka, 2014) states:

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions

"Regarding criterion 2:
The derivation of the index is described in the following publications:
Troshichev et al. (2006)
Janzhura and Troshichev (2008)
Janzhura and Troshichev (2011)
Troshichev and Janzhura (2012) (here, chapter 4 describes derivation of the provisional data set)"

A replica of the TPJ2011 publication discussed here is included in chapter 4 of Troshichev and Janzhura (2012) which form part of the abovementioned basis for the IAGA-endorsed index calculation methodology (Matzka, 2014). Thus, the TPJ2011 publication along with the Troshichev et al. (2006) and Janzhura and Troshichev (2011) publications have contributed to form basis for the endorsement of the PC index versions by IAGA resolution #3 (2013).

Furthermore, the TPJ2011 publication and its non-substantiated results are referenced in p. 15 of Troshichev (2017) and further referenced in page 4 of the ISO/TR23989:2020 technical report from January 2020. The report is issued by the Technical Committee of the International Standards Organization (ISO) considered to represent the ultimate authority in matters of the Space Environment.

Conclusions

- The reported investigations in Troshichev, O. A., Podorozhkina, N. A., and Janzhura, A. S. (2011): Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field, Ann. Geophys., 29, 1479-1489 (TPJ2011) are according to the authors based, to a large extent, on the PC index version, AARI_1998-2001 (AARI#3), developed by Troshichev et al. (2006). However, the AARI#3 version based on using IMF components in their GSE instead of GSM representation is invalid and has generated odd scaling parameters.

- It appears that the TPJ2011 publication serves to justify the adverse scaling parameters in the AARI#3 versions, which have been used by the authors for further publications for some years since they were developed in 2006. By stating that they use version AARI#3 scaling parameters for calculations of PC indices and then demonstrate in their Figs. 6, 7, and 8 small differences between PC index values derived by using scaling parameters of two slightly different AARI_1995-2005 (AARI#4) versions they have overlooked the potential failure of the AARI_1998-2001 (AARI#3) version from 2006.

- Contrary to statements in the text, the AARI#3 scaling parameters have been replaced in their Fig. 1 by those of the more recent version, AARI_1995-2005 (AARI#4) for the "with QDC" parameters. The "without QDC" parameters have a different, indefinable basis and have obviously incorrect relations to the "with QDC" parameters. With the mingling of parameter versions, the investigations relating to the use of quiet day levels ("with QDC") or just base levels ("without QDC") for the reference levels in the processing of polar magnetic data for derivation of PC index values have generated the incorrect results reported in their Figs. 2 and 3.

- The small differences between PC index values derived by using scaling parameters from two slightly different, but otherwise indefinable AARI#4 versions have been used to postulate invariability with respect to the solar cycle of derived index scaling parameters in the title, abstract and conclusions of the TPJ2011 publication. On the presented basis, this postulate must be considered unsubstantiated.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae Discussions Open Access EGU

Data availability

Geomagnetic data from Vostok were supplied from the INTERMAGNET data service web portal at http://intermagnet.org.

Solar wind plasma and magnetic field data based on data from the ACE, IMP, GeoTail, and WIND space missions were supplied from the OMNIweb data service at http://omniweb.gsfc.nasa.gov .

DMI PCN and PCS derivation methods and scaling parameters used since 2006 in PC index publications issued from DMI are documented in DMI Scientific Report, SR-06-04 from 2006 (revised 2007) available at http://www.dmi.dk/fileadmin/Rapporter/SR/sr06-04.pdf .

This report was updated in 2016 to use the same data from epoch 1998 to 2009 as those used for the IAGA-endorsed PC index version while the methodology has remained the same. The report is available at https://www.dmi.dk/fileadmin/user_upload/Rapporter/TR/2016/SR-16-22-PCindex.pdf

Concerning files of scaling parameter values corresponding accurately to the colour-coded displays in Troshichev et al. (2006, 2011) and precise values of the reference quiet day variations (QDCs), requests should be directed to Drs. O. A. Troshichev and A. S. Janzhura at the Arctic and Antarctic Research Institute in St. Petersburg, Russia.

Tables of the PCS scaling parameter values read from the colour-coded diagrams in Troshichev et al., 2006 are provided in Table A1 of the Appendix. Tables of hourly mean values of the scaling coefficients from AARI files (Parameters2011.rar, Janzhura 21-06-2011), for epoch 1995-2005 are included in Table A2 of the Appendix.

Acknowledgments. The staffs at the observatories in Qaanaaq and Vostok and their supporting institutes, the Danish Meteorological Institute, the Danish Space Research Institute (DTU Space), and the Arctic and Antarctic Research Institute in St. Petersburg, Russia, are gratefully acknowledged for providing high-quality geomagnetic data for this study. The efficient provision of geomagnetic data from the INTERMAGNET data service centre, the supply of data from IMP, WIND, ACE, and GeoTail missions and the excellent performance of the OMNIweb data portals are greatly appreciated. The author gratefully acknowledges the collaboration and many rewarding discussions in the past with Drs. O. A. Troshichev and A. S. Janzhura at the Arctic and Antarctic Research Institute in St. Petersburg, Russia.

References.

Janzhura, A. S. and Troshichev, O. A.: Determination of the running quiet daily geomagnetic variation, J. Atmos. Solar-Terr. Phys., 70, 962–972, https://doi.org/10.1016/j.jastp.2007.11.004, 2008.

Kan, J. R., and Lee, L. C.: Energy coupling function and solar wind-magnetosphere dynamo. Geophys. Res. Let., 6 (7), 577– 580, https://doi.org/10.1029/GL006i007p00577, 1979.

Matzka, J.: PC_index_description_main_document_incl_Appendix_A.pdf, 2014. Available at DTU Space web portal: ftp://ftp.space.dtu.dk/WDC/indices/pcn/.

McCreadie, H. and Menvielle, M.: The PC index: review of methods, Ann. Geophys., 28, 1887-1903, doi:10.5194/angeo-28-1887-2010, 2010.

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

McCreadie, H. and Menvielle, M.: Corrigendum to: "The PC index: review of methods, Ann. Geophys., 28, 1887-1903, 2010", Ann. Geophys., 29, 813-814, 2011.

Nielsen, J. B. and Willer, A. N.: Restructuring and harmonizing the code used to calculate the Definitive Polar Cap Index, Report from DTU Space, 2019. Available at: ftp://ftp.space.dtu.dk/WDC/indices/pcn/ .

Stauning, P.: The Polar Cap index: A critical review of methods and a new approach, J. Geophys. Res. Space Physics, 118, 5021-5038, https://doi.org/10.1002/jgra.50462 ,2013.

Stauning, P.: The Polar Cap (PC) Index. Derivation Procedures and Quality Control, DMI Scientific Report SR-16-22, Danish Meteorological Institute, Copenhagen, Denmark. pp. 103. Available at: https://www.dmi.dk/fileadmin/user_upload/Rapporter/TR/2016/SR-16-22-PCindex.pdf .

Stauning, P., Troshichev, O. A., and Janzhura, A. S.: Polar Cap (PC) index. Unified PC-N (North) index procedures and quality control. DMI Scientific Report, SR-06-04. 2006. (revised 2007 version available at http://www.dmi.dk/fileadmin/Rapporter/SR/sr06-04.pdf).

Troshichev, O. A.: Polar Cap (PC) Index, 2011. Available at: http://pcindex.org/ (supported-material).

Troshichev, O. A.: Polar cap magnetic activity (PC index) and space weather monitoring, Édition universitaires européennes, ISBN: 978-3-8381-8012-0, 2017.

Troshichev, O. A. and Janzhura, A. S.: Space Weather monitoring by ground-based means, Springer Praxis Books, Heidelberg, ISBN 978-3-642-16802-4, https://doi.org/10.1007/978-3-642-16803-1, 2012.

Troshichev, O. A., Janzhura, A. S., Stauning, P.: Unified PCN and PCS indices: method of calculation, physical sense and dependence on the IMF azimuthal and northward components, J. Geophys. Res., 111, A05208, https://doi.org/10.1029/2005JA011402, 2006.

Troshichev, O. A., Janzhura, A. S., Stauning, P.: Correction to "Unified PCN and PCS indices: Method of calculation, physical sense, and dependence on the IMF azimuthal and northward components, J. Geophys. Res., 111, A05208", J. Geophys. Res. 114, A11202, https://doi.org/10.1029/2009JA014937, 2009.

Troshichev, O. A., Podorozhkina, N. A., and Janzhura, A. S.: Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field, Ann. Geophys., 29, 1479-1489, https://doi.org/10.5194/angeo-29-1479-2011, 2011.

ISO Report: Space environment (natural and artificial) – Operational estimation of the solar wind energy input into the Earth's magnetosphere by means of the ground-based polar cap (PC) index, International Organization for Standardization (ISO), ISO Technical Report ISO/TR/23989:2020(E), http://iso.org/standard/77565.html, 2020.

Appendix.

Scaling parameter values.

Table A1. Hourly mean values of PCS Scaling coefficients read from Fig. 3 of Troshichev et al. (2006)

PCS Optimum angle parameters (in deg.) based on Vostok data 1998-2001.

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	16.0	18.2	30.0	38.0	46.6	43.5	46.6	41.1	39.8	30.6	21.7	16.0
01	8.8	13.0	26.5	37.0	48.0	43.5	46.4	37.2	36.4	26.2	17.0	11.0
02	1.5	7.4	23.5	36.5	49.5	44.6	45.6	36.0	33.5	22.0	12.2	6.5
03	-6.0	2.6	22.0	36.7	50.0	48.8	45.4	37.0	32.6	20.8	9.0	4.0

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

Annales Geophysicae
Discussions

04	-10.2	0.6	21.6	37.8	50.5	54.0	48.0	41.0	33.0	21.4	9.3	3.2
05	-11.0	1.3	23.8	41.6	54.0	59.5	54.0	48.2	36.8	23.6	13.0	5.0
06	-6.6	4.0	29.4	45.7	57.5	64.0	60.4	55.0	42.0	27.2	17.5	10.2
07	2.0	11.5	36.0	50.2	61.2	67.0	66.4	61.0	47.0	32.2	23.2	16.0
08	12.0	18.6	41.3	54.4	62.4	66.2	67.4	65.2	52.8	39.0	29.0	21.0
09	20.5	26.4	45.3	56.8	62.2	63.3	66.8	66.7	58.0	46.0	34.0	25.0
10	26.6	33.0	48.6	58.0	61.0	59.0	64.2	65.5	61.2	50.2	38.0	27.5
11	30.8	38.2	52.0	58.0	58.5	53.3	58.8	63.2	64.0	54.2	43.0	31.0
12	34.7	42.5	54.2	57.8	55.5	49.6	52.0	59.4	65.8	59.0	47.5	35.0
13	39.0	46.0	54.4	58.0	52.8	47.0	46.8	56.4	66.6	64.2	52.5	40.4
14	44.8	50.4	54.4	57.3	49.8	45.2	45.2	55.5	65.8	67.0	57.3	46.5
15	50.8	54.4	54.5	54.6	47.5	45.0	45.6	55.2	64.5	68.6	61.2	51.6
16	53.7	56.6	54.5	52.7	46.0	46.2	46.0	55.0	62.8	69.2	63.0	56.8
17	53.8	56.5	54.4	51.0	46.0	47.7	46.0	54.7	60.8	68.8	61.8	57.4
18	50.3	54.2	52.6	49.3	46.4	48.6	45.7	54.0	58.8	67.0	58.5	54.6
19	45.5	49.2	49.0	47.4	46.8	49.0	45.6	53.0	56.4	64.0	53.5	48.8
20	41.0	41.7	44.8	45.8	46.6	49.0	45.8	51.3	53.8	59.5	47.6	41.0
21	35.8	35.8	39.7	43.2	46.2	48.3	46.4	49.3	51.6	53.7	41.2	33.0
22	30.5	30.0	36.0	41.0	46.0	47.2	46.6	47.3	48.4	47.2	35.0	26.8
23	24.0	24.7	32.8	39.4	46.2	46.0	46.6	44.8	44.6	39.2	27.8	20.8

PCS Slope values (in nT/(mV/m)) based on Vostok data 1998-2001.

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	47.0	44.5	41.5	38.5	37.5	37.5	38.5	40.5	43.5	45.5	48.0	49.0
01	47.5	44.5	41.5	38.5	37.0	37.0	38.5	40.5	43.5	46.0	48.5	49.0
02	47.5	45.0	41.5	38.5	36.5	36.5	37.5	39.5	42.5	45.5	48.0	48.5
03	47.0	45.0	41.5	38.5	36.5	36.0	36.5	38.5	41.5	44.5	47.0	48.0
04	45.5	44.5	41.5	37.5	35.0	33.5	33.5	35.5	39.5	42.5	46.0	46.5
05	46.5	45.5	42.5	37.5	34.5	32.5	32.5	34.5	39.5	43.0	45.5	47.0
06	44.0	43.0	40.5	36.0	33.0	31.5	32.0	34.5	39.0	42.5	45.0	45.5
07	43.0	41.5	38.5	34.5	32.0	31.0	32.5	35.0	39.5	43.5	45.0	45.0
08	43.0	41.5	38.5	34.5	32.5	32.0	33.5	36.5	40.5	44.5	45.5	45.5
09	43.5	41.5	38.0	34.5	32.5	32.5	34.0	37.5	42.0	45.0	45.0	46.0
10	43.0	41.5	38.5	35.5	32.5	32.0	33.0	35.5	39.5	43.0	44.5	44.5
11	43.0	42.0	39.5	36.0	33.0	31.5	31.5	33.5	37.5	41.5	43.5	43.5
12	43.0	42.0	40.0	36.0	32.5	30.5	30.5	32.0	35.5	40.0	42.5	43.5
13	44.0	42.5	40.5	36.5	32.5	30.5	29.5	31.5	35.5	39.5	43.0	44.5
14	43.0	42.0	39.5	35.5	31.5	29.5	29.0	31.0	34.5	38.5	42.5	43.5
15	41.0	40.0	37.5	34.0	31.0	29.5	29.5	31.0	33.5	37.5	40.5	41.5
16	38.5	36.5	34.5	32.5	30.5	29.0	29.5	31.0	33.0	35.5	38.5	39.0
17	38.0	36.5	35.0	32.5	30.5	29.0	29.5	30.5	33.0	35.5	37.5	38.5
18	38.5	37.0	35.5	33.5	31.0	30.0	30.5	31.5	34.0	36.5	38.5	39.5
19	40.5	39.0	37.5	35.5	33.0	31.5	31.5	32.5	35.0	37.5	40.0	40.5
20	43.5	42.5	40.5	38.0	35.5	34.0	34.5	35.5	38.5	40.5	43.5	44.0
21	45.5	44.5	42.5	39.5	37.0	36.0	36.5	38.0	40.5	43.5	46.5	46.5
22	47.5	45.5	43.0	40.5	38.0	37.0	38.0	40.0	42.5	45.5	48.5	48.5
23	47.0	44.5	41.5	39.0	37.5	37.0	38.5	40.5	43.5	46.5	48.5	49.0

PCS Intercept values (in nT) based on Vostok data 1998-2001.

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
00	-4.0	-4.0	-4.0	-3.0	-3.0	-3.0	-2.0	-3.0	-4.0	-5.0	-5.0	-5.0
01	-3.0	-3.0	-3.0	-2.0	-2.0	-2.0	-1.0	-1.0	-2.0	-4.0	-4.0	-4.0
02	-3.0	-4.0	-4.0	-3.0	-2.0	-2.0	0.0	0.0	-1.0	-3.0	-3.0	-3.0
03	-4.0	-5.0	-6.0	-4.0	-3.0	-2.0	0.0	1.0	-1.0	-3.0	-3.0	-4.0
04	-7.0	-9.0	-9.0	-6.0	-4.0	-1.0	2.0	2.0	-1.0	-4.0	-5.0	-6.0
05	-14.0	-15.0	-14.0	-9.0	-5.0	-1.0	2.0	1.0	-4.0	-8.0	-11.0	-12.0
06	-16.0	-17.0	-15.0	-10.0	-5.0	-1.0	1.0	-1.0	-7.0	-12.0	-15.0	-15.0
07	-17.0	-17.0	-15.0	-10.0	-6.0	-2.0	-1.0	-3.0	-10.0	-15.0	-17.0	-17.0
08	-17.0	-17.0	-15.0	-11.0	-6.0	-4.0	-3.0	-6.0	-11.0	-16.0	-18.0	-18.0

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

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09	-16.0	-15.0	-13.0	-10.0	-6.0	-5.0	-5.0	-7.0	-12.0	-16.0	-17.0	-17.0
10	-13.0	-13.0	-12.0	-10.0	-7.0	-5.0	-5.0	-6.0	-10.0	-12.0	-13.0	-13.0
11	-14.0	-14.0	-13.0	-11.0	-8.0	-6.0	-5.0	-6.0	-9.0	-11.0	-12.0	-13.0
12	-15.0	-16.0	-15.0	-12.0	-9.0	-7.0	-5.0	-6.0	-8.0	-11.0	-13.0	-14.0
13	-17.0	-18.0	-17.0	-15.0	-11.0	-8.0	-6.0	-7.0	-9.0	-12.0	-15.0	-16.0
14	-17.0	-18.0	-17.0	-15.0	-11.0	-8.0	-7.0	-7.0	-9.0	-11.0	-14.0	-15.0
15	-14.0	-15.0	-14.0	-13.0	-11.0	-8.0	-7.0	-7.0	-8.0	-10.0	-11.0	-13.0
16	-11.0	-11.0	-12.0	-11.0	-10.0	-8.0	-8.0	-7.0	-7.0	-8.0	-9.0	-9.0
17	-9.0	-10.0	-11.0	-11.0	-10.0	-8.0	-7.0	-7.0	-7.0	-8.0	-8.0	-8.0
18	-9.0	-9.0	-10.0	-10.0	-9.0	-8.0	-7.0	-7.0	-8.0	-8.0	-9.0	-9.0
19	-9.0	-10.0	-11.0	-11.0	-10.0	-8.0	-7.0	-7.0	-8.0	-8.0	-9.0	-9.0
20	-11.0	-12.0	-13.0	-12.0	-10.0	-9.0	-8.0	-8.0	-9.0	-10.0	-11.0	-11.0
21	-12.0	-13.0	-13.0	-12.0	-10.0	-9.0	-8.0	-8.0	-10.0	-11.0	-12.0	-12.0
22	-11.0	-11.0	-11.0	-10.0	-8.0	-7.0	-7.0	-7.0	-10.0	-11.0	-12.0	-12.0
23	-8.0	-7.0	-7.0	-6.0	-5.0	-5.0	-5.0	-5.0	-7.0	-9.0	-9.0	-9.0

Table A2. Hourly mean values of PCS Scaling coefficients from AARI file (Parameters2011.rar, 21-06-2011)

AARI PCS Optimum angle values (deg.) based on Vostok data 1995-2005. Angle_Fi.1M

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	44.8	51.3	59.7	66.5	69.0	67.3	62.8	57.2	51.5	46.4	42.7	41.4
1	39.4	46.9	56.8	65.4	69.2	68.0	63.4	57.1	50.4	44.1	39.2	37.0
2	34.5	42.4	53.3	63.2	68.1	67.5	62.9	56.3	48.8	41.3	35.3	32.3
3	30.3	38.6	50.4	61.2	67.2	67.3	62.9	56.0	48.1	39.8	32.8	28.9
4	27.3	35.9	48.2	59.9	66.6	67.3	63.2	56.4	48.3	39.4	31.5	26.6
5	26.0	34.4	47.0	59.1	66.4	67.5	63.9	57.5	49.5	40.3	31.8	26.2
6	26.9	34.9	47.3	59.5	67.0	68.4	65.3	59.3	51.7	42.7	34.0	28.0
7	30.3	37.7	49.4	61.0	68.2	69.7	67.0	61.7	54.6	46.1	37.7	31.7
8	35.0	41.6	52.3	62.8	69.2	70.5	68.3	63.9	57.8	50.2	42.4	36.7
9	40.1	46.0	55.5	64.6	69.8	70.4	68.6	65.3	60.6	54.3	47.4	42.0
10	44.8	50.4	58.9	66.5	69.9	69.4	67.5	65.5	62.7	58.0	51.9	46.7
11	48.7	54.2	61.9	67.9	69.1	67.2	65.2	64.6	64.0	61.0	55.5	50.4
12	52.7	57.9	64.6	68.6	67.9	64.6	62.7	63.5	64.9	63.5	58.8	54.0
13	57.3	61.9	67.1	69.1	66.7	62.4	60.5	62.3	65.4	65.8	62.2	58.0
14	62.1	65.8	69.2	69.2	65.4	60.7	58.9	61.4	65.7	67.6	65.5	62.3
15	66.2	68.9	70.5	68.9	64.4	59.8	58.1	60.8	65.7	68.8	68.2	66.2
16	69.2	71.0	71.3	68.6	63.9	59.7	58.2	60.6	65.4	69.1	69.8	68.9
17	70.5	71.8	71.4	68.4	63.9	60.1	58.5	60.3	64.6	68.4	69.8	69.7
18	69.8	71.3	71.0	68.2	64.2	60.6	58.9	60.0	63.4	66.9	68.4	68.6
19	68.0	69.9	70.3	68.3	64.9	61.5	59.4	59.6	61.9	64.5	65.8	66.1
20	65.3	68.0	69.5	68.6	65.9	62.8	60.2	59.2	60.1	61.5	62.4	62.9
21	61.7	65.2	68.1	68.7	67.2	64.3	61.1	59.0	58.4	58.5	58.7	59.0
22	57.5	62.0	66.5	68.9	68.5	66.0	62.2	58.8	56.7	55.5	54.8	54.8
23	51.5	56.9	63.2	67.8	68.8	66.6	62.4	57.7	53.8	50.6	48.4	48.0

AARI PCS Slope values (nT/(mV/m)) based on Vostok data 1995-2005. Coeff_alpha.1M

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	45.3	45.2	43.2	39.3	34.8	31.7	31.5	34.2	37.8	40.5	42.4	44.1
1	45.7	45.6	43.5	39.4	34.8	31.6	31.5	34.3	38.0	40.5	42.4	44.4
2	46.6	46.0	43.3	39.0	34.4	31.2	31.1	34.2	38.0	40.6	42.8	45.2
3	47.4	45.9	42.4	37.8	33.2	30.2	30.3	33.6	37.5	40.4	43.3	46.3
4	47.7	45.2	40.9	36.1	31.7	29.0	29.3	32.4	36.3	39.6	43.3	46.9
5	47.6	44.4	39.6	34.7	30.6	28.2	28.4	31.2	34.8	38.4	42.8	46.8
6	46.5	43.3	38.4	33.7	29.9	27.7	27.7	30.2	33.7	37.4	41.9	45.8
7	44.1	41.0	36.6	32.7	29.5	27.4	27.3	29.7	33.2	36.9	41.0	44.0
8	41.7	38.6	35.0	31.9	29.2	27.4	27.4	29.5	33.0	36.9	40.5	42.5
9	41.4	37.7	34.3	31.5	28.9	27.2	27.3	29.4	33.0	37.3	41.3	43.0
10	43.3	38.7	34.5	31.1	28.2	26.5	26.7	29.0	33.0	38.1	43.2	45.4

https://doi.org/10.5194/angeo-2020-52
Preprint. Discussion started: 4 December 2020

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11	45.5	40.0	34.7	30.6	27.5	25.8	26.0	28.5	32.8	38.6	44.7	47.8
12	46.6	40.9	34.9	30.2	27.0	25.2	25.4	27.9	32.6	38.8	45.3	48.7
13	46.4	41.1	34.9	29.9	26.6	24.7	24.8	27.5	32.6	38.9	45.0	48.2
14	44.9	40.3	34.5	29.6	26.2	24.2	24.2	27.1	32.5	38.6	43.8	46.4
15	42.8	38.9	33.9	29.3	25.8	23.8	24.0	27.0	32.3	37.8	42.1	44.1
16	41.2	38.1	33.7	29.3	25.8	23.9	24.1	27.0	31.9	36.9	40.7	42.3
17	40.7	38.4	34.4	30.0	26.5	24.6	24.7	27.3	31.7	36.3	39.7	41.3
18	40.8	39.2	35.7	31.4	27.9	26.0	25.9	28.3	32.3	36.4	39.5	41.0
19	41.1	40.1	37.1	33.0	29.6	27.6	27.4	29.7	33.6	37.2	39.7	41.0
20	41.5	41.1	38.4	34.6	31.1	28.8	28.5	30.9	34.7	37.9	40.1	41.1
21	42.3	42.2	39.9	36.1	32.3	29.6	29.3	31.8	35.5	38.7	40.7	41.7
22	43.5	43.4	41.3	37.6	33.4	30.5	30.2	32.7	36.4	39.4	41.4	42.7
23	44.6	44.6	42.6	38.7	34.4	31.4	31.1	33.7	37.3	40.1	42.1	43.6

AARI PCS Intercept values (nT) based on Vostok data 1995-2005. Coeff_beta.1M

HR	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
0	0.1	-1.4	-2.8	-3.5	-3.4	-3.1	-2.6	-1.8	-0.2	2.1	3.0	1.7
1	0.8	-0.8	-2.4	-3.3	-3.5	-3.2	-2.7	-1.8	0.2	2.9	4.0	2.6
2	0.8	-0.6	-2.2	-3.3	-3.7	-3.6	-3.0	-1.8	0.3	3.4	4.5	2.8
3	0.3	-0.8	-2.3	-3.5	-4.1	-4.1	-3.4	-2.0	0.3	3.4	4.4	2.4
4	-0.3	-1.4	-2.7	-3.9	-4.5	-4.5	-3.9	-2.5	-0.1	2.8	3.6	1.6
5	-1.0	-2.1	-3.4	-4.4	-4.9	-5.0	-4.5	-3.2	-1.0	1.7	2.3	0.7
6	-1.6	-2.7	-4.1	-5.0	-5.3	-5.4	-5.1	-4.0	-2.0	0.3	1.0	-0.2
7	-2.4	-3.5	-4.7	-5.5	-5.8	-5.8	-5.6	-4.8	-3.2	-1.4	-0.7	-1.4
8	-3.7	-4.4	-5.3	-6.0	-6.2	-6.3	-6.2	-5.7	-4.6	-3.4	-3.0	-3.2
9	-5.6	-5.5	-5.9	-6.4	-6.7	-6.8	-6.8	-6.6	-6.1	-5.6	-5.7	-5.7
10	-7.7	-6.8	-6.6	-6.9	-7.2	-7.2	-7.2	-7.4	-7.5	-7.7	-8.3	-8.4
11	-9.7	-8.2	-7.4	-7.4	-7.5	-7.5	-7.5	-8.0	-8.7	-9.6	-10.5	-10.7
12	-11.1	-9.4	-8.2	-7.8	-7.7	-7.6	-7.7	-8.5	-9.7	-10.8	-11.9	-12.1
13	-11.7	-10.2	-8.8	-8.1	-7.8	-7.6	-7.7	-8.7	-10.1	-11.3	-12.3	-12.5
14	-11.7	-10.5	-9.2	-8.3	-7.9	-7.6	-7.7	-8.6	-10.0	-11.1	-11.9	-12.2
15	-11.4	-10.4	-9.2	-8.3	-7.8	-7.6	-7.6	-8.4	-9.5	-10.4	-11.0	-11.5
16	-10.8	-10.1	-8.9	-8.0	-7.6	-7.4	-7.5	-8.0	-8.7	-9.2	-9.8	-10.5
17	-10.1	-9.7	-8.5	-7.5	-7.1	-7.0	-7.2	-7.5	-7.9	-8.1	-8.7	-9.6
18	-9.4	-9.2	-8.1	-7.0	-6.5	-6.5	-6.6	-6.8	-6.9	-7.1	-7.7	-8.7
19	-8.4	-8.4	-7.5	-6.5	-5.9	-5.7	-5.7	-5.7	-5.7	-5.9	-6.5	-7.6
20	-7.0	-7.3	-6.7	-6.0	-5.4	-5.0	-4.7	-4.5	-4.4	-4.4	-5.1	-6.1
21	-5.3	-5.9	-5.8	-5.4	-4.8	-4.3	-3.9	-3.5	-3.0	-2.8	-3.2	-4.2
22	-3.3	-4.3	-4.7	-4.7	-4.2	-3.7	-3.3	-2.7	-1.8	-0.9	-1.0	-2.1
23	-1.4	-2.6	-3.6	-4.0	-3.7	-3.2	-2.8	-2.1	-0.8	0.8	1.2	0.1