Invalid Polar Cap (PC) indices: Erroneous scaling parameters.

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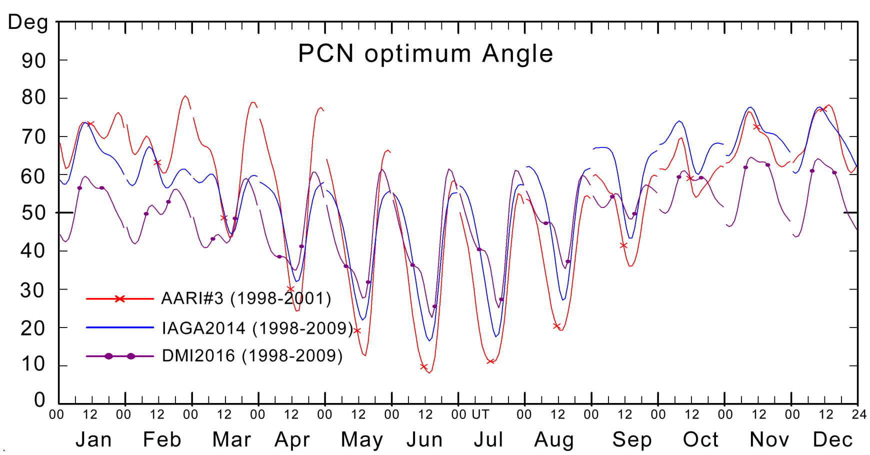
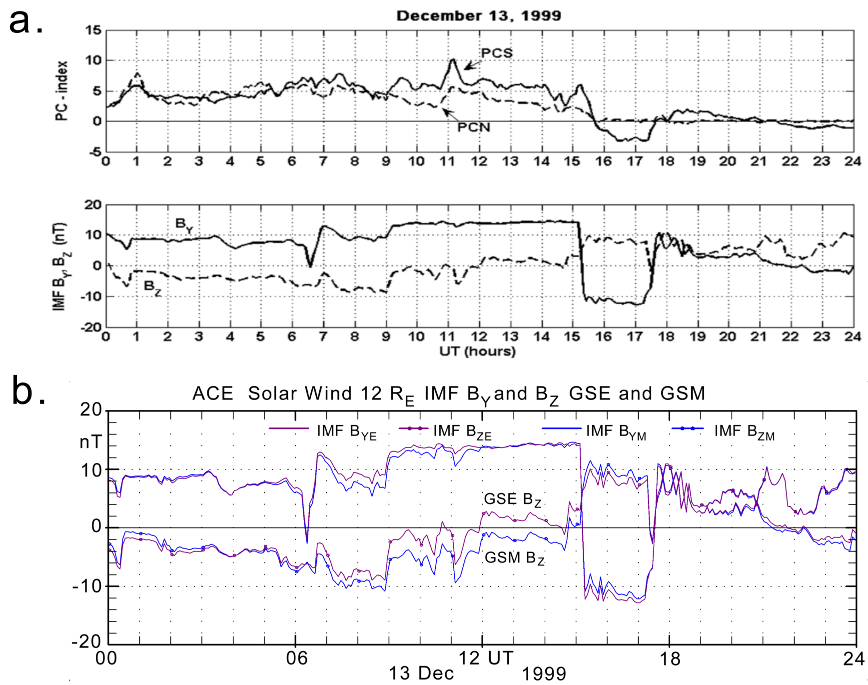
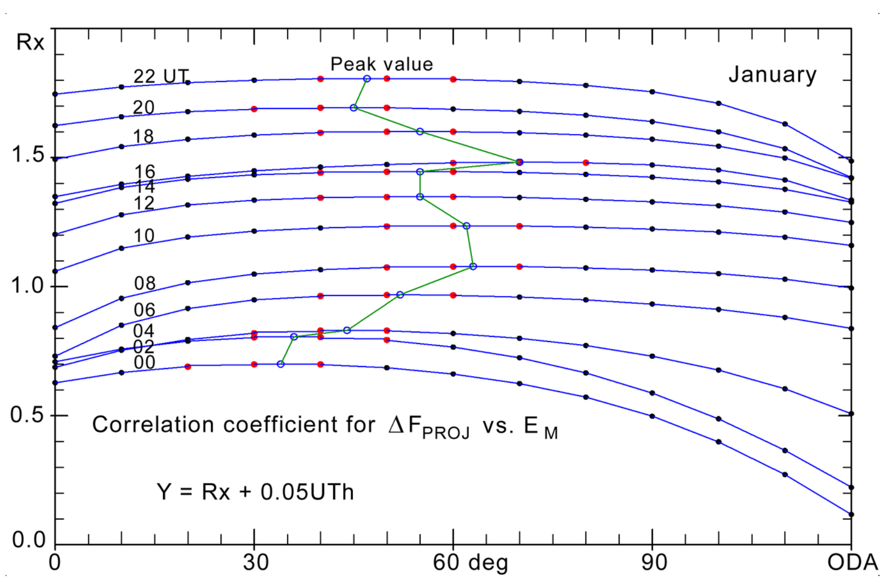
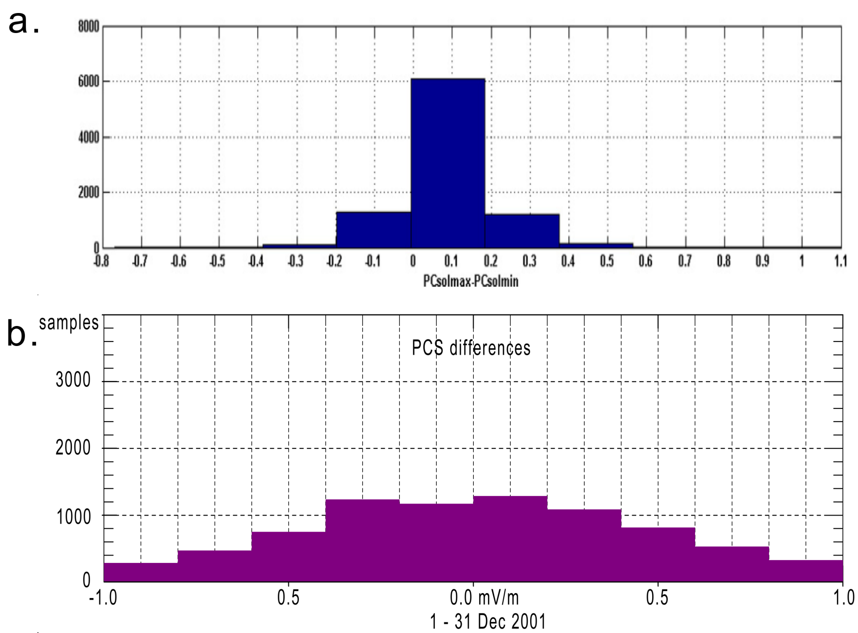
Abstract

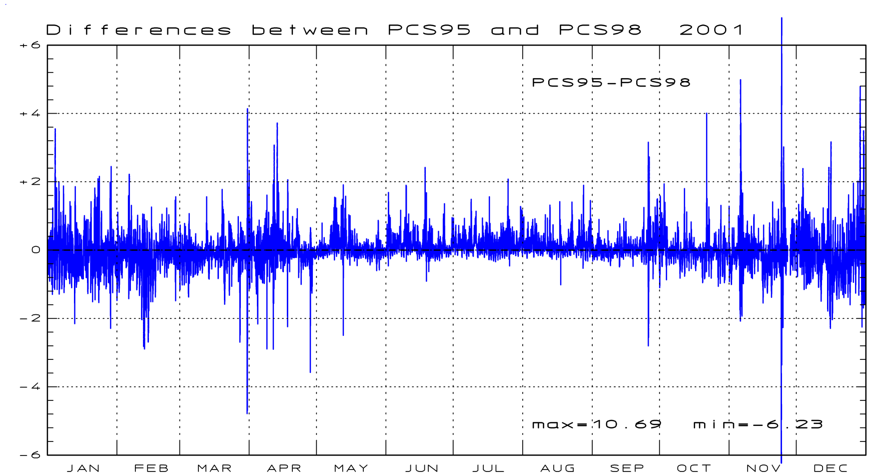
In the publication Troshichev et al. (2006) on the Polar Cap (PC) indices, PCN and PCS, an error was made by using components of the Interplanetary Magnetic Field (IMF) in their Geocentric Solar Ecliptic (GSE) representation instead of the prescribed Geocentric Solar Magnetospheric (GSM) representation for calculations of index scaling parameters. The mistake has caused a trail of incorrect relations and wrong conclusions extending since 2006 up to now (2020) which should be discontinued, for instance, by issuing a corrigendum note from the authors. The present contribution explains the error and discusses in an extended example its consequences for one of the publications that has referred to the invalid scaling parameter set. Further investigations reported here of the PC index versions recommended by the International Association for Geomagnetism and Aeronomy (IAGA) indicate occurrences of similar problems in the present derivation of index scaling parameters.




a.
December 13, 1999
PC - index
PCS
PCN
IMF B_Y, B_Z (nT)
B_Y
B_Z
UT (hours)
b.
ACE Solar Wind 12 R_E IMF B_Y and B_Z GSE and GSM
nT
IMF B_{YE}
IMF B_{ZE}
IMF B_{YM}
IMF B_{ZM}
GSE B_Z
GSM B_Z
12 UT
13 Dec
1999


Rx
Peak value
January
22 UT
20
18
16
14
12
10
08
06
04
02
00
Correlation coefficient for ΔF_{PROJ} vs. E_M
Y = Rx + 0.05UTh
60 deg
ODA


a.
8000
6000
4000
2000
0
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1
PCsolmax-PCsolmin
b.
samples
PCS differences
3000
2000
1000
0
-1.0
0.5
0.0 mV/m
0.5
1.0
1 - 31 Dec 2001


Differences between PCS95 and PCS98 2001
PCS95-PCS98
+6
+4
+2
0
-2
-4
-6
max=10.69 min=-6.23
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

31 May 2020

Invalid Polar Cap (PC) indices. Erroneous scaling parameters.

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Key points:

#1. Disclosure of invalid scaling parameters for Polar Cap (PC) index calculations.

#2. Analysis of related adverse consequences for derived publications on PC indices.

#3. Summary of publications devaluated by their use of inconsistent PC index versions.

Abstract. In the publication Troshichev et al. (2006) on the Polar Cap (PC) indices, PCN and PCS, 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 Magnetospheric (GSM) representation for calculations of index scaling parameters. The mistake has caused a trail of incorrect relations and wrong conclusions extending since 2006 up to now (2020) which should be discontinued, for instance, by issuing a corrigendum note from the authors. The present contribution explains the error and discusses in an extended example its consequences for one of the publications that has referred to the invalid scaling parameter set. Further investigations reported here of the PC index versions recommended by the International Association for Geomagnetism and Aeronomy (IAGA) indicate occurrences of similar problems in the present derivation of index scaling parameters.

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) .

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 Magnetospheric (GSM) representation have had grave consequences for the Polar Cap PCN and PCS index calibration parameters and index values. The GSE and GSM components of IMF differ by a rotation around the common 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.

The mistake is illustrated in Fig. 1 here where the IMF B_Y and B_Z components from Fig. 7 of TJS2006 are reproduced in Fig. 1a and compared to 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.

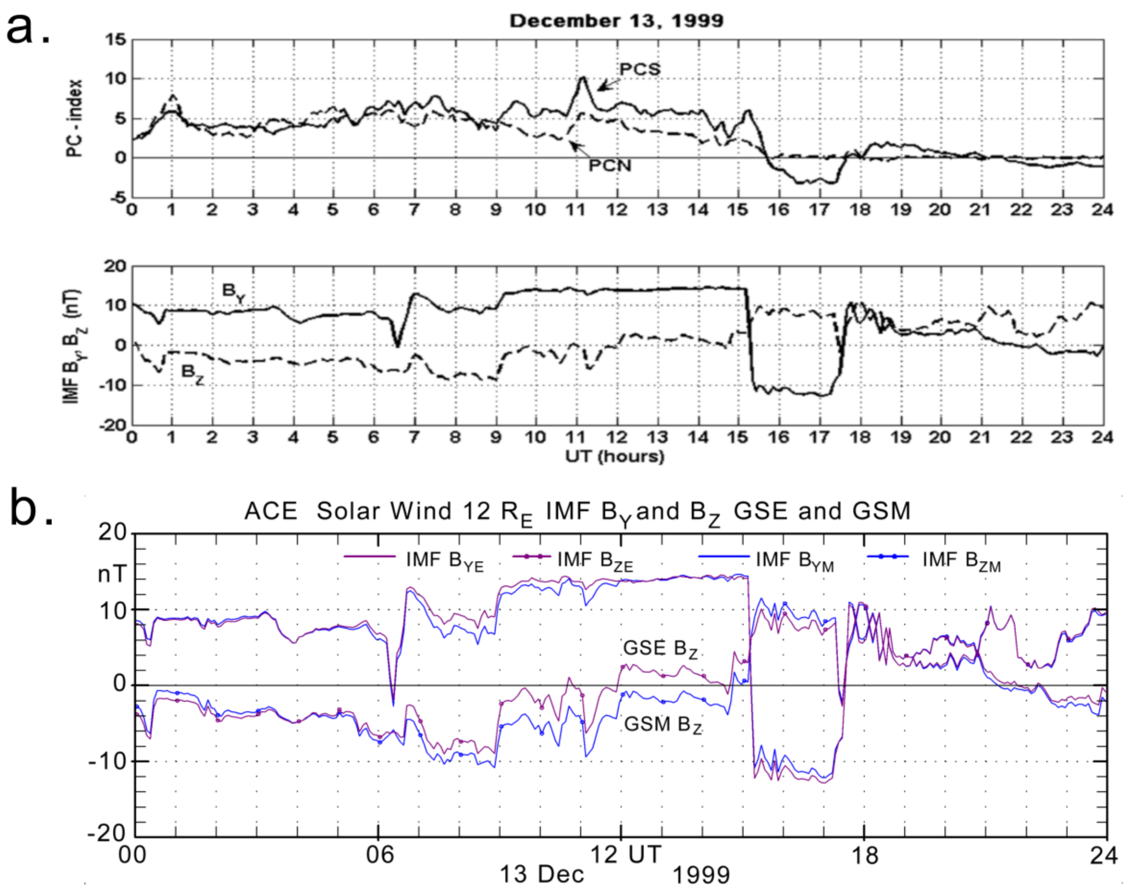

Figure 1. (**a**) IMF B_Y and B_Z components from Fig. 7 of Troshichev et al., 2006. (**b**) IMF B_Y and B_Z components in their GSE version (magenta line) and in their GSM version (blue line). The differences between GSE and GSM versions are most distinguishable between 12 and 14 UT.

The mistake has no strong impact on the remaining presentation of the PC index concept in TJS2006. Usually, such a mistake would be forgiven and forgotten 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 now (2020).

Thus, the calibration 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), in Troshichev (2017), and in the document Troshichev (2011) that forms the basis for the IAGA-recommended PC index versions (Matzka, 2014). Most recently, the TJS2006 publication and the incorrect results from the derived publication, Troshichev et al. (2011), have been referenced in a technical report, ISO/TR 23989 (2020-01), issued by the International Standards Organization (ISO).

The erroneous PC index scaling parameters derived from TJS2006 constitute the version AARI_1998-2001 usually named AARI#3 (McCready and Menvielle, 2010, 2011) which has been used in further publications. Thus, a corrigendum to TJS2006 should be published in order to caution against uncritical referencing to TJS2006 and to publications issued between 2006 and 2011 which may have used the AARI#3-based calibration parameters or derived PCN or PCS indices (see Stauning, 2013).

Corresponding problems with errors in the derivation of index scaling parameters have haunted the widely used PCN index version developed by Vennerstrøm (1991) and distributed until recently by the OMNIweb space data service. A further question of importance is whether the present PC index versions endorsed by the International Association for Geomagnetism and Aeronomy (IAGA) in their near-real time and final versions are reliable. A major obstacle for a thorough analysis of these index versions is the sparse amount of documentation of calculation methods. A survey of these problems is included in the discussion section.

2. Consequences of the error on scaling parameters for the PC indices.

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

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

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, the projection angle is defined by Eq. 2:

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

The optimal polar cap direction is characterized by its angle (φ) with the E-W meridian and derived from seeking optimal correlation between ΔF_{PROJ} and E_M. The calibration parameters are derived from regression to make the average PC indices equal to averages of E_M values throughout an extended epoch of archived data. All parameters are derived from relations with 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 TJS2006, the derived PCN and PCS calibration parameters (φ, α, β) are presented in the colour coded diagrams in their Fig. 3, which is reproduced here in Fig. 2 for convenience.

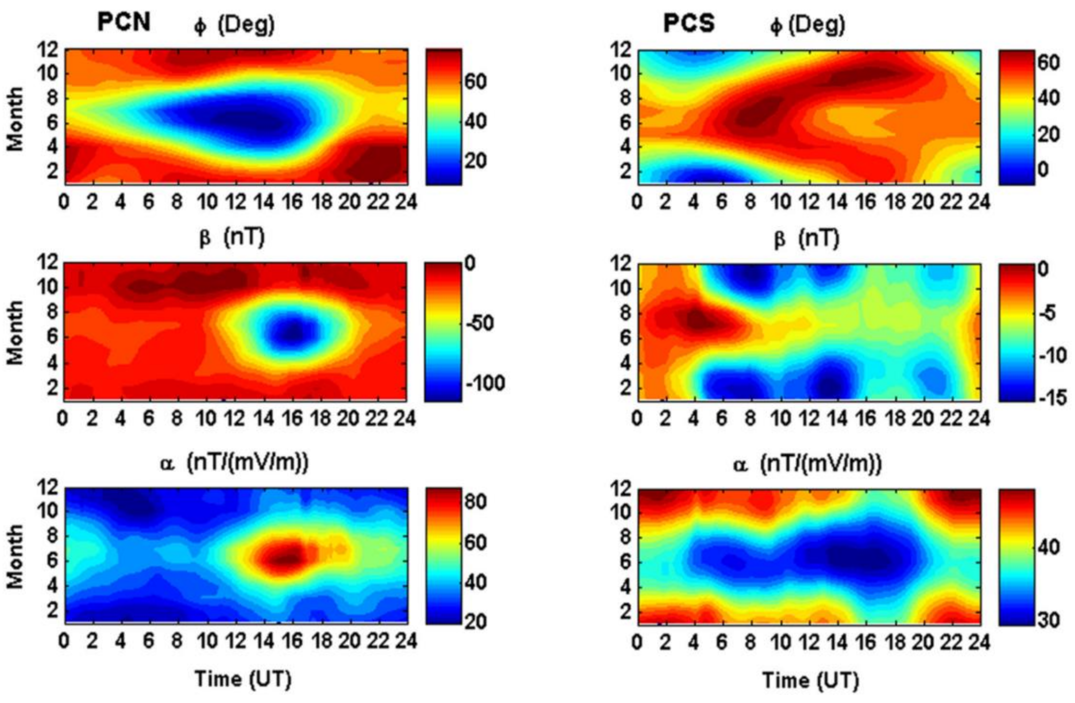

Figure 3. Angle ϕ and coefficients α and β used for calculation of the unified PCN and PCS indices derived on the basis of magnetic data from Thule and Vostok stations for 1998–2001.

Fig. 2. Reproduction of colour-coded displays of PC index calibration parameters from TJS2006.

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, which 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 representation is found in the optimum direction assumed perpendicular to the dominant flow direction.

In the derived publication, Troshichev et al. (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. These values are considered to represent PCS scaling parameters for a solar maximum epoch. The figure has also a column (left) for the calibration parameters in 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 presents calibration parameters based on the solar minimum years 1997+2007-2009, here named version AARI_1997+2007-2009 taken to represent solar minimum scaling parameters.

A problem for the analysis of possible effects of the invalid PCS scaling parameters derived in TJS2006 from using IMF components in their GSE representation is the unavailability of files of the parameters. Requests for access to such files have remained unanswered.

Instead, the colour-coded diagrams have been read-off to be converted to numerical files. Actually the readings of PCS calibration 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 where the colour coding has been supplemented by contour curves, which facilitates the reading of values.

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. 3 here. The magenta curves in Fig. 3 presents PCS optimum angle values for version AARI_1995-2005 (AARI#4) provided in a file from AARI.

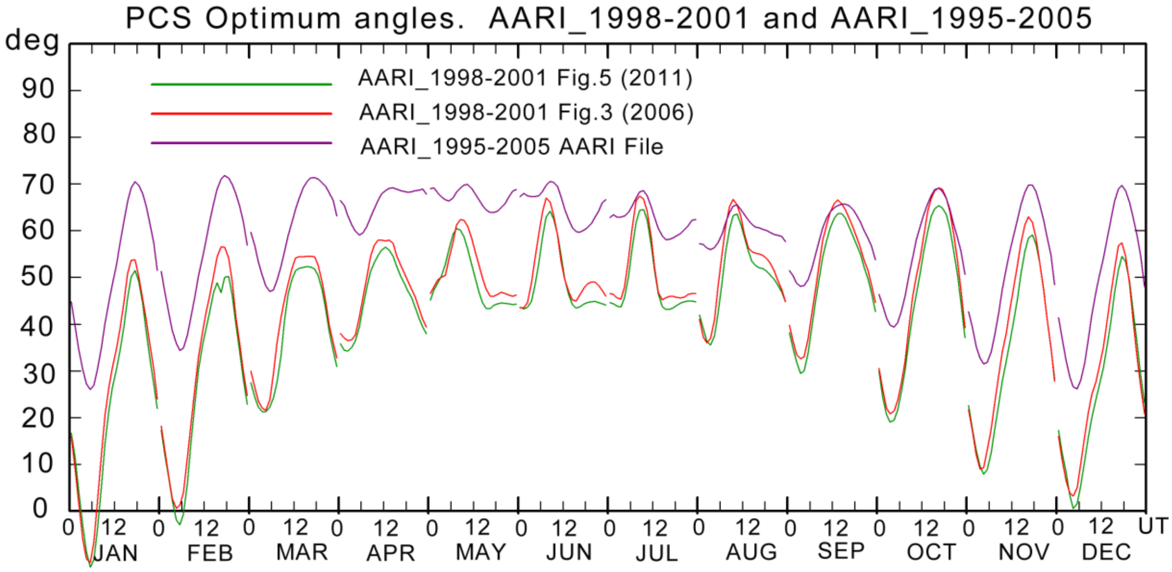

Fig. 3. Reading of the optimum angles for the PCS coefficients in version AARI_1998-2001 (AARI#3) from the diagram in Fig. 5a of Troshichev et al. (2011) in green line and those from upper right diagram of Fig. 3 from Troshichev et al. (2006) in red line. Optimum angles in a numerical file for the PCS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

For each of the 12 monthly sections of Fig. 3, 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) scaling parameters are also affected by the erroneous use of IMF components in the GSE representation in TJS2006. When applied to calculations of PC indices 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) versions. An example of differences in the PCS calculations is presented in Fig. 4.

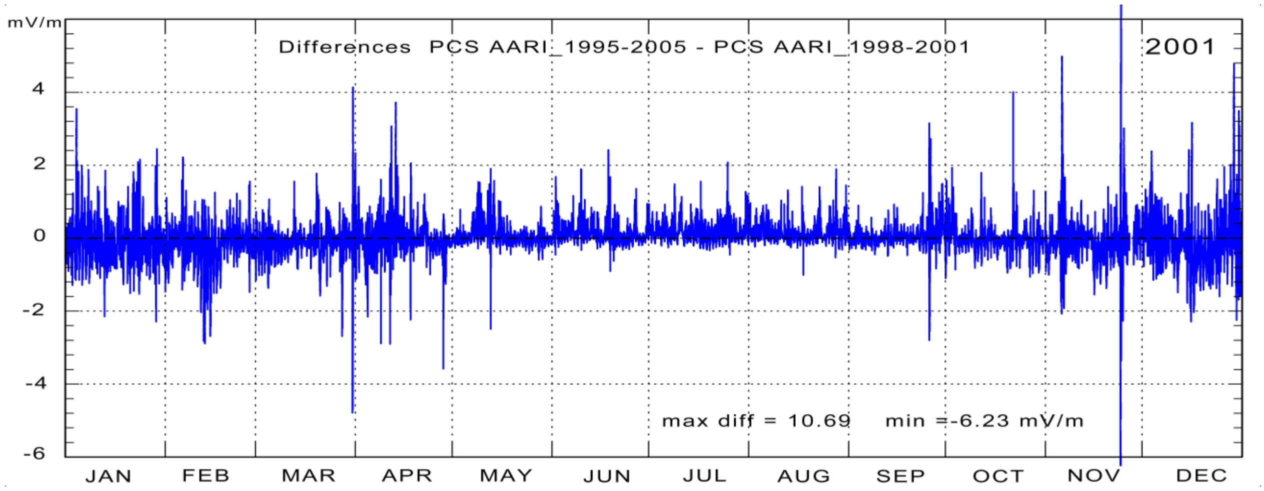

Fig. 4. Differences between PCS values derived with solar cycle average scaling parameters in the AARI_1995-2005 (AARI#4) GSM-based version and PCS values derived with GSE-based calibration parameters in the AARI_1998-2001 (AARI#3) version.

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. 4.

The erroneous PC index values might have affected individual cases used, for instance, in 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 transformation is expected to invalidate statistical investigation 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.

3. Use of the GSE-based scaling parameters in further publications.

First and corresponding author of TJS2006, Dr. Oleg A. Troshichev, has consistently maintained in discussions and mail exchanges that the differences between the GSE-based version AARI_1998-2001 published in 2006 and the more recent GSM-based version AARI_1995-2005 are minute. Thus, in his opinion there should be no point in naming the latter version AARI#4 to distinguish it from the AARI#3 version from 2006 named so by McCready and Menvielle (2010, 2011). Dr. Troshichev has been supported in his view by the examinations reported in Troshichev et al., 2011 (TPJ2011): “Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field", published in Annales Geophysicae, 29, 1479-1489, 2011. https://doi.org/10.5194/angeo-29-1479-2011 .

In TPJ2011 the AARI#3 PCS calibration parameters have been displayed in their Fig. 5 (left column) providing a copy of the colour-coded diagrams in the right column of Fig. 3 of TJS2006 for version AARI_1998-2001 (AARI#3). This version is taken to represent solar maximum scaling parameters while the parameters in the right column of their Fig. 5, version AARI_1995-2005 (AARI#4), are taken to represent solar cycle averages. The PCS scaling parameters in the middle column of their Fig. 5 are based on solar minimum years 1997 and 2007-2009 and are taken to represent solar minimum parameters.

The investigations reported in their Figs. 6, 7, and 8 indicate that the PCS index values derived by using the "solar max" parameters of the AARI#3 version from 2006 are very close ("*within 10%*") of 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 mistake, the AARI#3 calibration parameters in version, AARI_1998-2001, from TJS2006 are not at all used in the reported examinations. It has not been possible to deduce the origin of the scaling parameters actually used for two PCS versions being compared in TPJ2011.

3.1. The QDC issue.

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 was meant to provide basis for a discussion of the importance of using QDC correction of the observed magnetic data at calculations of PC scaling parameter and index values. The diagrams of their Figs. 1a, b, c display daily variation of the angle, φ, the slope of the regression line, α, and the intersept, 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.*"

There are two essential problems with their Fig. 1. The "with QDC" curves are not derived from the AARI_1998-2001 (AARI#3) version from TJS2006. They are from the AARI_1995-2005 (AARI#4) scaling parameter version. Furthermore, the "without QDC" curves are not derived from calculations of scaling parameters without using QDCs but of unknown origin.

The examination here is based on readings of the values presented in the diagrams of Fig. 1 and Fig. 5 of TPJ2011 in the absence of available numerical files from AARI for other than the AARI_1995-2005 (AARI#4) scaling parameter values. The different versions of the PCS optimum angle parameter (φ) are compared in Fig. 5 here.

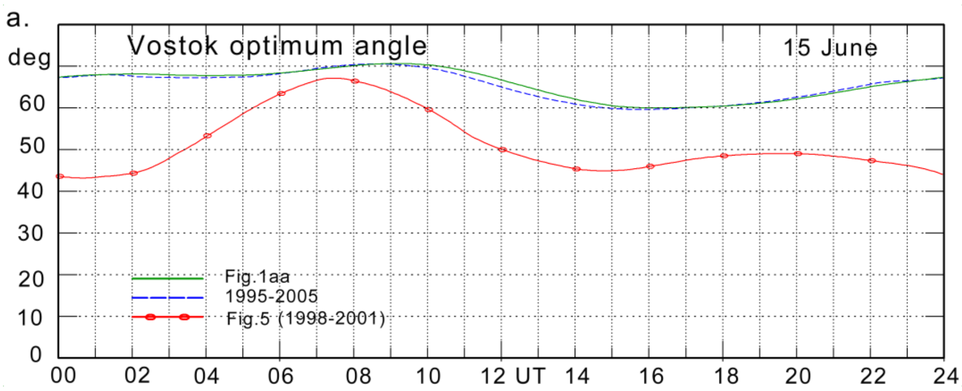

Fig. 5. Vostok optimum angles on 15 June. Angles read from Fig. 1aa of Troshichev et al., 2011 (green line). Angles from AARI file (Coeff_fi.1M, 21-06-2011), version#4, epoch 1995-2005, in blue, dashed line. Angles read from the left column of Fig. 5 (version#3, epoch 1998-2001) in red line with dots.

From Fig. 5 it is seen that the plot of the PCS optimum angles from the numerical file for AARI_1995-2005 version (blue dashed line) is very close to the plot in green line of the "with QDC" curve in Fig. 1a of TPJ2011. However, it is (incorrectly) specified in the text quoted above that the curves in Fig. 1 were derived from "*magnetic data from Vostok for 1998-2001*".

Thus, it appears evident that the "with QDC" optimum angle curve (green) in Fig. 1a of TPJ2011 represents the AARI_1995-2005 (AARI#4) version (blue, dashed) and not the AARI_1998-2001 (AARI#3) version. The optimum angles from the AARI_1998-2001 (AARI#3) version (red, dots) differ by up to 25° in June month from the other two optimum angle versions (cf. Fig. 3 here).

Corresponding to the presentation of the PCS optimum angles in Fig. 5, the slope coefficients have also been read-off from the display in Fig. 1b of TPJ2011 and from the colour-coded diagram in their Fig. 5. The slope parameters for June are displayed in Fig. 6 here. The values read from Fig. 1 of TPJ2011 are shown in green line, those from Fig. 5 of TPJ2011 in red line with dots. The values from the AARI_1995-2005 (AARI#4) file are displayed by the dashed blue line.

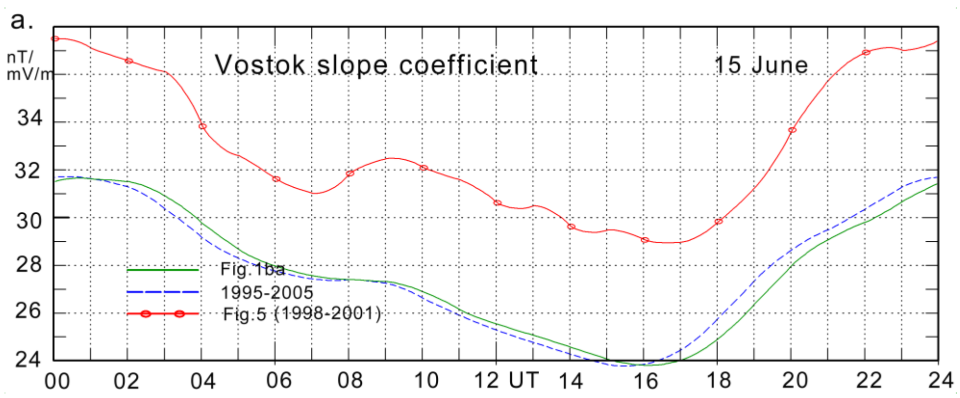

Fig 6. Vostok slope coefficients 15 June (with QDC). Slope values read from Fig. 1b of Troshichev et al., 2011 in green line. Slope values from AARI file (Coeff_alpha.1M, 21-06-2011), epoch 1995-2005, in blue dashed line. Slope values read from left column of Fig. 5 (epoch 1998-2001) in red line with dots.

The display in Fig. 6 confirms the inference from Fig. 5 that the "with QDC" calibration parameter values in their Fig. 1 (against their statement) are taken from the AARI_1995-2005 (AARI#4) version and not from the AARI_1998-2001 (AARI#3) version published in TJS2006.

For the data displayed in thin blue line in their Fig. 1a it is stated in p. 1484 of TPJ2011, as quoted above, that they present PCS optimum angles derived from the same data but without using QDC correction. However, it is seen at a glance that this could not be correct. Optimum angle values are derived by searching 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) 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 from the TPJ2011 authors of the real origin of the "no QDC" curves or to deduce their derivation from available data.

The slope values (α) for the "with QDC" and "without QDC" cases should also be nearly the same since the magnetic disturbance data samples used for the regression line are all displaced (parallel-shifted) by the same QDC-related amount. The intercept values will change by this amount (see Stauning, 2013).

Further examples of values read from the "with QDC" curves in Fig. 1 from TPJ2011 and corresponding calibration parameter values derived from readings of their Fig. 5 and from values of the available file derived from GSM-based calculations with data from epoch 1995-2005 are presented in Appendix A. They have confirmed beyond doubt that the "with QDC" values have been extracted from the AARI_1995-2005 (AARI#4) version and not, as claimed, from the AARI_1998-2001 (AARI#3) version from TJS2006. It has not been possible to deduce the origin of the "without QDC" curves in the diagrams of Fig.1.

Appendix A presents PCS scaling parameters derived with a "DMI" program (Stauning et al., 2006) where the QDC correction can be switched in and out without affecting other steps in the calculations. With these parameters and with Vostok magnetic data supplied from INTERMAGNET, the PCS values with and without QDC involvement have been calculated for comparison with the displays in Figs. 2 and 3 of TPJ2011. An example for 15 June 2002 is presented in Fig. 7 here.

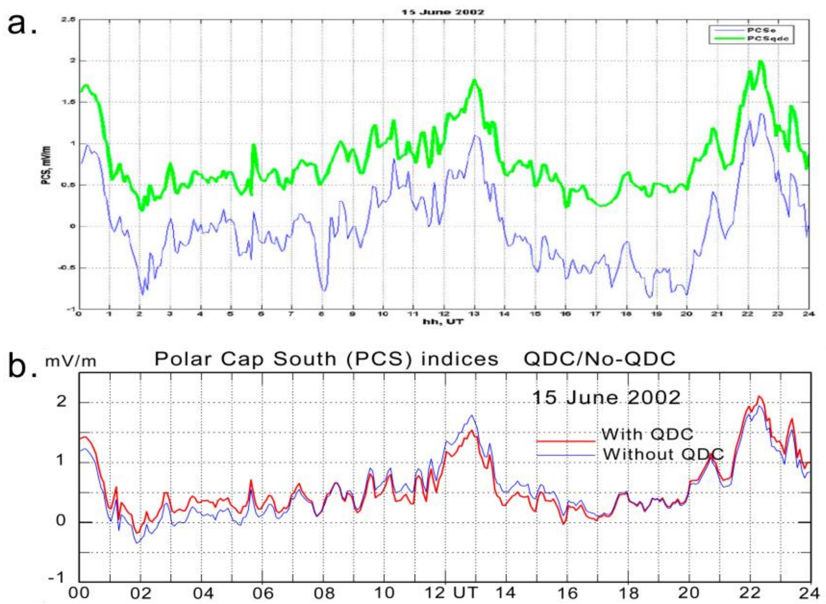

Fig. 7 PCS indices calculated with/without QDC. (a) Top field: PCS index values derived by Troshichev et al. (2011) for 15 June 2002 (copy of their Fig. 2a). (b) Lower field: Recalculation for 15 June 2002.

It is evident from comparing Figs. 7a and 7b that the differences between the "with QDC" and the "without QDC" cases have been substantially reduced in the recalculations. Actually, the devotees of the Vennerstrøm (1991) PC index calculation method (without QDC) and the AARI method (with QDC) in the yearlong struggle have missed the point that an epoch-average QDC correction is built into the intercept (β) scaling parameter as explained in Stauning (2013).

Appendix A, furthermore, presents a comparison of the with/without QDC PCS values in Fig. 2b of TPJ2011 with corresponding re-calculated values and also a comparison of the differences in PCS values derived with/without QDC throughout the year 2002 leading to the same conclusion. The "without QDC" values of unknown origin displayed in Fig. 1 of TPJ2011 are incorrect as deduced "at a glance" from their appearance and generate unreasonably large differences between PC index values derived with and without QDC involvements.

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

For the differences in PCS values displayed in Figs. 6, 7, and 8 of TPJ2011, the readings of the "solar max" scaling parameters from Fig. 3 of TJS2006 (or Fig. 5 of TPJ2011) have been supplemented by readings of the "solar min" scaling parameters in version AARI_1997+2007-09 from the middle column of diagrams in their Fig. 5. With these parameters and Vostok magnetic data supplied from Intermagnet, the corresponding PCS index values have been calculated for these cases. Further details are presented in Appendix A. Here, Fig. 8 presents a reproduction of their Fig. 7c with statistics on the PC indices for December 2001 and the corresponding statistical results from re-calculations. The QDCs used for the two set of PCS calculations whose differences are presented in Fig. 8b are the same and would not affect the results much.

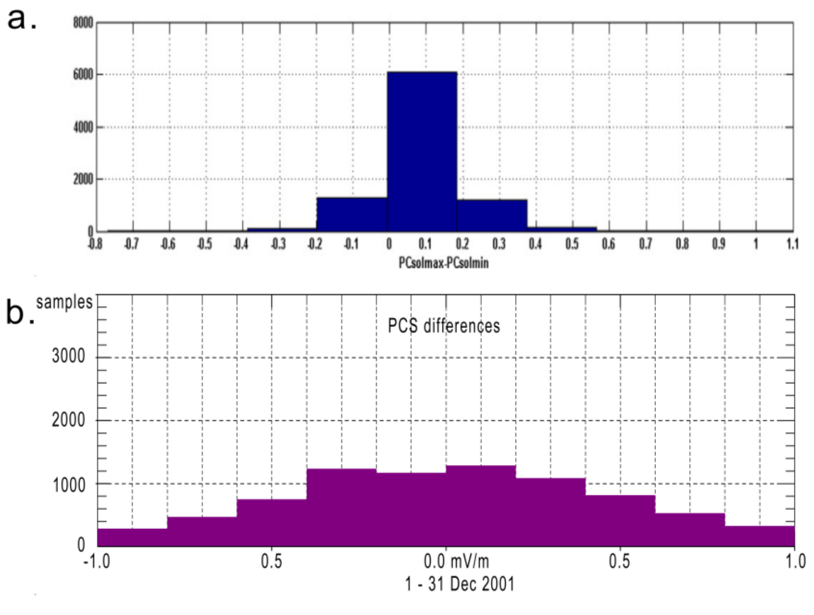

Fig. 8. Display of differences between PCS index values for December 2001 calculated with epoch 1998-2001 calibration parameters and with epoch 1997+2007-2009 calibration parameters, respectively. (a) Copy of Fig. 6a from TPJ2011. (b) Re-calculations using readings of scaling parameters from Fig. 5 of TPJ2011.

It is seen from Fig. 8b here that the differences between PCS index values calculated by using AARI_1998-2001 (AARI#3) and AARI_1997+2007-2009 scaling parameters are not at all as minute as shown in Fig. 8a (copy of Fig 6c of TPJ2011). There is a broad range of cases with differences up to and beyond 1 mV/m.

It has not been possible to deduce the origin of the scaling parameter sets used for 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.

Specific differences for June and November 2001 between PCS indices calculated by using AARI_1998-2001 and AARI_1995-2005 calibration parameters, respectively, are included in Appendix A. In all cases the differences between PCS indices calculated by using AARI_1998-2001 (AARI#3) and AARI_1995-2005 (AARI#4) calibration parameters massively exceed the values presented in Figs. 6, 7, and 8.

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

4. IAGA-endorsed PC index series

The investigations of scaling prameters have been extended to the PC index series endorsed by IAGA by Resolution #3 (2013). This section shall focus on the optimum direction angle (φ). This parameter can be calculated directly from the publicly available ground and space data. Version-specific features such as QDC involvement are unimportant. The scaling coefficients (φ,α,β) in the versions endorsed by IAGA have been provided at the AARI web site (http://pcindex.org). Optimum angle values have been re-calculated based on magnetic data from Qaanaaq (THL) derived from the INTERMAGNET web portal (http://intermagnet.org) and solar wind and IMF data supplied from NASA GSFC OMNI data service at http://omniweb.gsfc.nasa.gov). These values (PCN DMI version) are presented in Fig. 9 along with the IAGA-endorsed PCN optimum angle values and the values from the AARI_1998-2001 (version#3) PCN scaling parameter file issued in 2006.

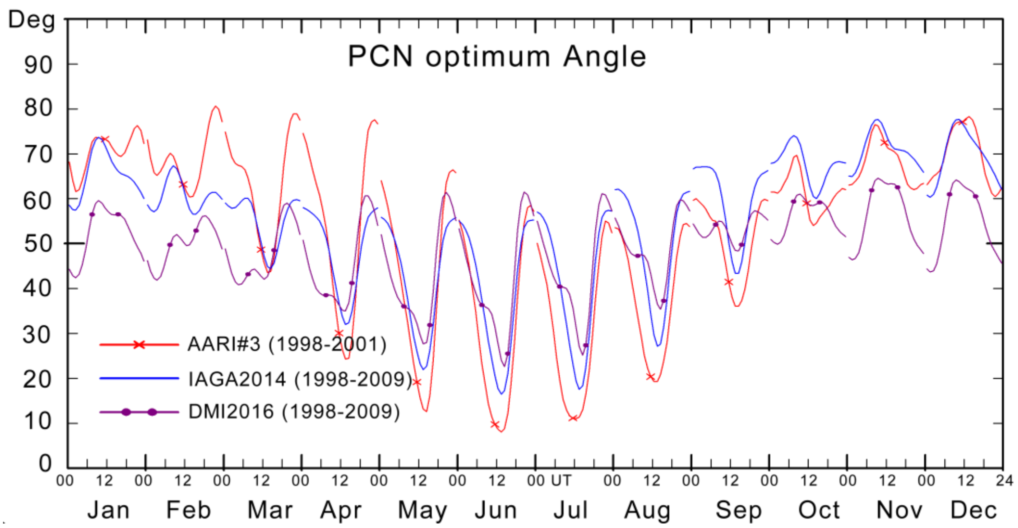

Fig. 9. PCN optimum angle (φ) values from AARI_1998-2001 (version#3, 2006) in red line. IAGA-endorsed values (IAGA2014) in blue line. Recent calculation (DMI2016) in magenta line.

Note in Fig. 9 the large differences by up to 30° between the AARI#3 (red line) and IAGA2014 (blue) versions, which are comparable to corresponding differences between PCS versions AARI_1998-2001 (version#3) and AARI_1995-2005 (version#4) illustrated in Fig. 3.

Note also the large differences by up to 25° between the IAGA2014 version and the DMI2016 (magenta line) versions. These differences are remarkable since the optimum angle values are calculated from the same geomagnetic and solar wind data and (in principle) using the same methodology.

The method is illustrated in Fig. 10 for January. In steps of 10° for a test optimum angle value (ODA) the coefficient of correlation (Rx) between E_M and ΔF_{PROJ} is calculated for each hour of this month using data from the epoch 1998-2009. These values are displayed by the dots placed according to the test angle values on the horizontal axis and connected by the blue line in Fig. 10. For 00 UT the Rx values can be read on the vertical scale. Subsequent values are displaced upward by adding 0.05 to the correlation coefficient value for each hour in UT for separation of curves. In the series of correlation values for each UT hour, the maximum value is found. This value and the neighbouring two values are marked by the red dots in Fig. 10. The three points are used to define a connecting parabola with vertical axis. The precise maximum correlation and optimum angle values are derived from the top of the parabola here marked by an open circle. For illustration these points are connected by a broken line (in green).

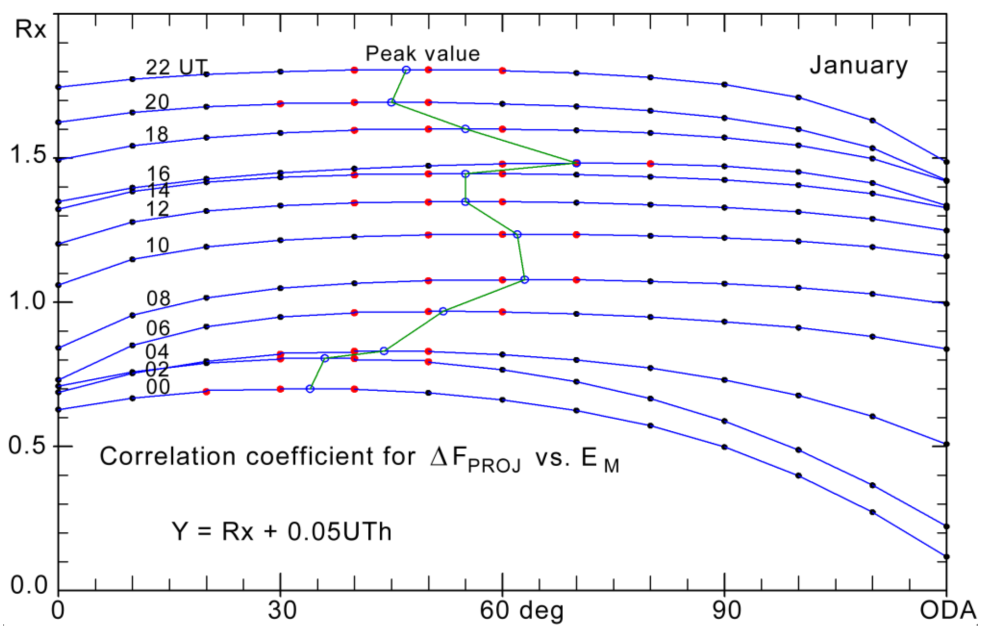

Fig. 10. Illustration of the method to derive values of the PC optimum angle parameter from optimizing the correlation between E_M and ΔF_{PROJ}.

In further steps the values are processed by bivariate smoothing over hours and months and combined interpolation in order to provide detailed values throughout the year.

Documentation of the calculations of IAGA2014 scaling parameters at AARI is not available. The DMI version is documented in pp. 31-35 of Stauning (2016). In the standard DMI version (Stauning, 2016) the magnetic disturbance values are measured from a reference level built from quiet daily variation (QDC) added to the secularly varying base level. Solar wind OMNI values composed from the mix of data from the ACE, IMP, WIND, and GeoTail satellites are used. The solar wind and IMF data are bow shock nose (BSN) values where the delays from the satellite to the

BSN position at around 12 Earth Radii (Re) is accounted for. From the BSN position and to the related effects on the polar cap convection the average delay is 18.8 min according to the analysis in Stauning (2016). A value of 20 min is subsequently used throughout in regression calculations. The data are screened to avoid samples taken during NBZ conditions by omitting cases where IMF B_Z > ABS(IMF B_Y) + 3 nT.

Fig. 11 presents displays (red line) of the optimum direction angles (IAGA2014) provided by the IAGA-endorsed coefficient file derived by AARI and several versions of DMI2016 optimum angles derived with different special modifications in order to see whether the considerable differences of up to 25° between the IAGA2014 and DMI2016 optimum angles could be explained.

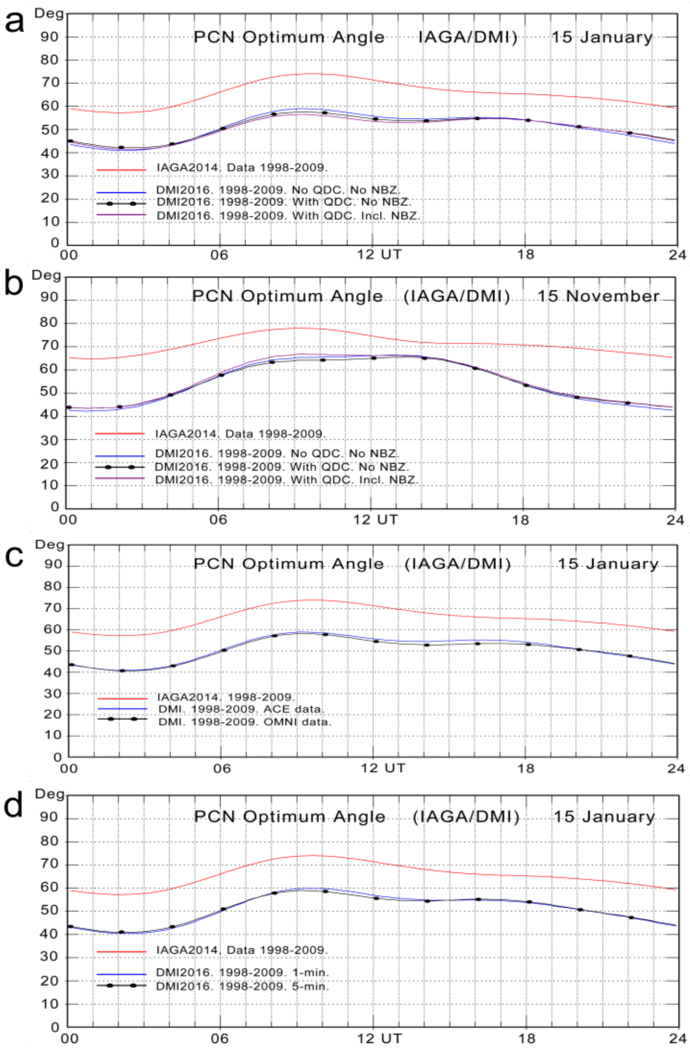

Fig. 11. Daily variations in optimum angle (φ) in IAGA2014 version (red line) and (a) OMNI- based DMI versions without (blue) and with QDC (black with dots) and incl. NBZ samples (magenta) for mid-January. (b) Daily optimum angle variations like Fig. 11a but for mid-November. (c) DMI versions based exclusively on 5-min ACE data (blue) and 5-min OMNI (all satellites) data (black with dots). (d) DMI versions based on 1-min (blue) and 5-min samples (black with dots)

It is seen from Fig. 11a that the use of QDC and the exclusion of NBZ samples have minor effects only on the optimum angle values. The QDC values, by their definition, refer to cases where the solar wind effects are minimal. Thus, they could not affect the correlation of solar wind and related geomagnetic data in any systematic way. The NBZ cases would generate contributions to correlation samples in directions opposite of the resulting optimal direction determined from the majority of samples. Thus, the inclusion of NBZ samples is of minor importance since the definition of optimum angle values is by maximum correlation and not by averaging.

From comparing Fig. 11a with Fig. 11c it is seen that the choice between ACE data (exclusively) and OMNI data (that may include ACE observations) makes no difference. From Fig. 11d it is seen that using 1-min or 5-min satellite and ground data samples in the correlations creates minor differences only.

In a further attempt to understand the differences between the IAGA2014 and DMI2016 optimum angles, an amount, ΔODA, varying between 0° and 30° was subtracted from the IAGA2014 optimum angles and the correlation coefficients (Rx) between E_M and ΔF_{PROJ} were re-calculated. For January optimum correlation was obtained at ΔODA=18° (cf. Fig. 11a), while for November optimum correlation was reached for ΔODA=15° (cf. Fig. 11b). In both cases the modified IAGA2014 optimum angles came very close to the DMI2016 optimum angle values.

5. Discussions

5.1. Troshichev et al., 2011.

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 be reported directly to the scientific community. There can be no question that the mistake 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 (mail to Troshichev) 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). A suggestion to issue a corrigendum to TJS2006 has been rejected by the corresponding (first) author.

The stated main purpose of TPJ2011 was to demonstrate the invariability of PC index calibration 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 calibration parameters, 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 calibration 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" version is definitely not presenting results 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 the 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) calibration 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 the conclusion drawn from documented errors in TPJ2011.

These concerns have been forwarded to the authors and to the reviewers of TPJ2011 in 2018 but have remained unanswered. A thorough assessment of the TPJ2011 article was sent to the Editorial Board of Annales Geophysicae on 30 August 2018 but dismissed without evaluation of the criticism. A commentary manuscript was submitted to the Annales Geophysicae Journal in February this year (2020) but rejected by the editor(s) without independent review.

5.2. Consequences of invalid PC index versions.

The erroneous scaling coefficients in AARI version #3 have been used to calculate PC index values used in several publications (see list (i) below) since 2006. It should be mentioned that the widely used PCN index version developed by Vennerstrøm (1991) and distributed from the OMNIweb space data service (http://omniweb.gsfc.nasa.gov) has also been haunted by errors in the calculations of index calibration parameters. Thus, PCN indices were calculated since 1991 (list ii) by a program holding a software error. The PCN series was recalculated by Papitashvili in 2001 (see Papitashvili et al., 2001). However, it was later found that the scaling parameters suffer from an invalid regression (Stauning, 2013) and this index version (list iii) was abandoned in 2014.

Thus, these 38 publications (for complete references see Stauning, 2013) have one feature in common. They are based on PC index versions now recognized being invalid and abandoned.

(i): *Troshichev et al.* [2006], *Janzhura et al.* [2007], *Troshichev et al.* [2007], *Troshichev and Janzhura* [2009], *Troshichev et al.* [2011].

(ii): Chun et al. [1999], Nagatsuma et al. [1999], Nagatsuma et al. [2000], Papitashvili andRasmussen [1999], Takalo and Timonen [1998a, 1998b,1999], Troshichev et al. [1991], Trochichevet al. [1996], Vassiliadis et al. [1996], Vennerstrøm [1991], Vennerstrøm et al. [1991, 1994].

(iii): *Chun et al.* [2002], *de Campra and Artigas* [2004], *Fiori et al.* [2009], *Gao* [2012], *Gao et al.* [2012a, 2012b, 2012c], *Henderson et al.* [2006], *Huang* [2005], *Johnsen and Lorentzen* [2012], *Lee et al.* [2004], *Liou et al.* [2003], *Liou et al.* [2004], *Lukianova* [2003, 2007], *Lukianova et al.* [2002], *Nagatsuma* [2002a, 2002b], *Nagatsuma et al.*, [2003], *Ridley and Kihn* [2004].

5.3. The IAGA-endorsed PC index series.

For the present IAGA-endorsed PCN and PCS index series distributed from the AARI web site (http://pcindex.org) and the web portal for the International Service of Geomagnetic Indices (ISGI) at http://isgi.unistra.fr the available documentation is sparse. The calculation of post-event ("final") PCN values from using the AARI2014 scaling parameter set is described in the documents by Matzka (2014) and Nielsen and Willer (2019). The calculations are based on the methods defined in TJS2006, TPJ2011, and also in Janzhura and Troshichev, 2011 (J&T2011) now being discussed elsewhere (Stauning, submitted, 2020). However, the available documentation does not comprise the derivation of the IAGA2014 scaling parameters.

The calculations of index scaling parameters reported here have not been able to confirm the IAGA2014 optimum angle parameters in spite of the use of the same space and ground data sets as those presumably used at AARI. The diversions such as the use or no use of QDC, choice of satellite data source, sample duration, and NBZ screening have failed to explain the considerable differences seen in Figs. 9 and 11a-d. One consistent feature in the displayed differences is the systematically larger values by 15-25° in the IAGA2014 optimum angles over the DMI values during the winter months. This difference was confirmed in section 4 by the resulting optimal correlation derived as the IAGA optimum angles were reduced by 15-20°. The calculations of the slope (α) and intercept (β) parameters rely on valid optimum angle (φ) values. Without full documentation of the calculations at AARI of PCN scaling coefficients, the IAGA2014 coefficient values should be considered questionable.

For the PCS index series there is no documentation beyond TJS2006 while for the near-real time PCN and PCS indices there is no documentation beyond TJS2006 and J&T2011 and there is no published validation of methods. I am aware that Dr. Troshichev argues that his many results provide sufficient validation of his PC index derivation scheme.

However, it is surprising that IAGA accepts the sparse documentation considering their " *Criteria for endorsement of indices by IAGA* ", in particular the statement: " *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*".

Conclusions

- It is suggested that the Journal of Geophysical Research publishes a Corrigendum note to be referenced in the internet version of the original article, Troshichev et al., 2006. A draft corrigendum note has been sent to the corresponding author, Dr. O. A. Troshichev, but has not been responded to. The proposed text for the note is:

“In the article, Troshichev, O.A., A. Janzhura, and P. Stauning (2006): Unified PCN and PCS indices: Method of calculation, physical sense, and dependence on the IMF azimuthal and northward components, *J. Geophys. Res.*, *111*, A05208, doi: 10.1029/2005JA011402, by mistake, the Interplanetary Magnetic Field (IMF) components B_Y and B_Z were used in their Geocentric Solar Ecliptic (GSE) version instead of the devised Geocentric Solar Magnetospheric (GSM) version in the calculation of PC index scaling parameters. The incorrect parameter sets are displayed in the colour-coded diagrams in Fig. 3 of the article. The remaining part of the article is not much affected by the incorrect scaling parameters. However, this parameter set, now named AARI#3 version, based on data from epoch 1998-2001, have been used in further publications issued between 2006 and 2011. Thus, we should caution against uncritical use of relations and conclusions published in papers that may have used the invalid AARI#3 version of scaling parameters and derived PC index values”.

- The publication: 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, 2011. https://doi.org/10.5194/angeo-29-1479-2011, holds erroneous illustrations in its Figs. 1, 2, 3, 6, 7, and 8 and conveys non-substantiated conclusions. This publication would need a comprehensive corrigendum in order to sustain the credibility of the authors and the Journal.

- It is suggested that IAGA requests full documentation of applied methods and index calculation software from approved PC index suppliers in agreement with sec. 2 of their “*Criteria for endorsement of indices by IAGA*”

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 remain 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, 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 included in the appendix. Tables of hourly mean values of the calibration coefficients from AARI files (Parameters2011.rar, 21-06-2011), for epoch 1995-2005 are also included.

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, 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.

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

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Troshichev, O. A., Janzhura, A. S., Stauning, P. (2006): 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.

Troshichev, O. A., Janzhura, A. S., Stauning, P. (2009): Correction to "Unified PCN and PCS indices: Method of calculation, physical sense, and dependence on the IMF azimuthal and northward components", *Journal of Geophysical Research*, 114, A11202. https://doi.org/10.1029/2009JA014937 .

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, 2011. https://doi.org/10.5194/angeo-29-1479-2011 .

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Appendix A: (for the Review process only)

Authentication of critical comments on: Troshichev et al.:Invariability of relationship between the polar cap magnetic activity and geoeffective interplanetary electric field, doi:10.5194/angeo-29-1479-2011.

1. Introduction.

Much of past reported scientific analyses on the relations between PC indices and magnetic disturbances such as polar magnetic variations, magnetic storms and substorms, and ring current enhancements, have been based on the PCN and PCS index versions developed at the Arctic and Antarctic Research Institute (AARI) in St Petersburg, Russia and defined in Troshichev et al. (2006).

The analysis of the publication, Troshichev et al. (2011) presented here, has disclosed that the PCN and PCS index calibration parameters presented in Troshichev et al. (2006), e.g. in their Fig. 3, and usually designated AARI#3 version (McCreadie and Menvielle, 2010, 2011) have been derived incorrectly by being referenced to the interplanetary magnetic field (IMF) parameters in their representation in Geocentric Solar Ecliptic (GSE) coordinates instead of using the prescribed Geocentric Solar Magnetospheric (GSM) representation. The relation between the IMF B_Y and B_Z components in GSE and GSM coordinates could be described by a rotation about the common IMF B_X direction. The rotation angle has daily variations of +/- 11.4° (dipole angle) superimposed on the yearly +/- 23.5° (ecliptic angle) variations. The systematic variations in the GSE/GSM rotation angle within +/- 34.9° generate adverse daily and seasonal excursions in the PC index scaling parameters, particularly the optimum angles, when based on IMF component in the GSE system compared to those based on IMF components in the prescribed GSM coordinate system.

The publication Troshichev et al. (2011) reports on differences between PC index values derived with and without correction for the quiet daily variation (QDC) and differences derived from using calibration parameters derived from epochs of high and low solar activity, respectively. In both cases the calibration parameter versions actually used in their calculations, as shall be shown, are not the stated ones. Hence, the reported relations and conclusions are invalid.

2. PC index versions

It is, of course, up to the PC index providers to name their version(s). It is, furthermore, quite legitimate to make developments to improve models as more data become available. However, the referenced nomenclature in the following statement in p. 1479 of Troshichev et al. (2011) is incorrect:

"*The parameters α, β, and 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 McCreadie and Menvielle, 2010).*"

The nomenclature in McCreadie and Menvielle (2010), as stated at the bottom entry of their Table 1. *Characteristics of the PC index*, is quite specific: Version AARI#3_2006 is based on Vostok polar magnetic data and ACE satellite data from 1998 to 2001 and is termed in the table as the "*official PCS index*".

To avoid misunderstandings, the present note shall use the nomenclature AARI#3=AARI_1998-2001, AARI_1997+2007-2009, and AARI#4=AARI_1995-2005, respectively (abbreviated to versions 98-01, 97&07-09, and 95-05 at times). The nomenclature follows Fig. 5 of Troshichev et al. (2011) where the three columns of colour-coded diagrams represent the scaling parameters (φ, α, β) for each of the three versions. The diagram is presented here in Fig. A1.

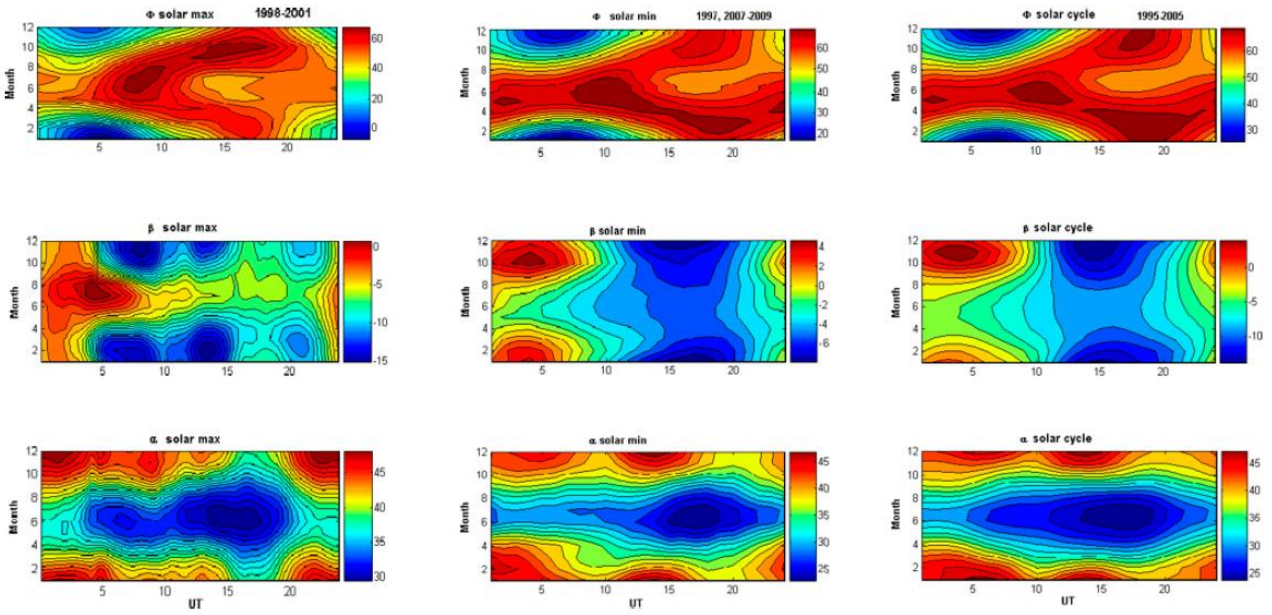


Fig. 5. Parameters ϕ, β, and α derived for Vostok station independently for epoch of solar maximum (1998–2001) [Troshichev et al., 2006], for epoch of solar minimum (1997, 2007–2008), and for complete cycle of solar activity (1995–2005) (AARI#3 version); the axis of abscises being for UT and axis of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

Fig. A1. Colour-coded diagrams of PCS scaling parameters based on different epochs of Vostok geomagnetic data. The version based on epoch 1998-2001 in the left column is the original version of the right column in Fig. 3 of Troshichev et al., 2006. It is named AARI#3 in McCready and Menvielle (2010, 2011) and is also named AARI_1998-2001 here. The version based on epoch 1995-2005 in the right column is here named AARI#4 (or AARI_1995-2005).

3. Epoch years for parameter values displayed in Fig. 1 of Troshichev et al. (2011).

A major issue in the present critical comment is the incorrect referencing to version AARI_1998-2001 (AARI#3) in Figs. 1, 2, and 3 of Troshichev et al. (2011) while in fact the parameters from version AARI_1995-2005 (AARI#4) are being used. This misplacement disguises the incorrectly derived AARI#3 index calibration parameters published in Troshichev et al. (2006).

In p. 1484 of Troshichev et al. (2011) 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.*"

The scaling parameters φ, β and α derived for Vostok (with full allowance for QDC) are displayed in their Fig. 5 for epochs of solar maximum (1998-2001) in the left column which is also displayed as the right column of Fig. 3 of Troshichev et al., 2006. 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 below. For the parameters for the full cycle (1995-2005) the parameters are also provided in files (Angle_Fi.1M, Coeff_alpha.1M, Coeff_beta.1M) made available from AARI at an earlier communication ("Parameter.rar" of 21-06-2011). The mean hourly values derived from these files are shown in Table 2.

The optimum angles (with QDC) for 15 June and 15 November are displayed by green heavy lines in the two diagrams of Fig. 1a of Troshichev et al. (2011). Fig. A2 here displays in green line the angles read from the "with QDC" curve. The angle values derived from the parameter file, Angle_Fi.1M, 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 are displayed by the red line with dots.

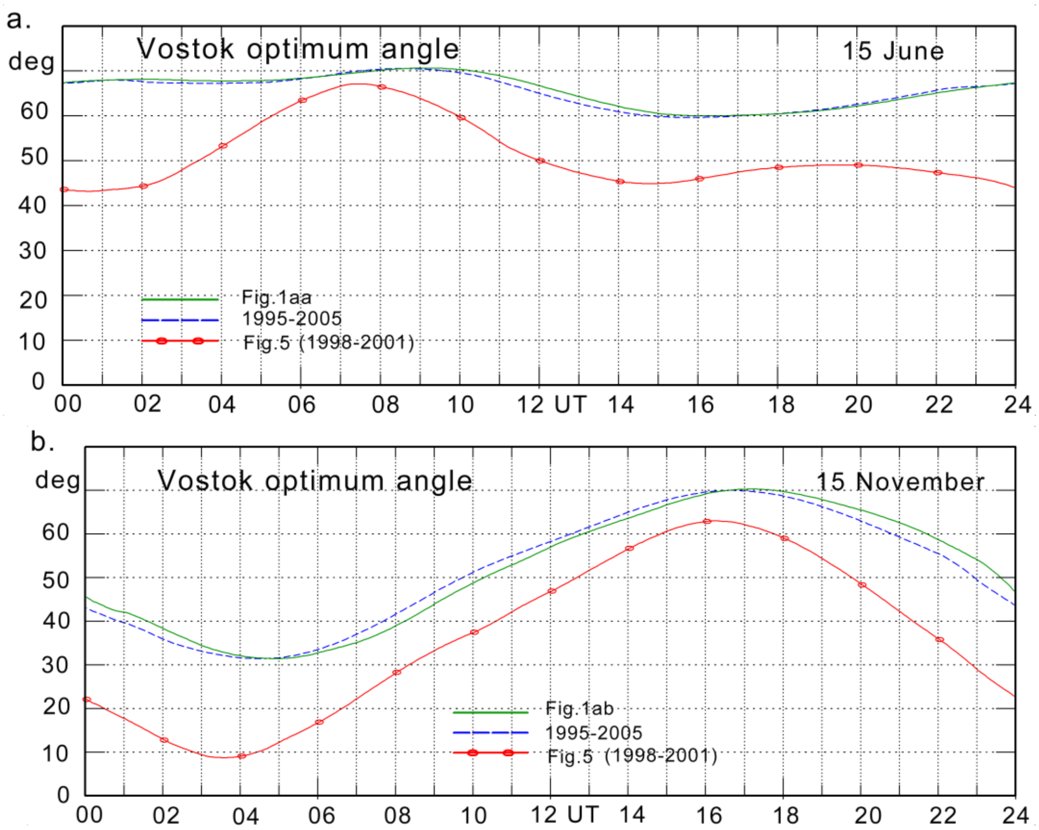


Fig. A2. (**a**) Vostok optimum angles on 15 June. Angles read from Fig. 1aa of Troshichev et al., 2011 (green line). Angles from AARI file (Coeff_fi.1M, 21-06-2011), epoch 1995-2005, in blue, dashed line. Angles read from the left column of Fig. 5 (epoch 1998-2001) in red line with dots. (**b**) The corresponding diagram for 15 November (Fig.1ab) using notation and line colours like those of Fig. A2(a).

From the displays of optimum angles by the green lines in Figs. A2(a) and (b) here it is clear that the angles represented by solid green lines in Fig. 1a of Troshichev et al. (2011) for 15 June and 15 November (with QDC) represent the AARI_1995-2005 version presented in Fig. A2 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.

Fig. A3 here displays in green line the slope values plotted by the heavy green line in Fig. 1ba (15 June, "with QDC" curve) of Troshichev et al. (2011). 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.

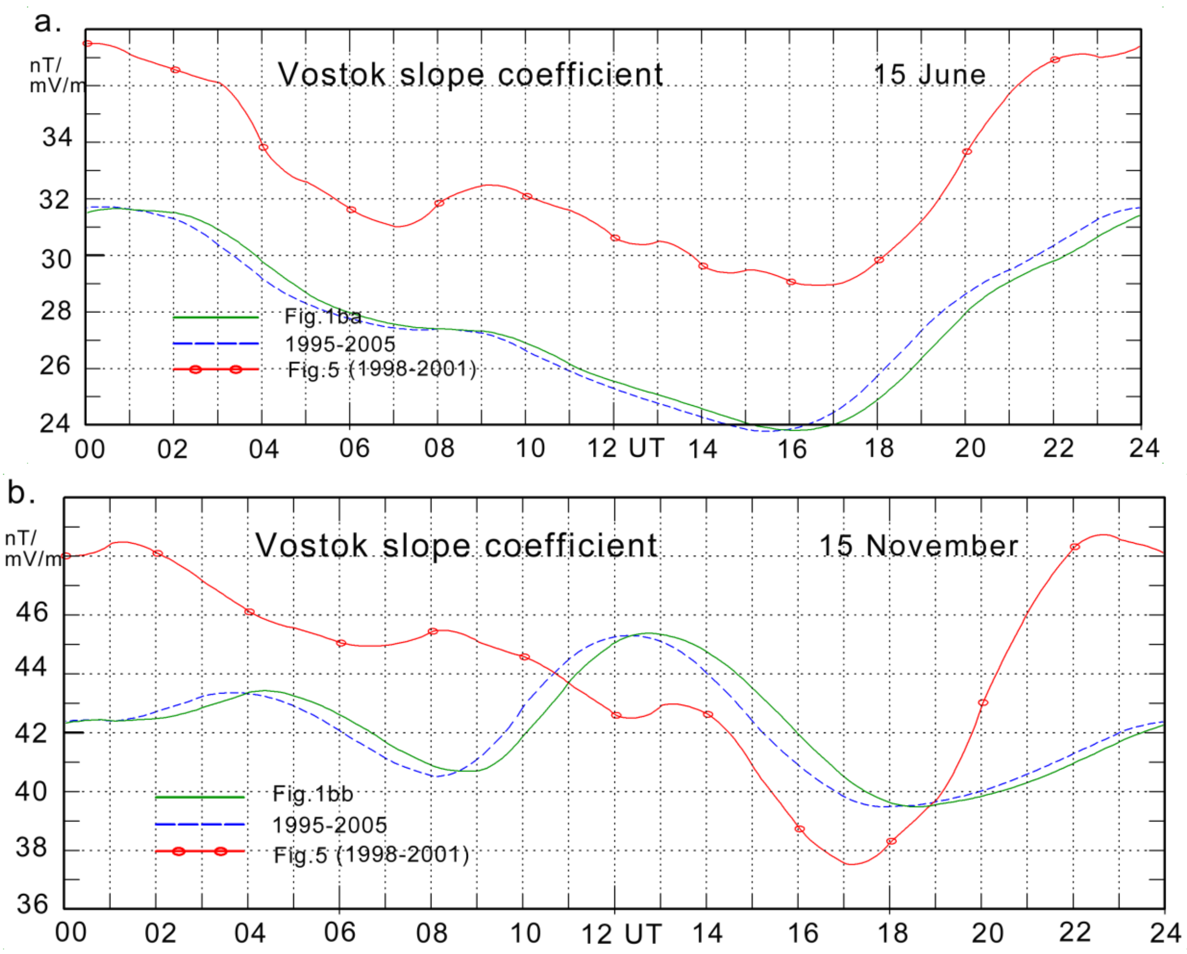


Figure A3. (**a**) Vostok slope coefficients 15 June (with QDC). Slope values read from Fig. 1ba of Troshichev et al., 2011 in green line. Slope values from AARI file (Coeff_alpha.1M, 21-06-2011), epoch 1995-2005, in blue dashed line. Slope values read from left column of Fig. 5 (epoch 1998-2001) in red line with dots. (**b**) The corresponding diagram for 15 November (ref. Fig.1bb) using notation and line colours like those of Fig. A3(a).

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

In corresponding diagrams displayed in their Fig. 1c for the intercept values, the “with QDC” curves (in heavy green line) are again, as seen in Figs. 3a,b here, values derived from the AARI_1995-2005 version#3 and not the AARI_1998-2001 version#3 as claimed in their statements.

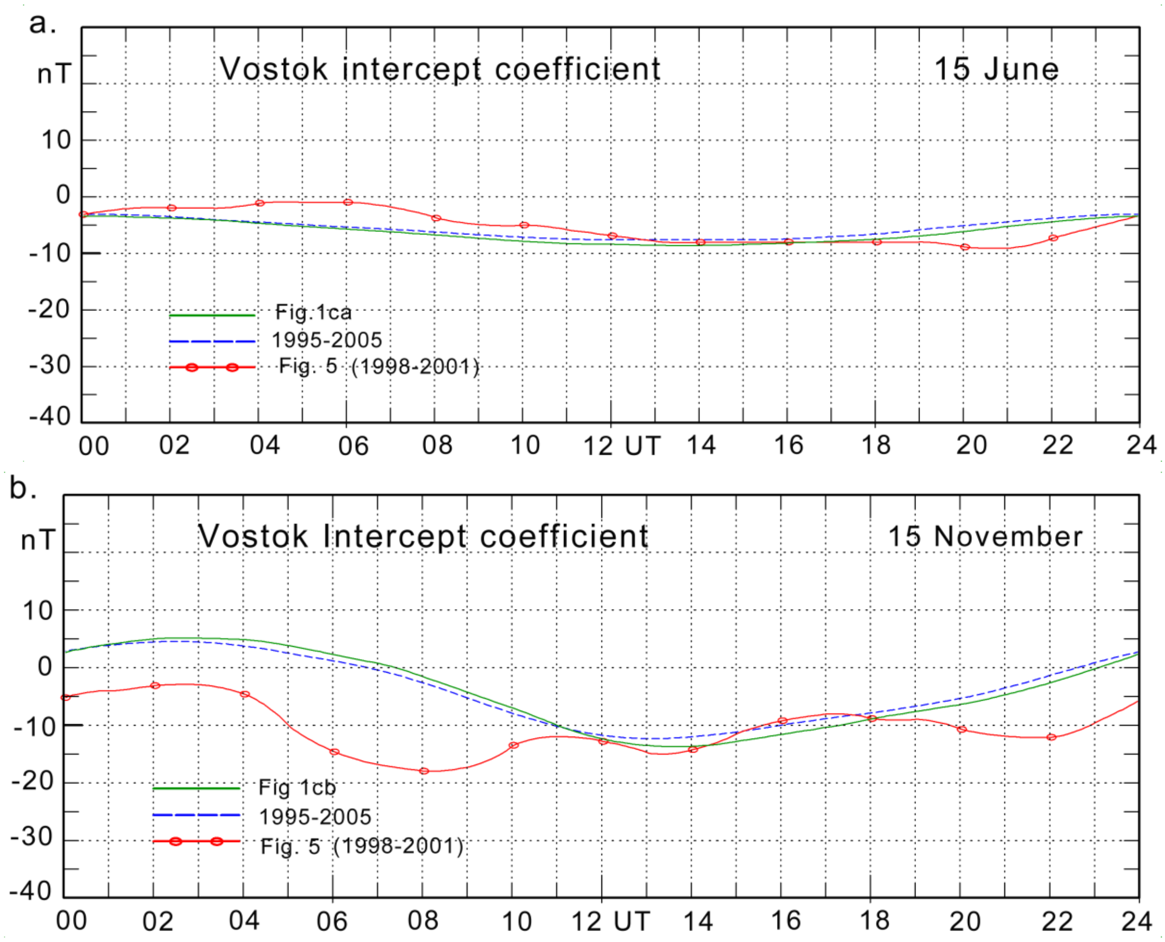


Fig. A4 (**a**) Vostok intercept coefficients 15 June (with QDC). Intercept values read from Fig. 1ca of Troshichev et al., 2011, in green line. Slope values from AARI file (Coeff_beta.1M, 21-06-2011), epoch 1995-2005, in blue dashed line. Intercept values read from left column of Fig. 5 (epoch 1998-2001) in red line with dots. (**b**) The corresponding diagram for 15 November (ref. Fig.1cb) using notation and line colours like those of Fig. A4(a).

The close correspondence between values in the AARI files of calibration parameters derived for epoch 1995-2005 version#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 calibration 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. A2(b), A3(b) and A4(b) here are not displayed in Fig. 1 of Troshichev et al. (2011). Thus, the statement in p. 1484 of Troshichev et al. (2011), pointing to the scaling parameter values shown in their Fig. 5 based on epoch 1998-2001 for the displays in their Fig. 1, is incorrect.

4. The QDC vs. no-QDC effects on calibration parameter derivation.

By its definition, the quiet daily variation (QDC) is not related to the disturbance electric field, E_M (or E_{KL}) in the solar wind. The quiet samples, from which the QDCs are derived, are those where E_M is insignificantly small (Janzhura and Troshichev, 2008). Consequently, at the correlation between the polar magnetic disturbances, ΔF_{PROJ}, and the solar wind electric fields, E_M, the QDC samples are just noise and could not contribute to the systematic maximising of the correlation that defines the optimum direction angle, φ.

The values of the optimum angle, φ, found with QDC correction of magnetic variation data shall be the same as those found without QDC correction of data apart from minor fluctuations. Thus, the relations between the QDC and no-QDC curves in Fig. 1a of Troshichev et al. (2011) are seen to be incorrect at a glance. The two curves are definitely not presenting optimum angles derived with the same program using the same epoch of data differing in the QDC correction of data only.

For each moment of time throughout a year the slope, α, and intercept, β, are found by linear regression on a number of samples for the same moment of time through an epoch spanning several years. This process is illustrated in Fig. A5 (from Stauning, 2013) for the QDC vs. no-QDC cases.

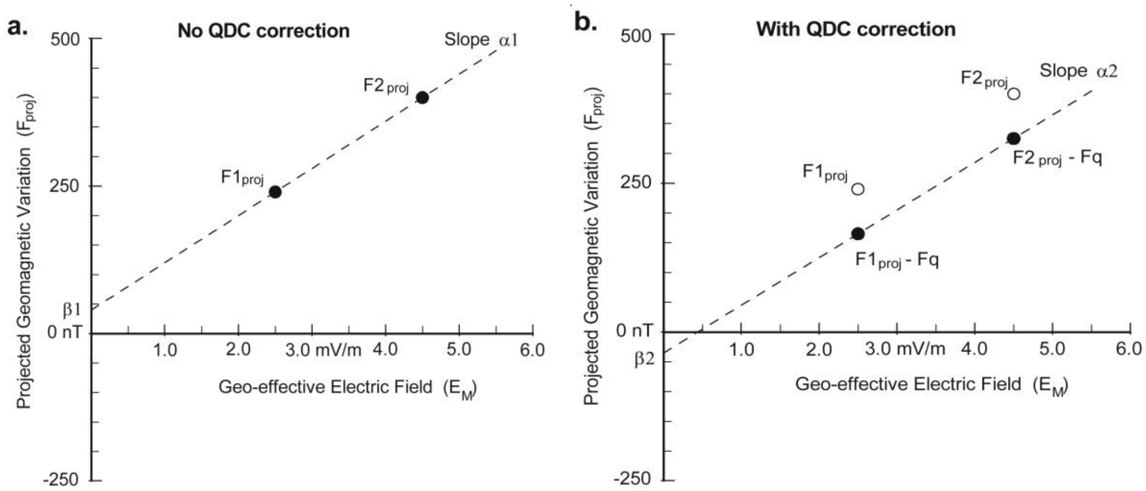


Fig. A5. Illustration of regression on samples of ΔF_{PROJ} vs. E_M ($=E_{KL}$) with (right field) and without (left field) QDC correction. Fq is the value of the projected QDC vector. (from Stauning, 2013).

The QDC correction of samples shifts the regression line down (or up) by the (projected) QDC value, Fq. Thus, the slope remains unchanged, α2=α1, while the intercept is changed by the amount Fq to provide β2=β1-Fq. When samples from years of different solar activity conditions with different QDC values are involved then the resulting slope values, in principle, will be the same while the intercept values will change by an amount close to the mean of the projected QDC values throughout the epoch. With these guidelines in mind it is easy to see at a glance that the diagrams in Fig. 1a of Troshichev et al. (2011) of optimum angles and Fig. 1b of slopes for cases with QDC correction and cases without QDC involvements display incorrect relations. There should be minor differences only.

5. The "no-QDC" curves in Fig. 1 of Troshichev et al. (2011)

5.1 Optimum angles. In the "DMI" correlation program (Stauning et al., 2006) used to derive the optimum angle parameter, the QDC values could be included or left out without changing the program in any other respect. 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. A6(b) (middle field) here presents the resulting optimum angles for 15 Nov in the QDC and the no-QDC cases for a light level of smoothing. Fig. A6(c) (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.

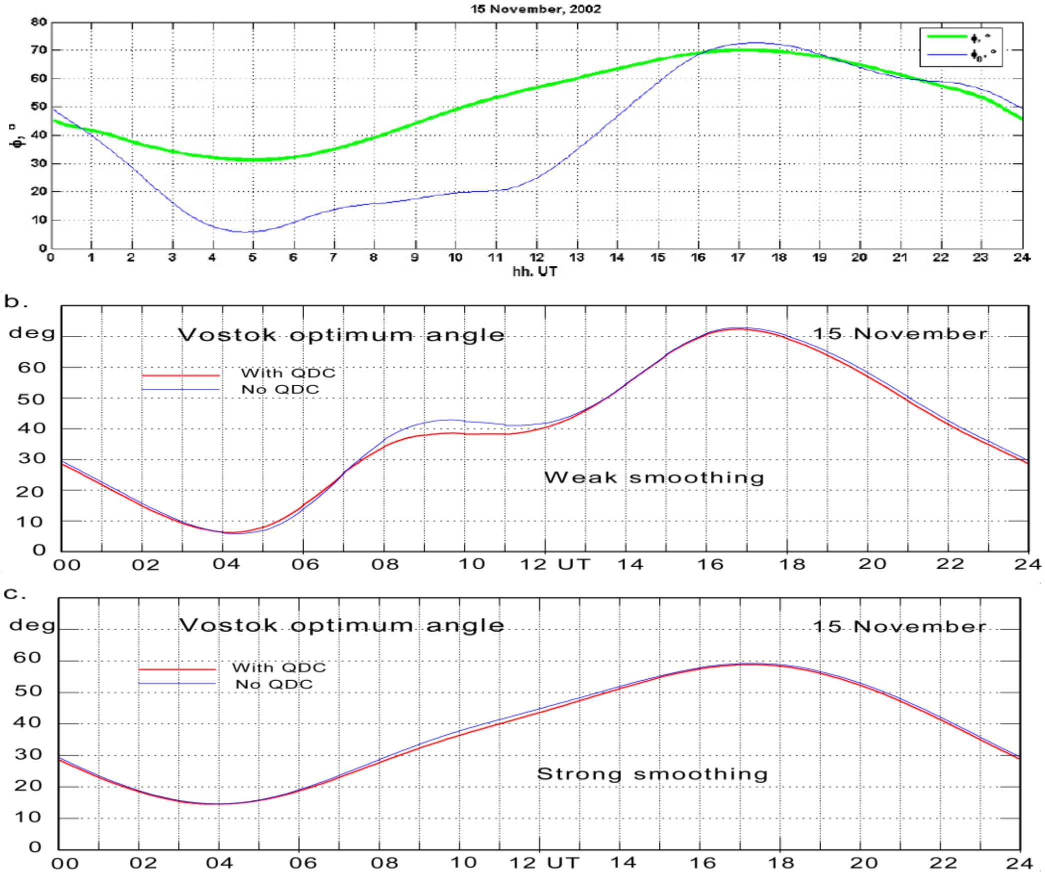
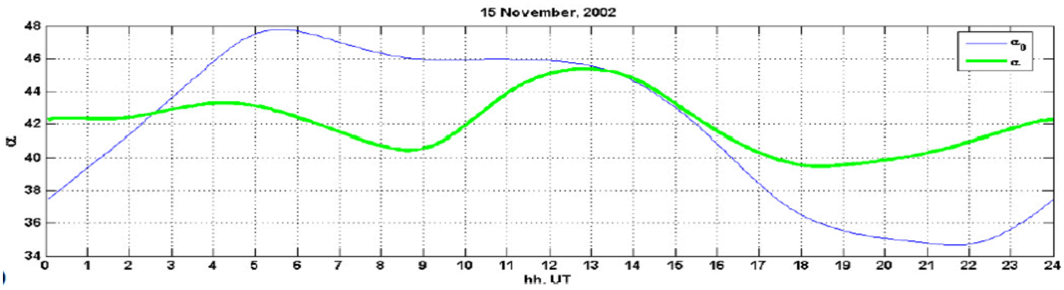


Fig. A6. Optimum angles for Vostok on 15 Nov. The top field (**a**) displays the QDC (heavy green line) and no-QDC (thin blue line) calculations of optimum angles by Troshichev et al., 2011 shown in their Fig. 1ab. Middle field (**b**) displays results from the re-calculation with and without QDC with light smoothing. Bottom field (**c**) displays the re-calculation of optimum angles with and without QDC with strong averaging/smoothing.

5.2. Slope values. The corresponding relations between slope values in Fig. 1bb of Troshichev et al. (2011) and re-calculated values are displayed in Fig. A7.



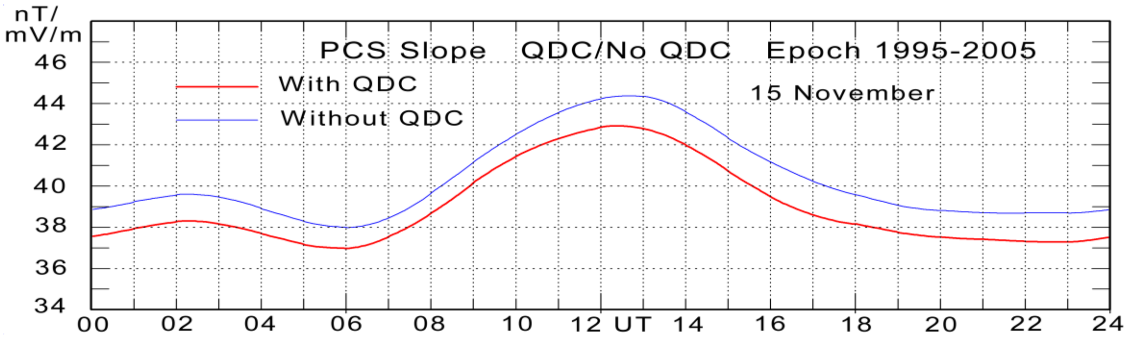


Fig. A7. Display of slope values, α, for 15 Nov calculated with QDC (red) and without QDC (blue) to be used for derivation of PCS indices. Top field: slope values derived by Troshichev et al., 2011 (copy of their Fig. 1bb). Bottom: re-calculation of QDC/no-QDC slopes.

5.3. Intercept parameters. The relations for the intercept values are displayed in Fig. A8.

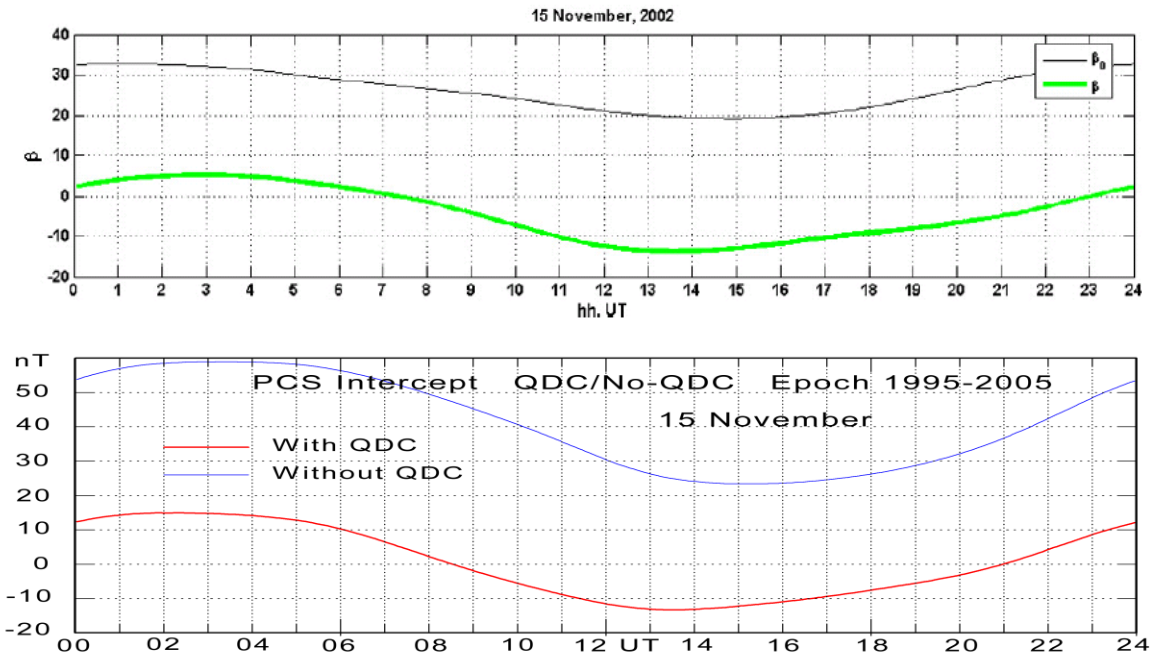


Fig. A8. Display of intercept values, β, for 15 Nov calculated with QDC (red) and without QDC (blue) for derivation of PCS indices. Top field: intercept values presented in Troshichev et al., 2011 (copy of their Fig. 1cb). Bottom: recalculation of QDC/no-QDC intercept values.

A6. PCS values with/without QDC.

Re-calculated values of the 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 Troshichev et al. (2011) are displayed in Fig A9.

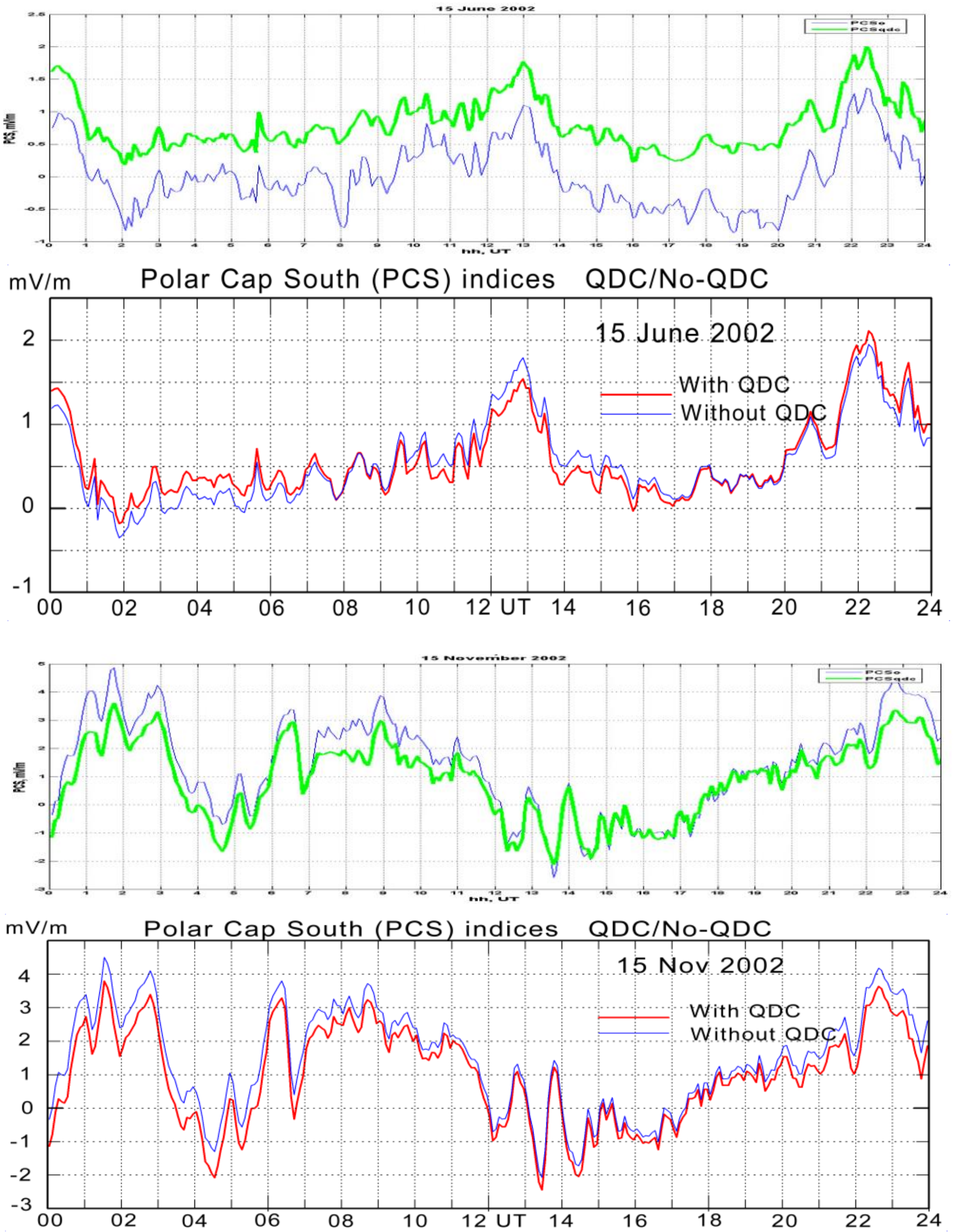
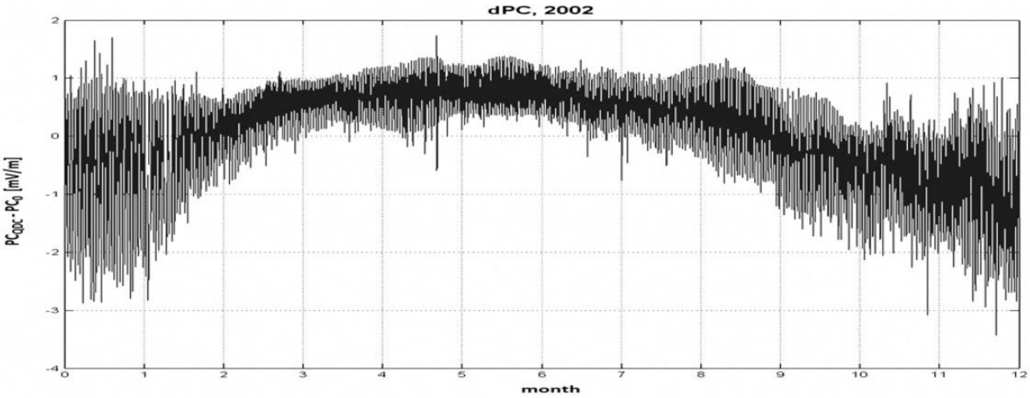


Fig. A9. PCS indices calculated with/without QDC. Top field: PCS index values derived by Troshichev et al. (2011) for 15 June 2002 (copy of their Fig. 2a). Next lower field: Recalculation for 15 June 2002. Lower two fields present corresponding sets for 15 November 2002.

The overall results for 2002 are displayed in the bottom field of Fig. A10 here in the format of Fig. 3 from Troshichev et al. 2011 which is displayed in the upper field of Fig. A10.



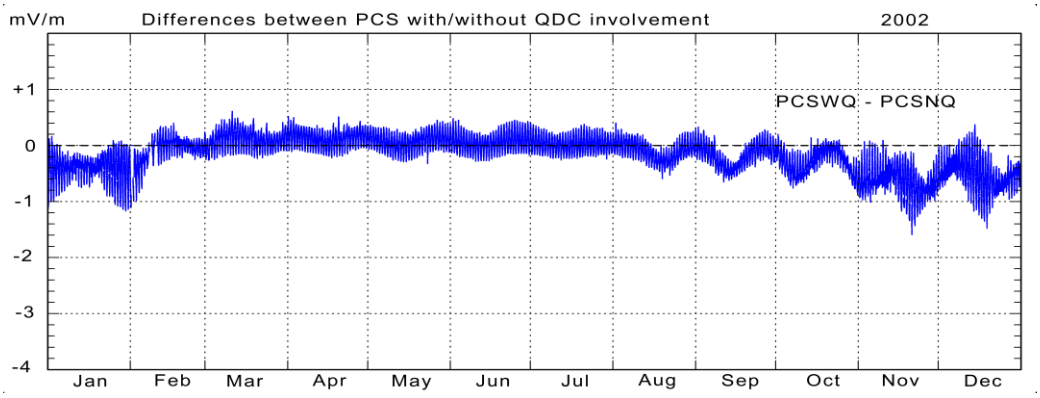


Fig. A10. Display of differences between PCS values calculated with and without QDC reductions of Vostok magnetic data for 2002. Top field: Calculations by Troshichev et al., 2011 (copy of their Fig. 3). Bottom: Re-calculation of the PCS QDC/no-QDC differences.

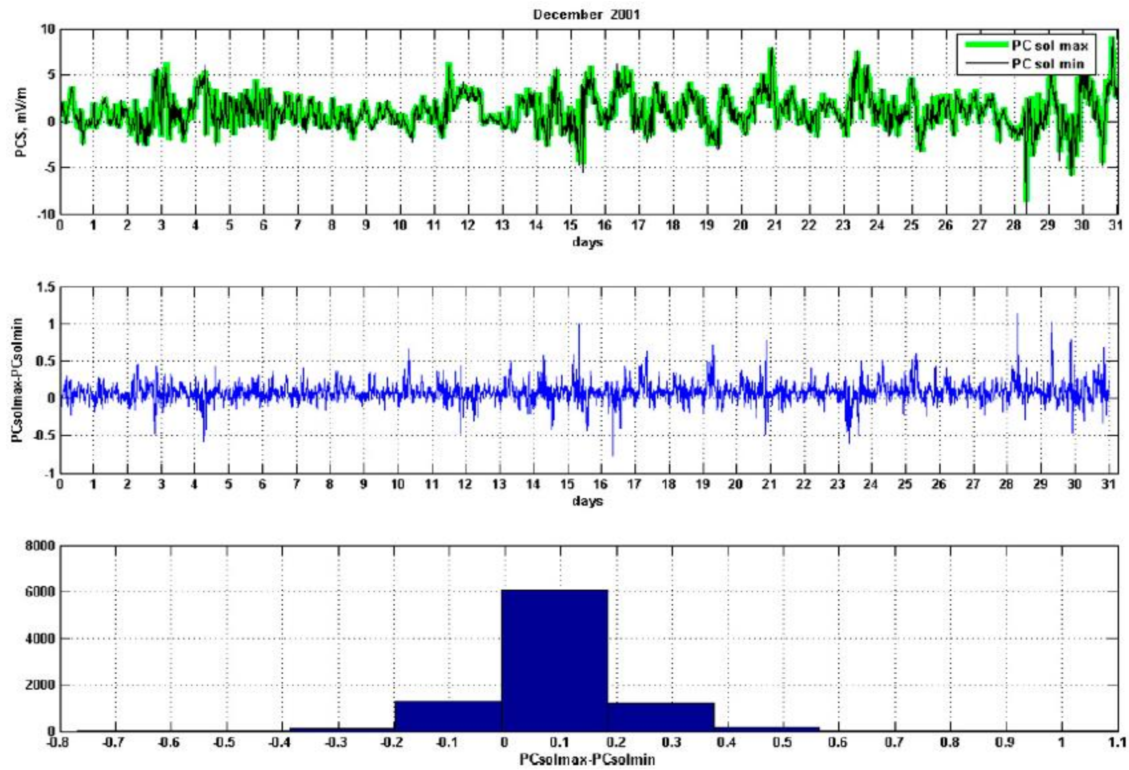
The top field of Fig. A10 presents the differences between the QDC/no-QDC PCS index values throughout 2002 displayed in Fig. 3, p.1483, of Troshichev et al. (2011), while the diagram in the bottom field of Fig. A10 presents the corresponding re-calculated values using data with and without QDC reduction. The plots in Fig. A10 indicate that the differences between PCS index values calculated with QDC reduction of Vostok data and PCS index values calculated without QDC are 2-3 times larger in the Troshichev et al. (2011) publication than in the re-calculation.

A7. The real differences between PCS index values calculated (with QDC adjustments) from version AARI_1998-2001 (AARI#3) and version AARI_1997+2007-2009.

PC index values have been calculated from Vostok data using the scaling parameters for version AARI_1998-2001 (AARI#3) determined from the graphical display in Fig. 5 of Troshichev et al. (2011) (or Fig. 3 of Troshichev et al., 2006) and those of version AARI_1997+2007-2009 read from the middle column of their Fig. 5 for comparisons with the results presented in their Figs. 6, 7, and 8. Fig. A11(a) displays a copy of Fig. 6 from Troshichev et al. 2011, while Fig. A11(b) displays results from re-calculations using scaling parameters derived from their Fig. 5 for both PCS series.

Fig. A12 displays the corresponding set of diagrams for June 2001. Fig. A12(a) presents a copy of Fig. 7 from Troshichev et al. (2011). Fig. A12(b) displays PCS values and their differences calculated by using scaling parameters read from their Fig. 5. Fig. A13(a) displays a reproduction of the middle diagram of Fig. 8 of Troshichev et al. (2011) while Fig. A13(b) displays differences between PCS values derived by using scaling parameter versions AARI#3 and AARI#4.

a.



b.

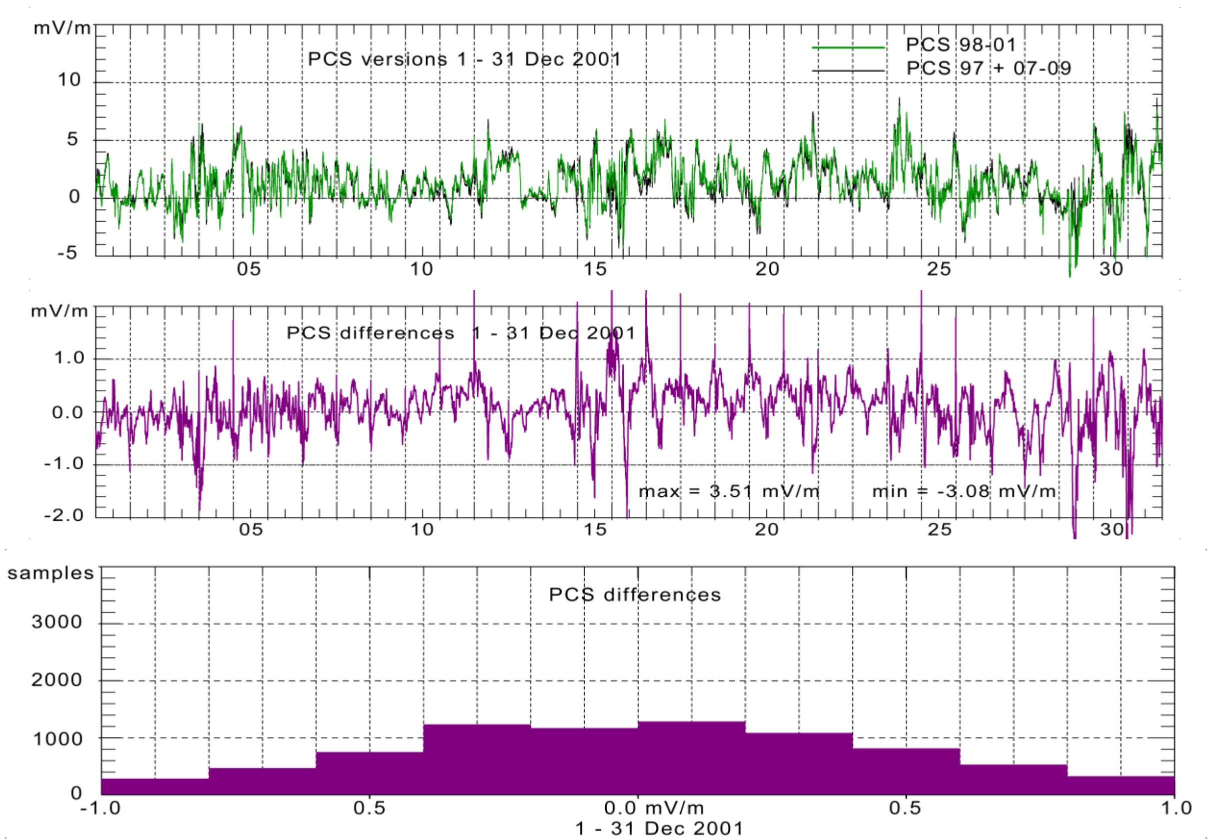
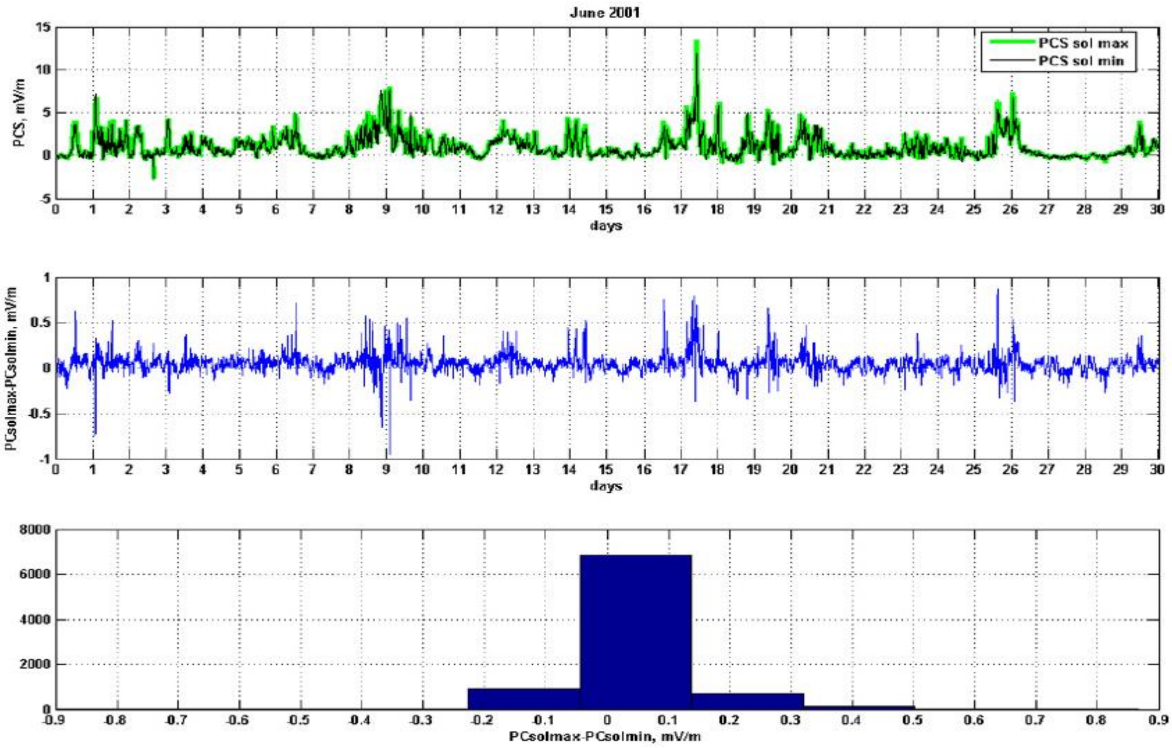


Fig. A11. (a) Reproduction of Fig. 6 of Troshichev et al. (2011). (b) Re-calculations of PCS values.

a.



b.

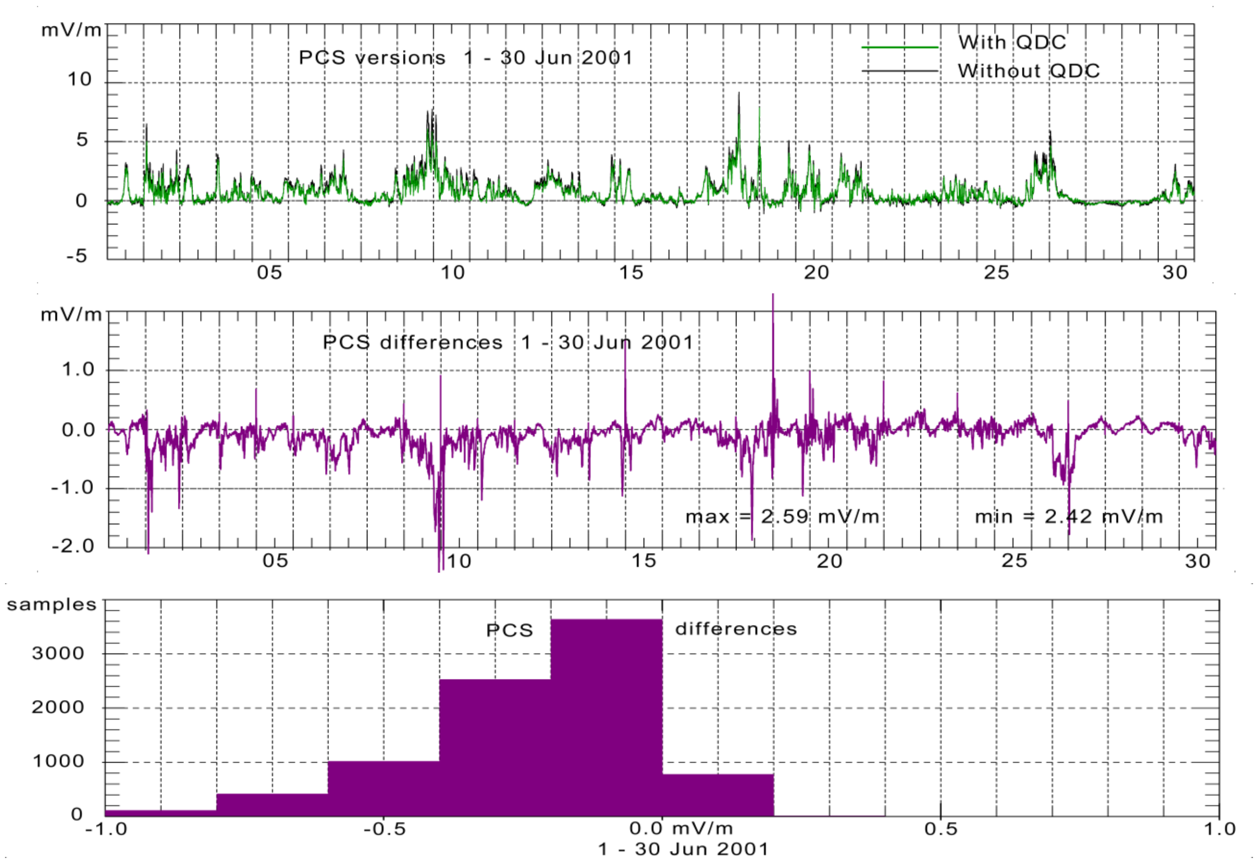
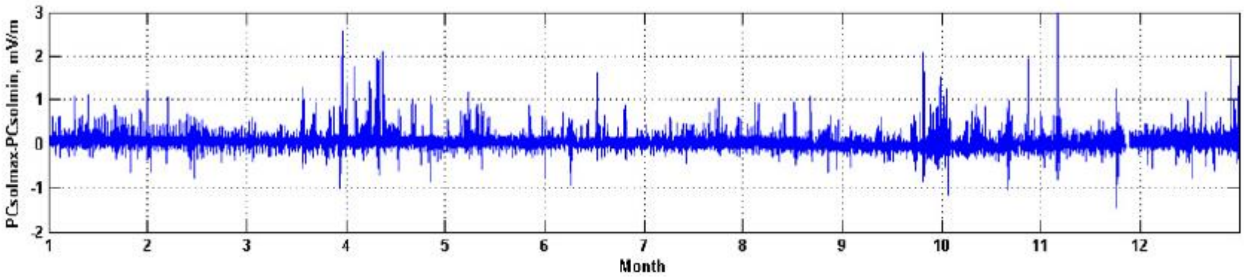


Fig. A12. (a) Reproduction of Fig. 7 fro Troshichev et al. (2011). (b) Re-calculation of PCS values.

a.



b.

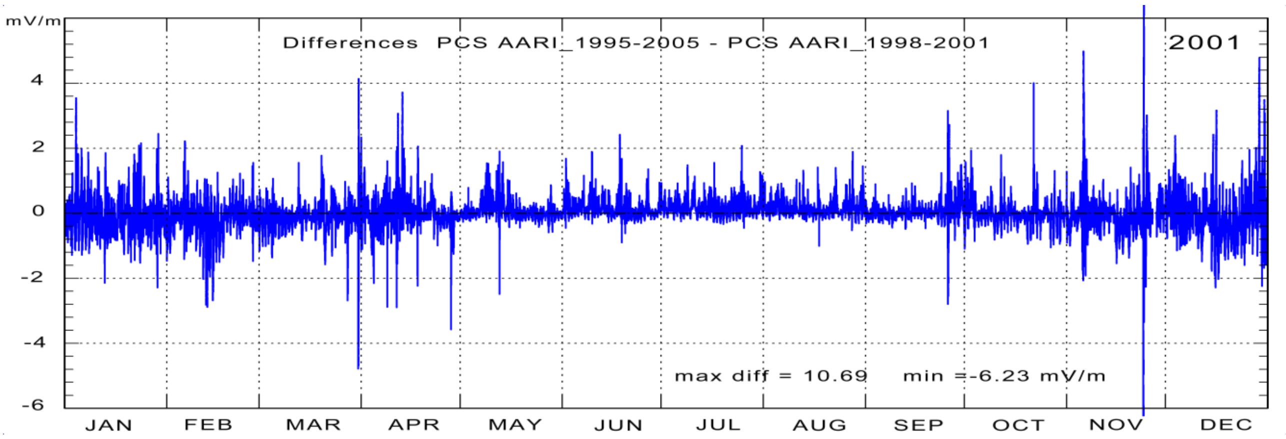


Fig. A13. (a) Reproduction of Fig 8 (middle) in Troshichev et al. (2011). (b) Calculation of PCS differences based on using AARI_1998-2001 (AARI#3) and AARI_1995-2005 (AARI#4) scaling parameters, respectively.

The PCS differences in Fig. A13(b) are based on using the AARI_1998-2001 (AARI#3) scaling parameters for one set of values and the AARI_1995-2005 (AARI#4) solar cycle average scaling parameters for the other set of PCS values.

The considerable enlargement of PCS differences displayed in Figs. A11(b), A12(b), and A13(b), which have used scaling parameters read from Fig. 5 of Troshichev et al. (2011), compared to PCS differences displayed in Figs. A11(a), A12(a), and A13(a) reproduced from Figs. 6, 7, and 8 demonstrates that the latter figures are incorrect. Against explicit statements, the scaling parameters in version AARI_1998-2001 (AARI#3) derived in Troshichev et al. (2006) are not at all involved in the calculations of PCS index values in Troshichev et al. (2011). The origin of the scaling parameters actually used has not been found.

Appendix Conclusions.

It is regrettable that the PCS calibration parameters for version AARI_1998-2001 used in the analysis of Troshichev et al. (2011) had to be based on reading the values from colour-coded diagrams instead of being made available in a numerical file. However, the accuracy in the reading process has been tested by reading values for the AARI_1995-2005 (AARI#4) version from the right column of Fig. 5 and comparisons with available numerical values and is adequate for support of the inferences and conclusion presented here.

In summary, Figs. 1, 2, 3, 6, 7, and 8 of Troshichev et al. (2011) are incorrect. The comparisons of the with QDC and without QDC cases as well as the comparisons of solar max and min cases use ill-defined scaling parameter versions and remain inconclusive. A corrigendum to Troshichev et al. (2006) should be published in order to caution against uncritical referencing to results presented in publications issued between appr. 2006 and 2011 which have used the AARI#3-based calibration parameters or the derived PCN or PCS indices. Another corrigendum should be issued to caution against the relations and conclusions published in Troshichev et al. (2011). If such corrigenda – against expectations – are not issued then the misplaced use of calibration parameters from version AARI_1995-2005 (AARI#4) might be seen as an attempt to disguise the erroneous parameters of version AARI_1998-2001 (AARI#3) provided in Troshichev et al. (2006).

Copenhagen 29 May 2020

Peter Stauning

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Scaling parameter values.

Table 1. 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
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) base don 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
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 2. Hourly mean values of PCS Scaling coefficients from AARI file (Parameters2011.rar, 21-06-2011)

AARI PCS Optimum angle values (in 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 (in 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
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 (in 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

Figure 1.

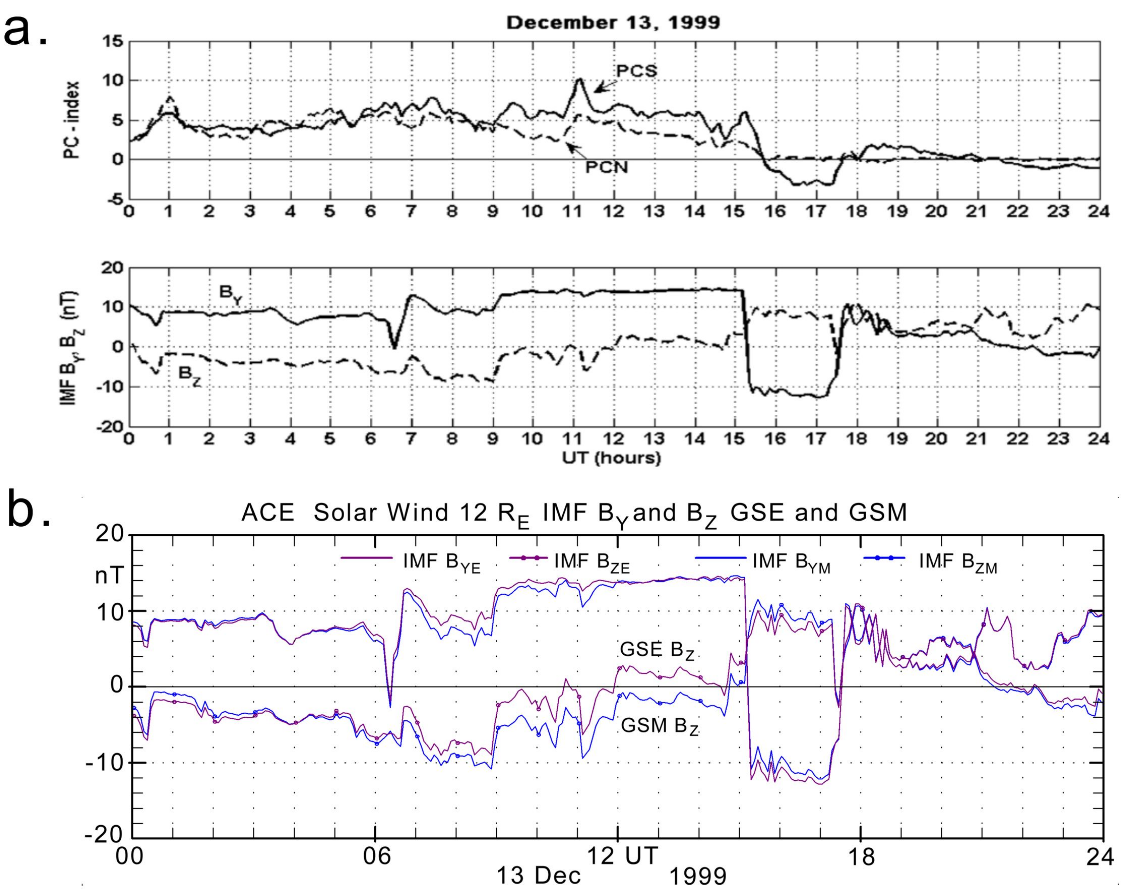

a.
December 13, 1999
PC - index
PCS
PCN
IMF B_Y, B_Z (nT)
B_Y
B_Z
UT (hours)
b.
ACE Solar Wind 12 R_E IMF B_Y and B_Z GSE and GSM
nT
IMF B_YE
IMF B_ZE
IMF B_YM
IMF B_ZM
GSE B_Z
GSM B_Z
12 UT
13 Dec
1999

Figure 2.

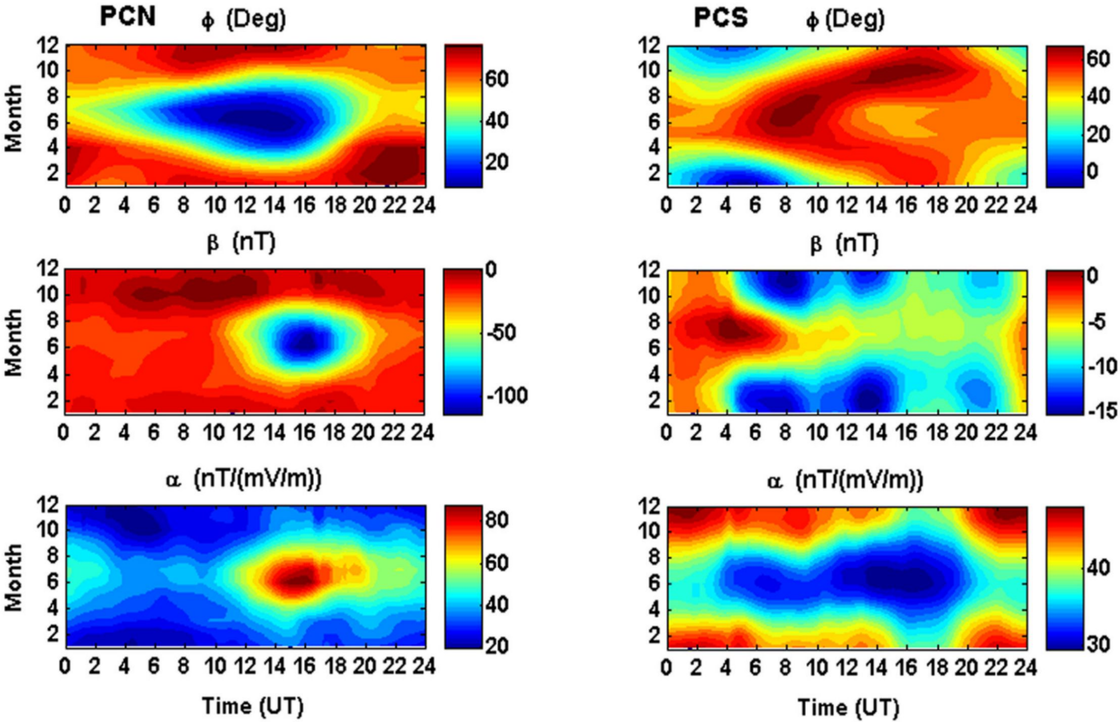


Figure 3. Angle ϕ and coefficients α and β used for calculation of the unified PCN and PCS indices derived on the basis of magnetic data from Thule and Vostok stations for 1998–2001.

Figure 3.

PCS Optimum angles. AARI_1998-2001 and AARI_1995-2005
deg
AARI_1998-2001 Fig.5 (2011)
AARI_1998-2001 Fig.3 (2006)
AARI_1995-2005 AARI File
90
80
70
60
50
40
30
20
10
0
0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 0 12 UT
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC

Figure 4.


Differences between PCS95 and PCS98 2001
PCS95-PCS98
max=10.69 min=-6.23
+6
+4
+2
0
-2
-4
-6
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC

Figure 5.

a.
Vostok optimum angle
15 June
deg
0
10
20
30
40
50
60
00
02
04
06
08
10
12 UT
14
16
18
20
22
24
Fig.1aa
1995-2005
Fig.5 (1998-2001)

Figure 6.


a.
Vostok slope coefficient
15 June
nT/
mV/m
34
32
30
28
26
24
00
02
04
06
08
10
12 UT
14
16
18
20
22
24
Fig.1ba
1995-2005
Fig.5 (1998-2001)

Figure 7.

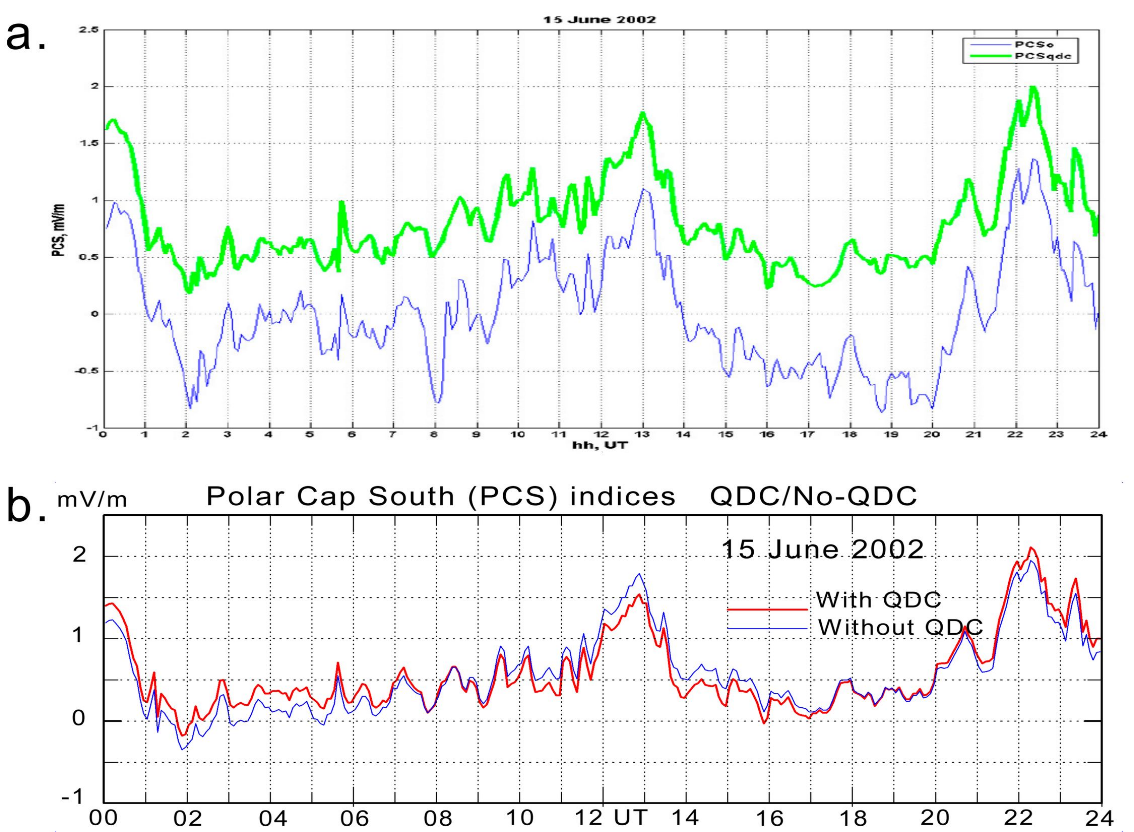

a.
15 June 2002
PCSo
PCSqdc
PCS, mV/m
hh, UT
b.
mV/m
Polar Cap South (PCS) indices QDC/No-QDC
15 June 2002
With QDC
Without QDC
UT

Figure 8.

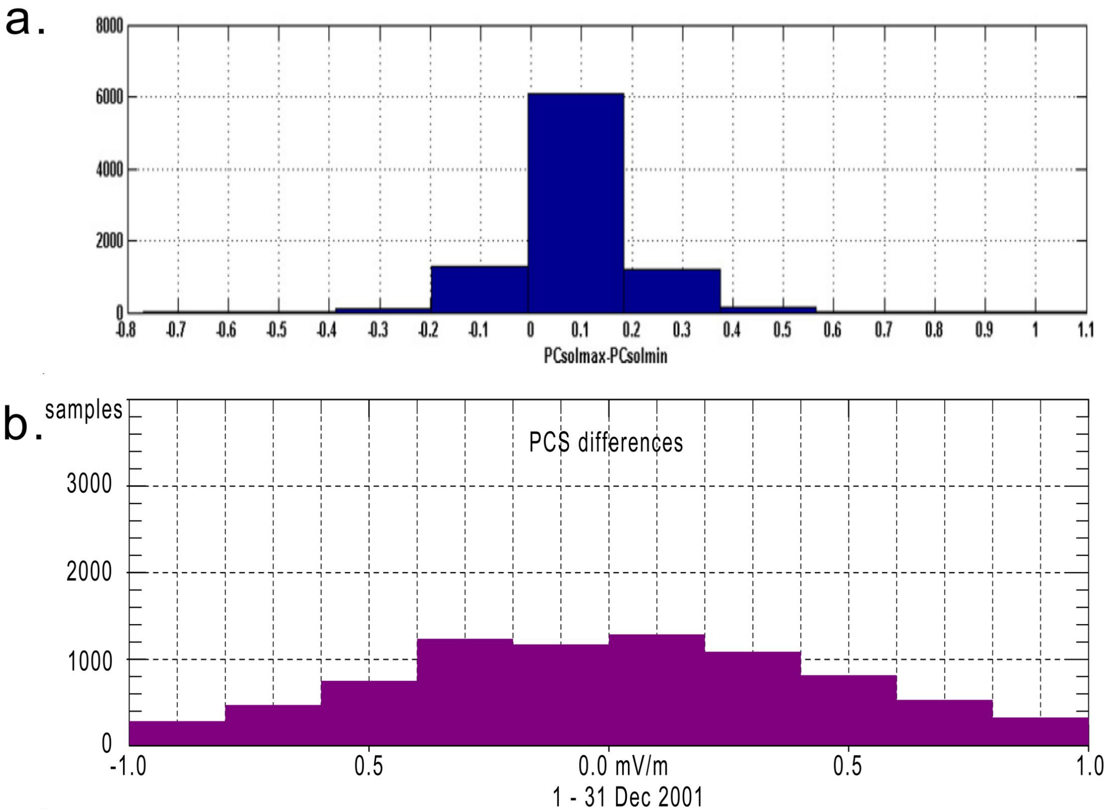

a.
8000
6000
4000
2000
0
-0.8 -0.7 -0.6 -0.5 -0.4 -0.3 -0.2 -0.1 0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1 1.1
PCsolmax-PCsolmin
b.
samples
PCS differences
3000
2000
1000
0
-1.0
0.5
0.0 mV/m
0.5
1.0
1 - 31 Dec 2001

Figure 9.

Deg
PCN optimum Angle
90
80
70
60
50
40
30
20
10
0
AARI#3 (1998-2001)
IAGA2014 (1998-2009)
DMI2016 (1998-2009)
00 12 00 12 00 12 00 12 00 12 00 12 00 UT 00 12 00 12 00 12 00 12 00 12 24
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

Figure 10.

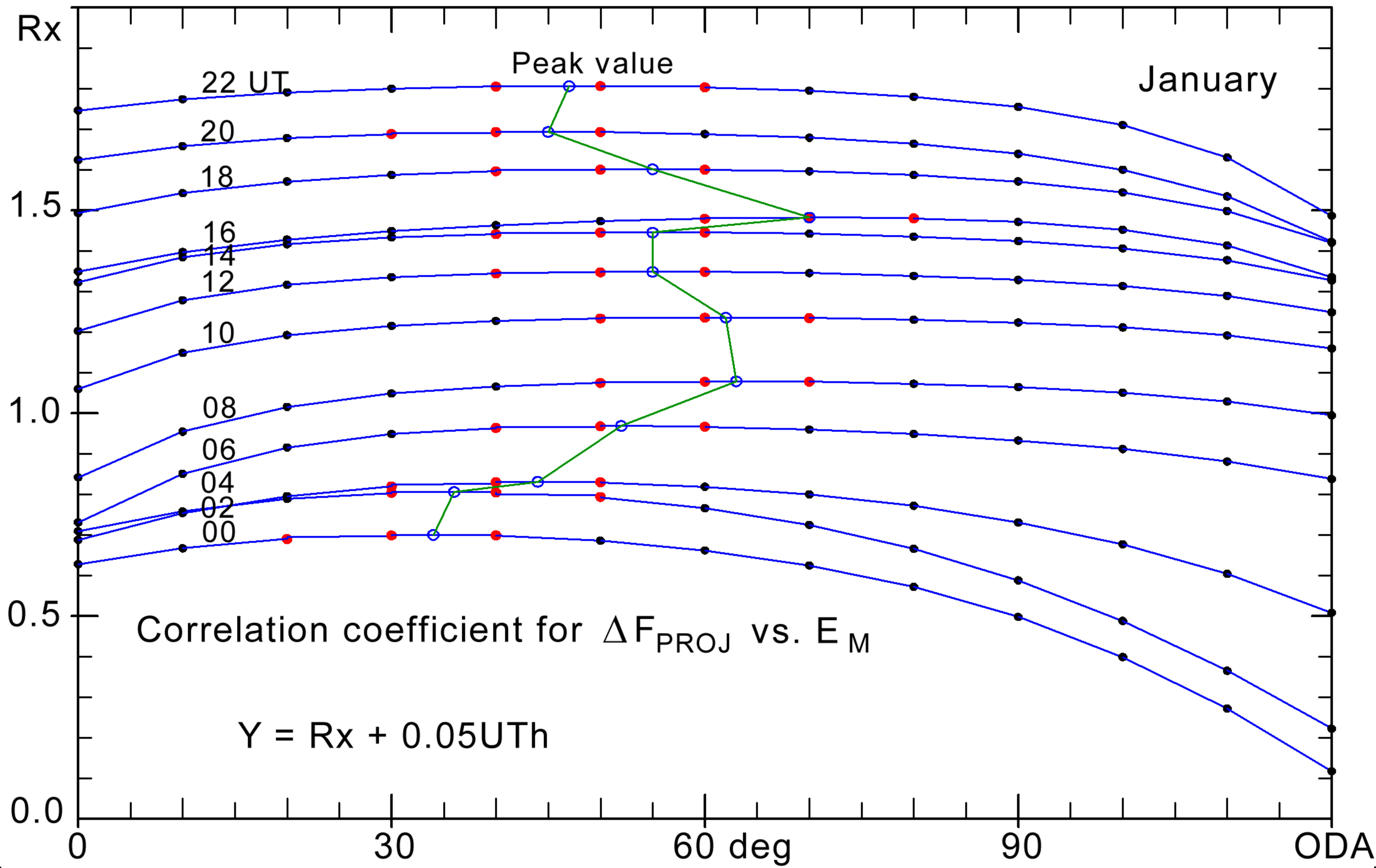
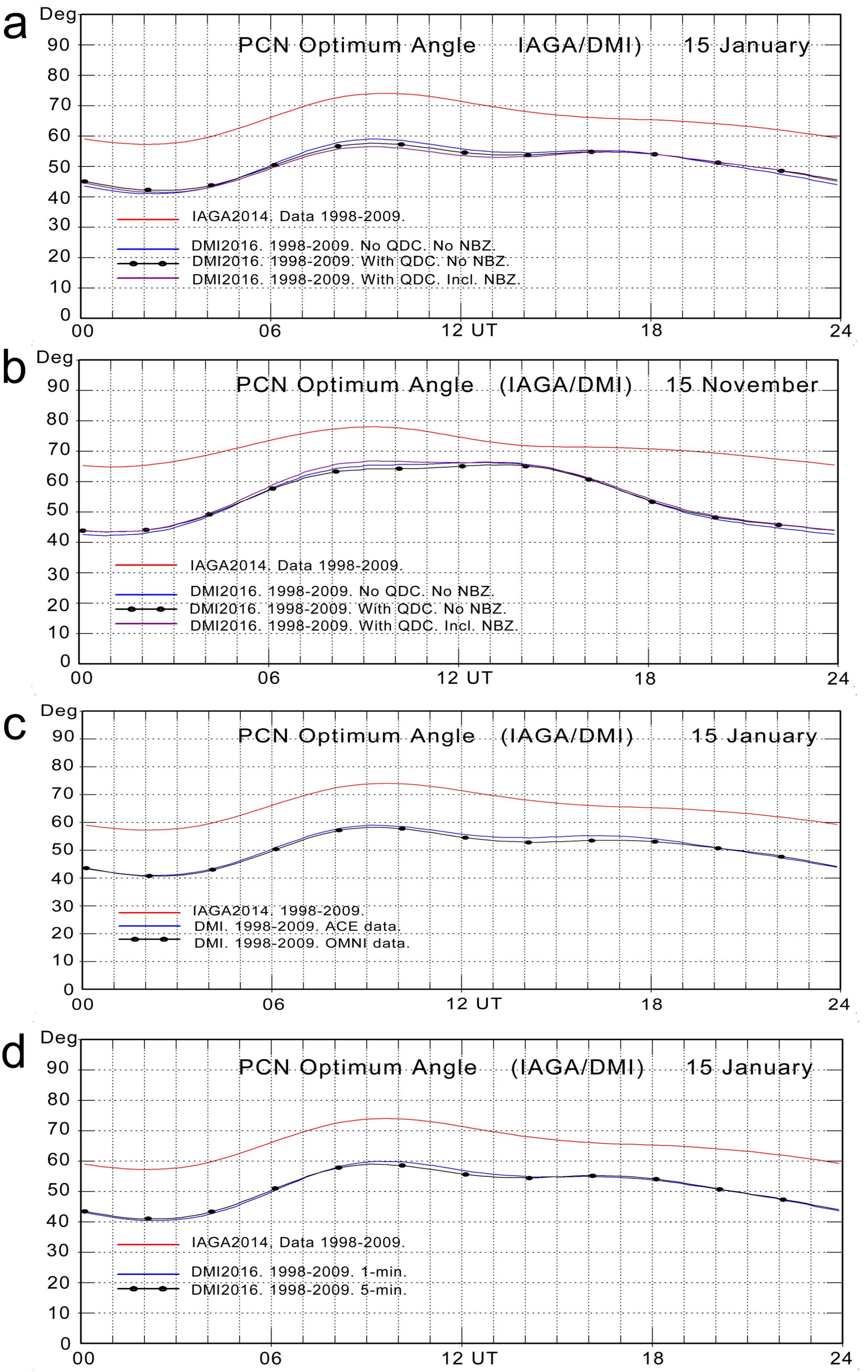

Rx
Peak value
January
22 UT
20
18
16
14
12
10
08
06
04
02
00
1.5
1.0
0.5
0.0
Correlation coefficient for ΔF_{PROJ} vs. E_M
Y = Rx + 0.05UTh
0
30
60 deg
90
ODA

Figure 11.


a
Deg
PCN Optimum Angle IAGA/DMI) 15 January
IAGA2014. Data 1998-2009.
DMI2016. 1998-2009. No QDC. No NBZ.
DMI2016. 1998-2009. With QDC. No NBZ.
DMI2016. 1998-2009. With QDC. Incl. NBZ.
00 06 12 UT 18 24
b
Deg
PCN Optimum Angle (IAGA/DMI) 15 November
IAGA2014. Data 1998-2009.
DMI2016. 1998-2009. No QDC. No NBZ.
DMI2016. 1998-2009. With QDC. No NBZ.
DMI2016. 1998-2009. With QDC. Incl. NBZ.
00 06 12 UT 18 24
c
Deg
PCN Optimum Angle (IAGA/DMI) 15 January
IAGA2014. 1998-2009.
DMI. 1998-2009. ACE data.
DMI. 1998-2009. OMNI data.
00 06 12 UT 18 24
d
Deg
PCN Optimum Angle (IAGA/DMI) 15 January
IAGA2014. Data 1998-2009.
DMI2016. 1998-2009. 1-min.
DMI2016. 1998-2009. 5-min.
00 06 12 UT 18 24