Comment on "Troshichev et al. 2020: The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances.": Invalid data base.

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Abstract

Examination of the contribution from O.A. Troshichev, S. Dolgacheva, N.A. Stepanov, and D.A. Sormakov: "The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances. https://doi.org/10.1029/2020JA028491 " has disclosed inconsistencies in the applied methods and serious errors in the calculated values. Some of the discrepancies reported in the present commentary affect directly the illustrations presented in their contribution while other possible errors may not be apparent since the use of relative values in their presentation makes thorough assessments difficult.

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P. Stauning: Comment on "Troshichev et al. 2020: The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances.": Invalid data base.

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Abstract. Examination of the contribution from O.A. Troshichev, S. Dolgacheva, N.A. Stepanov, and D.A. Sormakov: "The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances. https://doi.org/10.1029/2020JA028491 " has disclosed inconsistencies in the applied methods and serious errors in the calculated values. Some of the discrepancies reported in the present commentary affect directly the illustrations presented in their contribution while other possible errors may not be apparent since the use of relative values in their presentation makes thorough assessments difficult.

Plain language summary

The publication by Troshichev et al. (2020) is devaluated by inconsistencies in the applied methods and errors in the presented material, among others, in their figures 1 and 2 while further potential errors are disguised by the use of relative instead of actual parameter values.

1. Introduction

The contribution from O.A. Troshichev, S. Dolgacheva, N.A. Stepanov, and D.A. Sormakov (2020): "The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances. https://doi.org/10.1029/2020JA028491 published in J. Geophys. Res. Space Physics holds correlations between various solar and solar wind parameters and geospace magnetic disturbance indices.

Much of the work is based on relations involving the Polar Cap (PC) indices, PCN (North) and PCS (South). These indices are presently submitted jointly by the Arctic and Antarctic Research Institute (AARI) and the Danish Space Research Institute (DTU Space). The publication conveys the impression that these indices are applied in versions endorsed by the International Association for Geomagnetism and Aeronomy (IAGA) by its Resolution #3 (2013), which they, being provisional values, are not.

There are serious inconsistencies in the reported methodologies and considerable errors in the reported index parameters and index values, particularly in the applied Polar Cap South (PCS) values that suffer from invalid data or errors in the processing software.

The values presented in the figures, particularly in their Figs. 1 and 2, are untenable. The referencing is improperly biased.

2. Polar Cap (PC) index versions and classifications

Polar Cap PCN (North) and PCS (South) index values are available at the web portal of the International Service of Geomagnetic Indices (ISGI) at http://isgi.unistra.fr/indices_pc.php . For the interval of years (1998-2019) considered in the commented publication, PCN index values are here classified as "definitive" index values while PCS (South) values are classified as "provisional". Definitive PCN values and description of derivation methods are available at DTU Space at https://doi.org/10.11581/DTU:00000057 . PCN and PCS values are furthermore presented at the AARI web portal https://pcindex.org in what appears to be "quick-look" versions judging from the data availability statements of the publication, Troshichev et al. (2020), discussed here.

The publication states in the abstract: "*The polar cap magnetic activity PC index is regarded as indicator of the solar wind energy that enters into the magnetosphere during the solar wind – magnetosphere coupling (Resolutions of XXII IAGA Assembly, 2013). This paper presents the results of statistical analysis of relationships between yearly values of PC index and such indicators as the magnetic activity indices (AE and Dst)*". This formulation is repeated in a slightly different version in the introduction in section 1: "*Taking into account this distinctive feature of the PC index, the International Association of Geomagnetism and Aeronomy (IAGA) approved PC index as 'a proxy for the energy that enters into the magnetosphere during solar wind-magnetosphere coupling' Resolution of XXII IAGA Assembly, 2013)*".

These statements might convey the impression that the PC indices in the version used here have been endorsed by IAGA by Resolution #3 (2013) issued at the IAGA General Assembly in 2013. But this not the case.

From, for instance, the file PCND2010.1M (Definitive) of indices from DTU Space, the first few lines are (Eq. 1):

Scientific_data_and_models/World_Data_Center_for_Geomagnetism, Copenhagen. (1)

DATE TIME DOY PCN

2010-01-01 00:00:00.000 001 0.01

2010-01-01 00:01:00.000 001 0.01

2010-01-01 00:02:00.000 001 0.01

From the file PCSP2010.1m (Provisional) downloaded from ISGI, the PC indices are:

DATE TIME DOY PCS (2)

2010-01-01 00:00:00.000 001 0.25

2010-01-01 00:01:00.000 001 0.26

2010-01-01 00:02:00.000 001 0.29

From http://pcindex.org the corresponding index series used in the article discussed here is:

#year-month-day h:m PCN PCS (3)

2010-01-01 00:00 0.09 0.25

2010-01-01 00:01 0.09 0.26

2010-01-01 00:02 0.09 0.29

The PCN indices in Eq. 3 are clearly not from the same index series as the definitive version displayed in Eq. 1 but more likely from the quick-look or provisional version as the provisional PCS values from ISGI in Eq. 2.

IAGA endorsements are only provided to definitive index series and could not comprise the indices (Eq. 3) used here in spite of the references to IAGA resolution #3 (2013).

3. Quiet day QDC) reference level.

The quiet day reference level (QDC) serves to define the magnetic variation being scaled to form the PC indices. In section 3.1 of the commented (Troshichev et al., 2020) publication it is stated "*To examine the QDC alteration in course of solar cycles we examined the yearly-averaged amplitudes of QDC at the northern and southern polar cap stations and counted their sum (QDCtotal) for each year during 1998-2019 (see http://geophys.aari.ru/PCspaceweather).*

The QDCtotal amplitude for 2001 can be read from Fig. 1 to within ±1 nT to give 135 nT and the referenced yearly values in the Table for 2001 at the referenced web file are almost the same:

Year Version QDC_N (nT) QDC_S (nT) QDCtot (nT) (4)

2001 Table 66.99001 67.11466 134.10467

2001 Fig.1 135.0

QDC values for the X- and Y-components based on magnetic data from OMNIweb and using the QDC method from Troshishev et al. (2006) provides the values shown in Eq. 5 at the line marked "OMNI". DTU-Space has supplied QDC X- and Y-component values for 2001 derived at an interim step of the PCN calculations (definitive values). These values are provided in the line marked "DTUS" of Eq. 5:

Noting that the QDC X- and Y-component values need to be vectorially added provides the scalar values for the QDC_N and QDC_S components for the northern and southern hemisphere shown in Eq. 5:

Year Version QDC-X_N QDC-Y_N QDC_N QDC-X_S QDC-Y_S QDC_S QDC_tot (5)

2001 OMNI 67.0 63.6 92.4 59.3 102.7 118.6 303.4 nT

2001 DTUS 66.9 63.9 92.5 nT

Thus, the QDC ranges in two hemispheres are 92.4 and 118.6 nT, respectively, while the "QDCtot" for 2001 is 303.4 nT and not the value of 134.1 nT as stated in the table or read from Fig. 1. Looking closer at the numbers discloses readily that the values displayed in the table of the AARI web reference are values derived for one component, the X-component, only.

Thus, the values displayed in their Fig. 1 are incorrect by considering the X-component only. It is quite possible that the QDC dependence on solar illumination and solar wind impact are different for the northward (X-) and the eastward (Y-) components. In any event it should be defined properly in the article (Troshichev et al., 2020) how the "QDCtot" values are constructed.

4. Polar cap index values.

In section 2 of the publication (Troshichev et al., 2020) the authors state: "*the daily PC index was estimated as a daily sum of the positive hourly indices divided by 24 h*". In the supporting web site http://geophys.aari.ru/PCspaceweather ("MEAN" link) it is explained that positive PCN and PCS values only were used in the averaging instead of using both positive and negative PC index values. This is clearly the method for the PCC index developed by Stauning in 2006 and published in Stauning (2007). This issue shall be dealt with in section 6. For present, the method is used to the letter to derive PC index values to be compared to the values displayed in Fig. 2a

In the following examples we shall consider the years 2003 (PCN only), 2007, and 2011 with easily recognizable peaks in PC index values shown in Fig. 2a. These values shall be compared to corresponding values downloaded initially from the AARI web site (https://pcindex.org) and ISGI (http://isgi.unistra.fr) in 2017 and confirmed by downloads in October 2021 and January 2022, respectively, which must be the indices used in the publication.

In order to distinguish between the different versions, they are named by suffix "FIG" when read from Fig 2a of Troshichev et al. (2020), "ISG" when downloaded from ISGI web at http://isgi.unistra.fr and "ORG" when downloaded from AARI web at https://pcindex.org (before 2 Oct 2021) and "ORN" (new ORG) after 23 December 2021. In principle, these different version should provide the same yearly average PC index values (including PCN = PCS averages) each year. Obviously they do not.

Yearly averages for 2003: (6)

PCN_{FIG}(2003)=1.000 : PCS_{FIG}(2003)=0 (no data)

PCN_{ISG}(2003)= 1.490 : PCS_{ISG}(2003)=0

PCN_{ORG}(2003)=1.487 : PCS_{ORG}(2003)=0

PCN_{ORN}(2003)=1.490 : PCS_{ORN}(2003)=0

For 2007: (7)

PCN_{FIG}(2007)=0.600 : PCS_{FIG}(2008)=0.505

PCN_{ISG}(2007)=0.900 : PCS_{ISG}(2007)=0.826

PCN_{ORG}(2007)=0.907 : PCS_{ORG}(2008)=0.789

PCN_{ORN}(2007)=0.900 : PCS_{ORN}(2007)=0.802

For 2011: (8)

PCN_{FIG}(2011) =0.540 : PCS_{FIG}(2011)= 0.730

PCN_{ISG}(2011)= 0.862 : PCS_{ISG}(2011)=1.080

PCN_{ORG}(2011)=0.870 : PCS_{ORG}(2011)=1.045

PCN_{ORN}(2011)=0.862 : PCS_{ORN}(2011=0.895

The values presented above hold several questionable features such as:

(i) The strong disagreements between the index values read from Fig. 2a of Troshichev et al. (2020) and those provided from the other index versions show that the values in Fig.2a have been derived by some procedure differing from the averaging process defined in their section #2.

(ii) The differences between the PCN and PCS values in 2007 must relate either to poor data or to errors in the processing. If the problem resides in the data, then the problem, most likely, is with the data from Vostok used to derive the provisional PCS indices, since the PCN data basis is definitive values from Qaanaaq (THL) used for definitive PCN index values.

(iii) Differences between yearly averages of PCN and PCS indices should be small (a few %) since both PCN and PCS indices are calibrated with respect to the common merging electric field, Ekl (Kan and Lee, 1979). Differences as large as those seen in Fig. 2 up to 0.2 mV/m (appr 30%) should cause reflections by the authors and experienced readers over data quality and validity of data processing methods.

(iv) The yearly mean values of Ekl reported at the supporting web site http://geophys.ari,ru/PCspaceweather differ strongly from the PCN and PCS values displayed in Fig. 2a which, most likely, is why they are not included in the figure with their real values but first transformed to relative values for displays in Figs. 2b, 3 and 4a.

(v) The very strong differences between PCN and PCS index values in their "FIG", "ISG", and "ORG" versions in 2011 are most likely caused to a large extent by errors in the AARI data processing for the PCS indices (the Vostok data are good). The error was detected in 2018 (Stauning, 2018a) and reported at that time to the index providers and to IAGA EC but the cautioning was neglected and dismissed, respectively. Further reporting of the erroneous PCS indices are provided in Stauning (2018b, 2020, and 2021) and in "NotePCSindexExamination-27-12-2012.pdf" at https://doi.org/10.17632/mph b8d7cv5.1 .

5. Reference level.

It is stated in section 2 of the commented manuscript that: "*The polar cap magnetic disturbance value F at stations Thule and Vostok is counted from level of quiet daily variation (QDC – Quiet Daily Curve), which is determined for each day of year [Troshichev at al., 2006]*".

However, the procedures defined in Troshichev et al. (2006) and further specified in Janzhura and Troshichev (2008) are not in agreement with the index derivation methods endorsed by IAGA by Resolution #3 (2013) upon recommendation by a IAGA Task Force by the statement: " *The PC index being recommended for endorsement at IAGA 2013 Merida, Mexico is defined by the following publications: Troshichev et al. (2006 and 2009), Janzhura and Troshichev (2008) , Janzhura and Troshichev (2011)*" (Menvielle et al., 2013).

In Troshichev et al. (2006) the quiet reference level is defined in section 2.1 by the statement: "*Magnetic deviations D and H are calculated from a certain level, "curve of quiet day" which presents the daily magnetic variation, observed at the particular station during extremely quiescent days*".

In the documentation (Matzka and Troshichev, 2014) submitted to IAGA in 2013 in order to fulfil the requirements in "*Criteria for endorsement of indices by IAGA*" (2009), the magnetic variations are measured from a baseline derived as the median of recorded values smoothed over 7 days . Such median baselines are not mentioned in Troshichev et al. (2006). The reference level method used at DTU Space for calculations of the provisional and definitive PCN indices (Nielsen and Willer, 2019) builds on the additional descriptions provided in Janzhura and Troshichev (2011) as noted in the document: *PC_index_description_main_document.pdf* available from http://isgi.unistra .fr/Documents/References/PC_index_description_main_document.pdf .

It should be noted that the reference level defined in the documentation presented in Matzka and Troshichev (2014) presently being used at DTU Space and which includes a median term, is not a quiet level in the sense defined by Troshichev et al. (2006). A median-based reference level is dynamically tracking the disturbance level.

6. Referencing

The list of references lacks reference to Janzhura and Troshichev (2008) for further descriptions of the automated QDC methodology and also lacks reference to the development of the QDC concept by Janzhura and Troshichev (2011) (including the near-real time version) used in the basis for the IAGA endorsement in 2013 (Matzka and Troshichev, 2014; Menvielle et al., 2013).

Another issue is the use of the combination of positive PCN and PCS values in the parameter named "PCmean" here. This parameter is actually the same as the "PCC index" developed by Stauning in 2006 and published in Stauning (2007) with accurately the same arguments as those presented in section #2 of Troshichev at al. (2020).

Before submission to J. Space Weather, Drs. Troshichev and Janzhura were invited by mail 20-11-2006 to share authorship for a publication on the new PCC index. However, Dr. Troshichev on behalf also of Dr. Janzhura declined on the invitation by mail 20-11-2006 with the arguments: "*We do not agree conceptually with incorporation of new combined index PCC*" and "*We do not agree conceptually with your suggestion to exclude the negative PC indices from consideration*". The full text of the mails holding the invitation and the rejection are available.

The PCC index parameter was used in the contribution by Stauning, Troshichev, and Janzhura (2008) where Dr. Troshichev is co-author. The PCC index concept was further used in Ch. 16 of Stauning (2012) next to Ch. 15 written by Dr. Troshichev, in Stauning (2016, 2018, 2020, 2021), and in several draft manuscripts forwarded to Dr. Troshichev for his information and possible comments.

Still, in the comprehensive list of references to Troshichev et al. (2020), which includes 71 items, there is no mentioning of the initial presentation of the PCC index concept by Stauning (2007).

The case of neglect of crediting the original work has been forwarded to the AGU Ethical Committee.

Conclusions

- The correlation studies and conclusions presented in the commented article by Troshichev et al. (2020), *The PC index variations during 23/24 solar cycles: relation to solar wind parameters and magnetic disturbances*, https://doi.org/10.1029/2020JA028491 are devaluated by inconsistencies in the definition of data processing methods and the use of invalid data.

- The calculations of quiet day reference levels (QDC) presented in their Fig. 1 use only one component, the northward X-component, with the unresolved risk that the other component, the eastward Y-component, contributes a different dependence on the related solar and solar wind parameters.

- Contrary the impression conveyed by the repeated referencing to the IAGA Resolution #3 (2013), the indices used in the commented article are not in the version endorsed by IAGA but provisional values.

-The data displayed in their figure 2a do not agree with values derived by using the described methods to the letter on the original geomagnetic data. The display holds cases of clearly questionable index values, where the yearly averages, however derived, of PCN and PCS indices that should be equal within a few %, differ by up to 30%.

- The processing of Vostok geomagnetic data at AARI by authors of the commented publication neglecting the cautioning provided in 2018 have given values that deviate by up to 3 mV/m (geomagnetic storm level) compared to the most recent (December 2021) PCS index values submitted also from AARI.

- In spite of conveying a quite comprehensive list of references with 71 items, the referencing is not providing proper credit to earlier works of substantial importance for the methodology used in the commented publication

Data availability statement.

The data used in the present commentary have been downloaded from the web portals: http://geophys.aari.ru/PCspaceweather , https://pcindex.org , http://isgi.unistra.fr/indices_pc.php , https://intermagnet.org , and http://omniweb.gsfc.nasa.gov

Conflict of interests: The author declares that he has no conflict of interests in the present case.

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Note on invalid Polar Cap South (PCS) indices

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1. Introduction.

The Polar Cap (PC) indices, PCN (North) and PCS (South) based on magnetic data recorded at the central polar cap observatories in Qaanaaq (Thule) in Greenland and Vostok in Antarctica, respectively, were developed through the pioneering works of Troshichev and Andrezen (1985) and Troshichev et al. (1988). Further PC index developments were made by Vennerstrøm (1991), Troshichev et al. (2006), Stauning et al. (2006), and Stauning (2007, 2011, 2016, and 2018c).

To derive PC index values, magnetic variations related to the transpolar convection of plasma and magnetic fields are calibrated, in a statistical sense throughout an epoch of accumulated data, to equal values of the merging electric field (coupling function), E_M, (Kan and Lee, 1979), defined from parameters in the impinging solar wind. Through their association with E_M, the PC indices represent the merging processes between the solar wind magnetic fields extending from the Sun and the terrestrial magnetic fields considered to control the input of energy from the solar wind to the magnetosphere.

The report ISO/TR23989:2020 issued by the Technical Committee of the International Organisation for Standardization (ISO) for the natural and artificial Space Environment discusses the operational estimation of the solar wind energy input into the Earth's magnetosphere. The report aims at providing guidelines for the use of operative ground-based information on the polar cap magnetic activity defined by the PC indices. The report notes: "*The solar wind energy incoming into the magnetosphere predetermines development of the magnetospheric disturbances: magnetic storms and substorms. Magnetospheric disturbances include a wide range of phenomena and processes directly affecting human activity, such as satellite damage, radiation hazards for astronauts and airline passengers, telecommunication problems, outages of power and electronic systems, effects in the atmospheric processes, and impact on human health.*"

Based on a proposal on the calculations of PC indices submitted jointly from the Arctic and Antarctic Research Institute (AARI) and DTU Space (Matzka and Troshichev (2014) and with recommendation from the IAGA Task Force (Menvielle et al, 2013), the General Assembly of the International Association for Geomagnetism and Aeronomy held in Merido, Mexico in 2013, agreed on Resolution #3,(2013):

IAGA, **noting** that polar cap magnetic activity is not yet described by existing IAGA geomagnetic indices, **considering** that the Polar Cap (PC) index constitutes a quantitative estimate of geomagnetic activity at polar latitudes and serves as a proxy for energy that enters into the magnetosphere during solar wind-magnetosphere coupling, **emphasising** that the usefulness of such an index is dependent on having a continuous data series, **recognising** that the PC index is derived in partnership between the Arctic and Antarctic Research Institute (AARI, Russian Federation) and the National Space Institute, Technical University of Denmark (DTU, Denmark), **recommends** use of the PC index by the international scientific community in its near-real time and definitive forms, and **urges** that all possible efforts be made to maintain continuous operation of all geomagnetic observatories contributing to the PC index.

The resolution was later in 2013 endorsed by IAGA Executive Committee (EC). The calculations of PC indices were divided between DTU Space, who derived the provisional and the definitive PCN indices, while AARI derived and published the near-real time PCN and PCS indices and the provisional PCS indices. PCS indices were never derived in definitive versions. The issuing of near-real time (quick-look) and provisional PCN and PCS indices was initiated in February 2014 from the AARI web portal, http://pcindex.org (now https://pcindex.org). The definitive PCN indices, as they became available, were published at the DTU Space's web at http://space.dtu.dk and later also, along with the provisional PCS indices, at the web portal, http://isgi.unistra.fr , of the International Service of Geomagnetic Indices (ISGI) supported by IAGA.

The problems to be discussed here are related to the dual and very different PCS versions both issued from AARI. One PCS version has been available at the AARI portal http://pcindex.org since 2014 and up to October 2021 in versions either unlabeled or in the recent year labeled "definitive". The indices in this version were also made available with the label "provisional" at the ISGI portal http://isgi.unistra.fr (and still are as of 18 January 2022). The other (new) PCS version has been issued since December 2021 from the "definitive" link of the AARI portal, https://pcindex.org although, according to IAGA rules, they should be labeled "provisional" since the basic Vostok data are not "observatory quality".

For extended intervals of time, the differences between the two PCS versions range between approximately -2 mV/m and +3 mV/m. Noting that onset level for magnetic storms and substorms is 1.5 ±0.5 mV/m (e.g., according to Troshichev et al., 2014), such differences are invalidating for applications of the PCS indices in the worst of the two versions for space weather monitoring and for other works that may have used them.

2. The polar cap (PC) indices

In the agreed formulation, the PC indices are derived from the expression shown in Eq. 1 (see, e.g., Troshichev et al. (1988, 2006); Stauning et al., 2006; Stauning, 2016).

$$PC = (\Delta F_{PROJ} - \beta)/\alpha \approx E_M \quad : \quad E_M = V_{SW} \cdot (B_Y^2 + B_Z^2)^{½} \cdot \sin^2(\theta/2) \qquad (1)$$

where ΔF_{PROJ} is the projection to an optimum direction of the horizontal magnetic disturbance vector, $\Delta \boldsymbol{F}$, measured from a quiet reference level, $\boldsymbol{F}_{RL}$, while α (slope) and β (intercept) are calibration parameters. As indicated by Eq. 1, all scaling parameters are derived from statistical relations with the solar wind merging electric field, E_M, in the formulation of Kan and Lee (1979), which involves the solar wind velocity V_{SW} and the transverse components of the Interplanetary Magnetic Field (IMF) in their Geocentric Solar Magnetospheric representation, while θ is their polar angle.

The processing of polar magnetic data to form the PC indices is described in Appendix_A of Mazka and Troshichev (2014) and is based on the methods defined in Troshichev et al. (2006), Janzhura and Troshichev (2008), Janzhura and Troshichev (2011) and ch. 4 of Troshichev and Janzhura (2012). The computer software initially developed by A. Janzhura has recently been adjusted by Nielsen and Willer (2019). The PC index derivation methods have been questioned and modifications suggested in Stauning (2013a,b, 2015, 2018a, 2020, and 2021c).

The magnetic observations used for the PCN indices are derived from data of IAGA-endorsed observatory standard which enables the calculation of "definitive" PCN index values. The magnetic observations at Vostok suffer, among others, from the unstable ice sheet position and the extreme climatic conditions, which imply that the observational quality just enables the characterization as "provisional" for the data and the derived PCS indices, not "definitive".

These characteristics are readily seen in Fig. 1 with the monthly averages (in blue line) of the recorded data from the quietest (QQ) 5 days of the month selected according to the tables from ISGI (http://isgi.unistra.fr). The red dots display yearly averages of all data from QQ days.

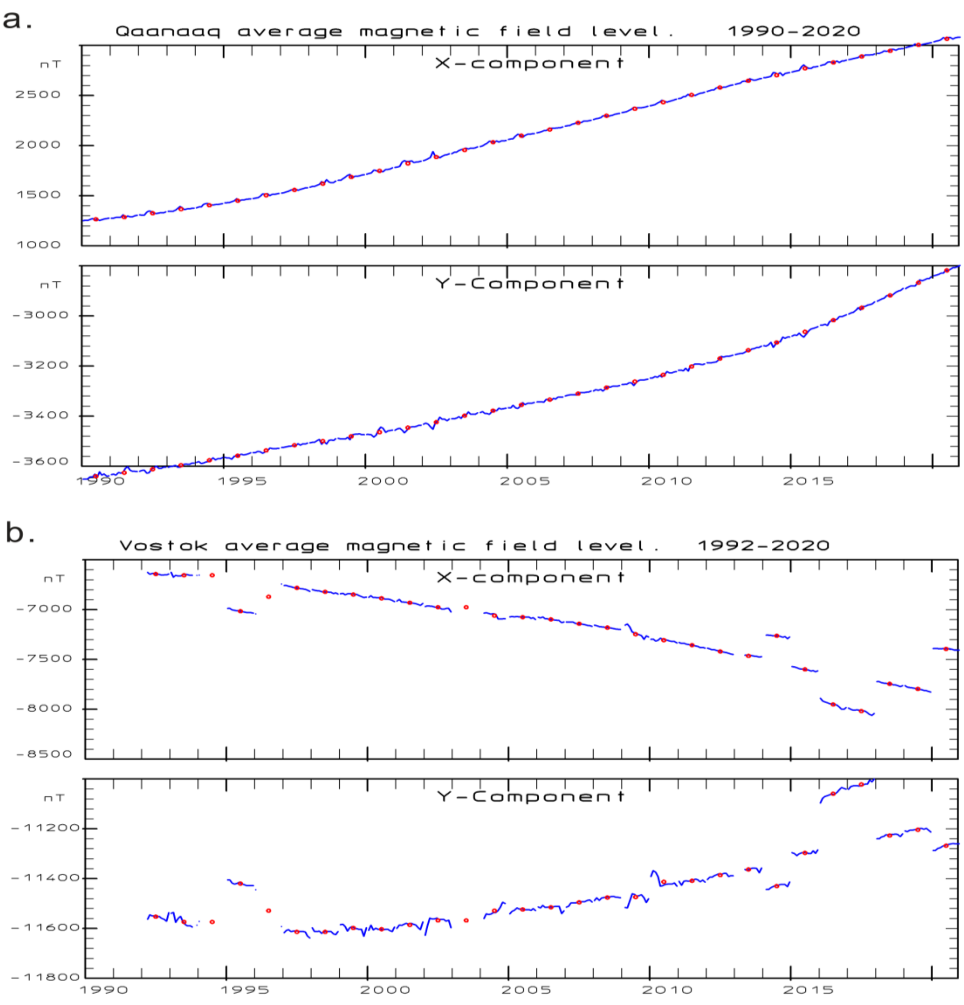

Fig. 1. Monthly (blue line) and yearly (red dots) average X- and Y-component values compiled throughout all hours of the 5 quietest days each month (http://isgi.unistra.fr). (a) Qaanaaq (THL). (b) Vostok (VOS). (data from https://intermagnet.org and http://www.wdc.bgs.ac.uk) (from Stauning, 2021a).

It is readily seen from Fig. 1 that deriving stable baseline values for Vostok data presents challenges. Fig. 2 from Stauning (2021a) extends the illustrations of the difficult Vostok data to including intervals with data otherwise characterized as "definitive" by INTERMAGNET (http://intermagnet.org).

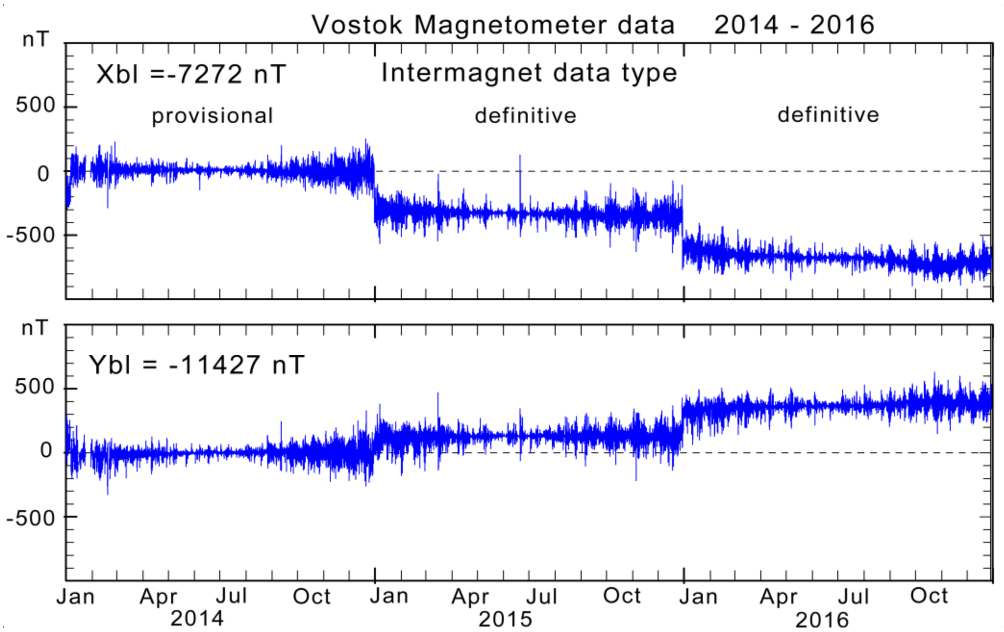

Fig. 2. Display of hourly values of the X and Y components of magnetic data from Vostok (VOS) using fixed base line levels (Xbl=-7272 nT, Ybl=-11427 nT) throughout the 3 years.

3. PCS index quality.

The PCS indices have been issued from the AARI web portal http://pcindex.org in the same version since their release in February 2014 and up to December 2021 only interrupted by a short pause in November 2021 due to missing security certificate. After December 2021 the PCS indices have been submitted from the present https://pcindex.org address (note the "s" in the address) with links carrying to "preliminary" and "definitive" versions, respectively. Note, that the download on 2 October 2021 gave the same index values whether the preliminary or the definitive link was used. In recent years the PCS indices have been provided from ISGI (http://isgi.unistra.fr) until present (18 January 2022) and there labelled "provisional".

The PCS data series up to December 2021 is invalid. It became evident in 2018 by observing excessive daily excursion varying between -1.5 and 2.5 mV/m superimposed on the PCS index values expected from other index data series based on the same Vostok data source or on data from Dome-C as shown in Fig. 3 (Stauning, 2018). These excessive daily systematic variations are readily seen in the field labelled "PCS (Vostok – IAGA)" in Fig. 3 (from Stauning, 2018).

The failure in the Vostok-based PCS indices was reported to the index providers in March 2018, who never replied, and to IAGA EC, who replied (21 May 2018) that "*users of the index should be aware of the risk of using it and not rely on a provisional or quick-look index for definitive science*" (sic!).

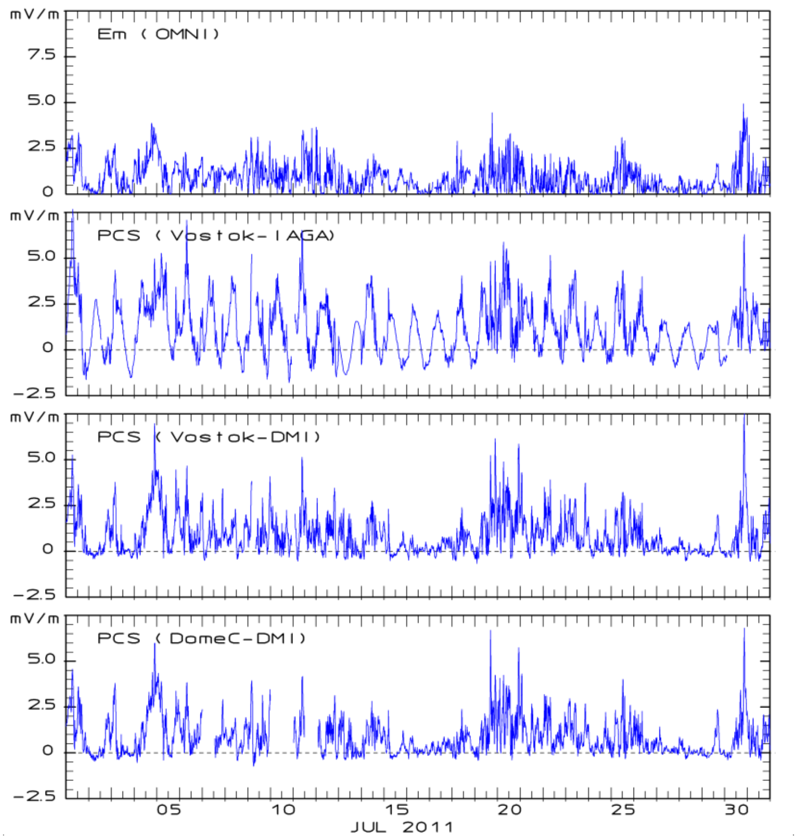

Figure 3. From top of the diagram display of (a) the solar wind merging electric field, E_M, derived from OMNIweb data, (b) PCS index values (http://pcindex.org) derived from Vostok magnetic data by the IAGA-endorsed procedure, (c) PCS index values derived from Vostok data and (d) PCS values derived from Dome-C data by DMI methods (from Stauning, 2018b).

These irregularities have been further investigated on basis of PCS data from AARI web site http://pcindex.org and the ISGI http://isgi.unistra.fr web portal. Illustrative results are displayed in Fig. 4 (from Fig. 12 of Stauning, 2020)

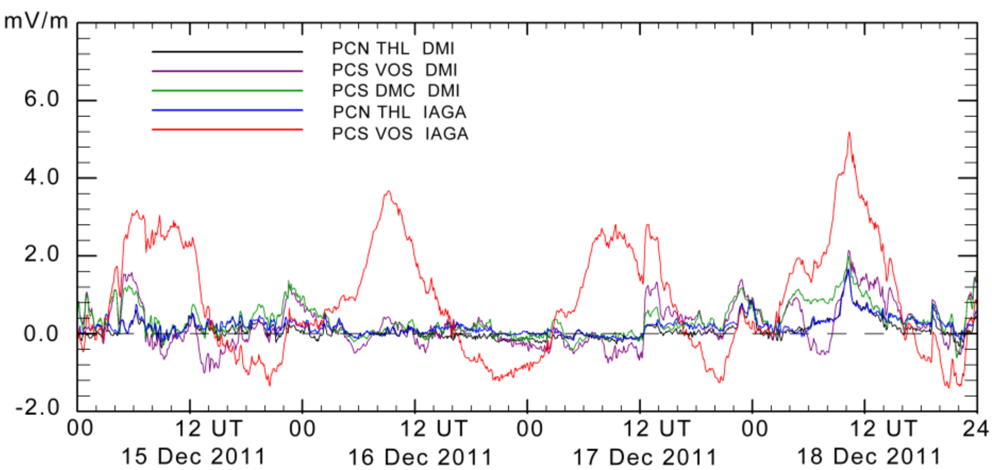

Figure 4. Display of published PCN (blue line) and PCS (red) values from 15-18 December 2011. PCN values (black) from Qaanaaq data, PCS from Vostok (magenta) and Dome-C (green) data derived by a different method (DMI, Stauning, 2016) have been added to the diagram. (from Stauning, 2020)

Figure 4 presents a display of different PCS versions. The versions “PCN THL IAGA” in blue line and “PCS VOS IAGA” in red line display PCN and PCS indices downloaded from the AARI portal http://pcindex.org (at that time without “s” in the address) confirmed by download from http://isgi.unistra.fr . The other versions have been derived by using DMI methods (Stauning, 2016) with data from Qaanaaq, Vostok and Dome-C, respectively.

AARI and ISGI have index plotting applications associated with their index platforms. Examples from http://pcindex.org and http://isgi.unistra.fr are displayed in Figs. 5a,b (from Stauning, 2020)

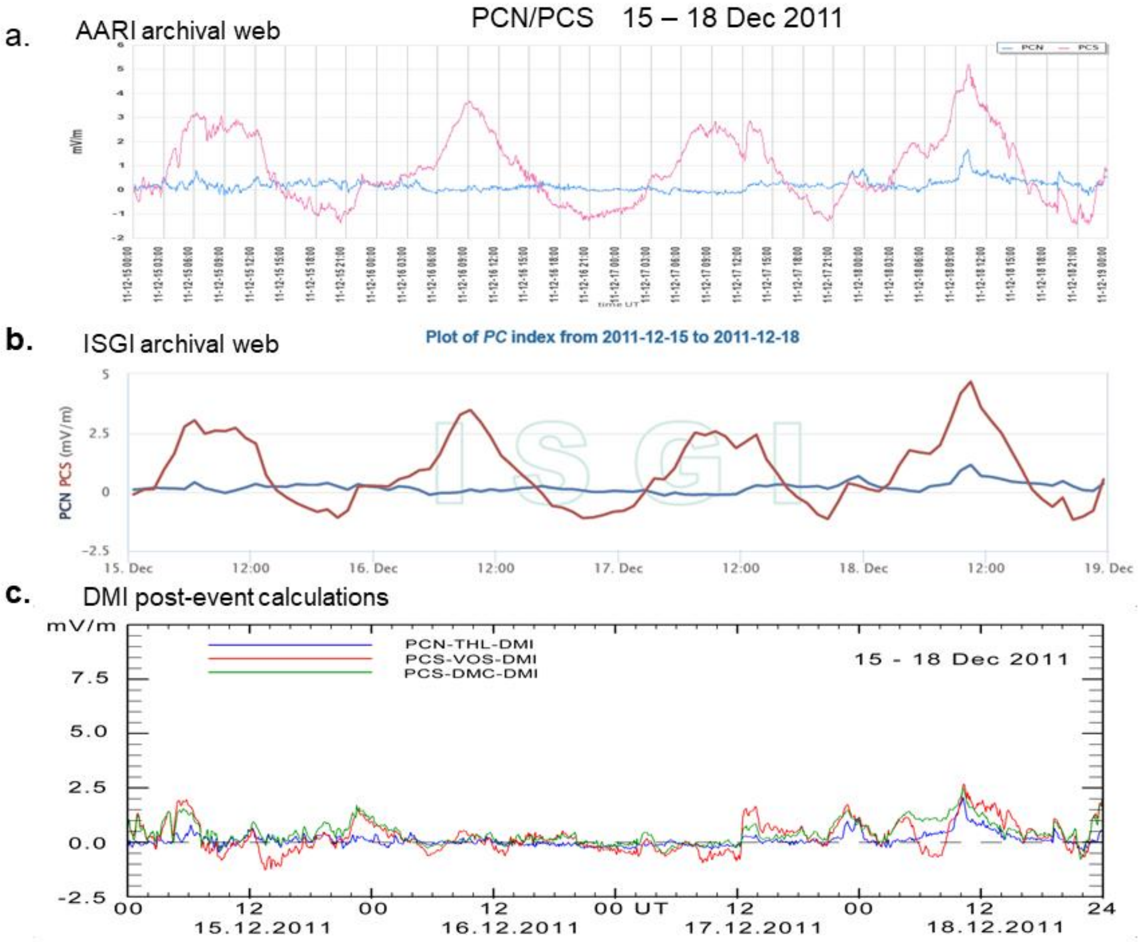

Fig. 5. Display of PCN and PCS values throughout 15 to 18 December 2011 in (a) AARI (pcindex.org), (b) ISGI (isgi.unistra.fr), and (c) DMI PCS versions (from Stauning, 2020)

The systematic daily excursions of amplitudes in the AARI PCS indices (red lines) between appr. -1 mV/m and 3 mV/m are most easily seen in quiet intervals such as panels (a) and (b). For the days in question the Kp indices varied between 1_0 and 4_- while the Dst(min) indices varied between -11 and -39 nT with 18 December being the most disturbed day. PCS indices derived by DMI methods (Stauning, 2016) are shown in panel c.

With the new AARI PCS index version being available since December 2021 at https://pcindex.org it is now possible to directly compare the two index series submitted from AARI before and after December 2021. An example is displayed in Fig. 6.

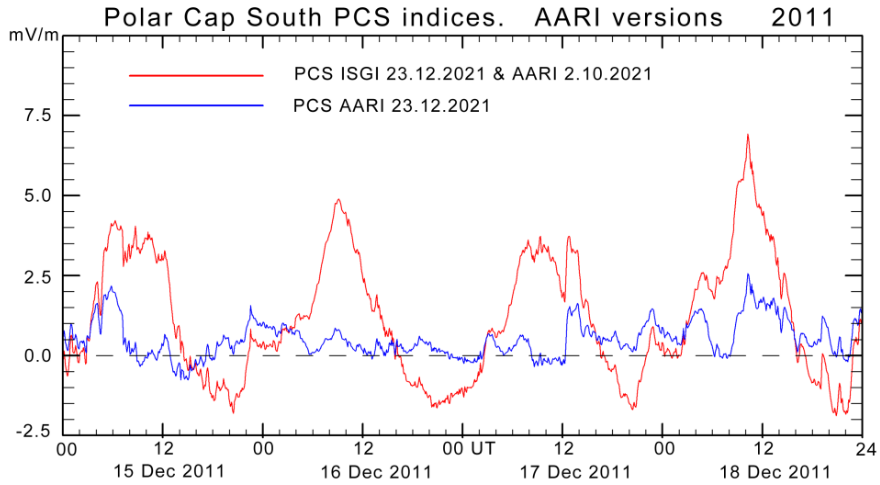

Fig. 6. Differences for 15-18 December 2011 between PCS values in red line downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values in blue line downloaded from AARI https://pcindex.org on 23 December 2021.

In Fig. 6 the pre-December2021 PCS indices for 15-18 December 2011 (“PCS-ISGI”) are displayed in red line while the post-December2021 PCS indices (“PCS-AARI”) are displayed in blue line. Their differences ranging between -2 mV/m and +3.0 mV/m are easily detected. It appears obvious that the series marked “ISGI” is invalid. However, both index series are provisional and are not endorsed by IAGA resolution #3 (2013). It has not been possible to re-calculate these indices in order to locate the failure in the processing procedures since there is no description of the PCS calculations available from AARI other than reference to Troshichev et al. (2006). DTU Space has informed that AARI uses the same procedures as they use.

Another example of the differences between pre-December2021 (red line) and post-December2021 (blue line) PCS indices is displayed in Fig. 7 for 18-21 December 2014. The daily excess PCS indices are again easily spotted. There might be similar problems in the new PCS index series.

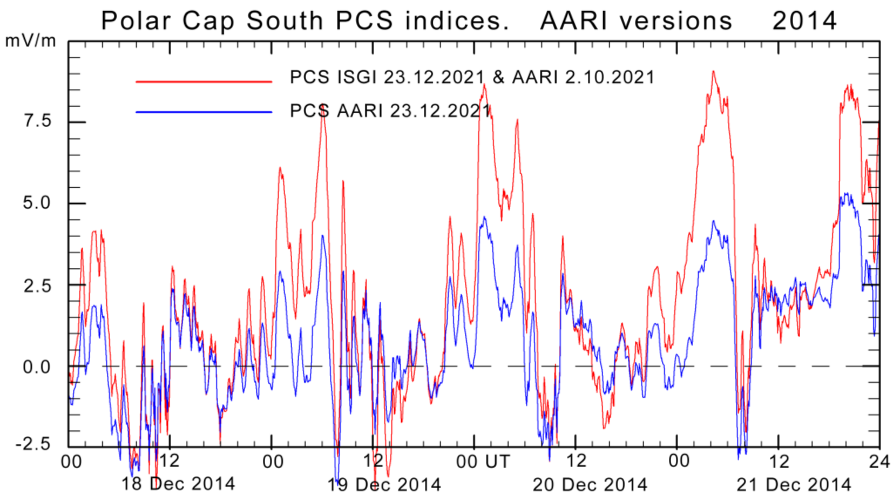

Fig. 7. Differences for 18-21 December 2014 between PCS values in red line downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values in blue line downloaded from AARI https://pcindex.org on 23 December 2021.

A more comprehensive view of the differences between pre- and post-December 2021 PCS indices is provided in Fig. 8 with the differences between pre- and post-December2021 PCS indices displayed by their hourly average values for 2011. Note that the PCS(ISGI) values are the same as the pre-December2021 AARI PCS values, which were downloaded from the "definitive" link of https://pcindex.org on 2 October 2021.

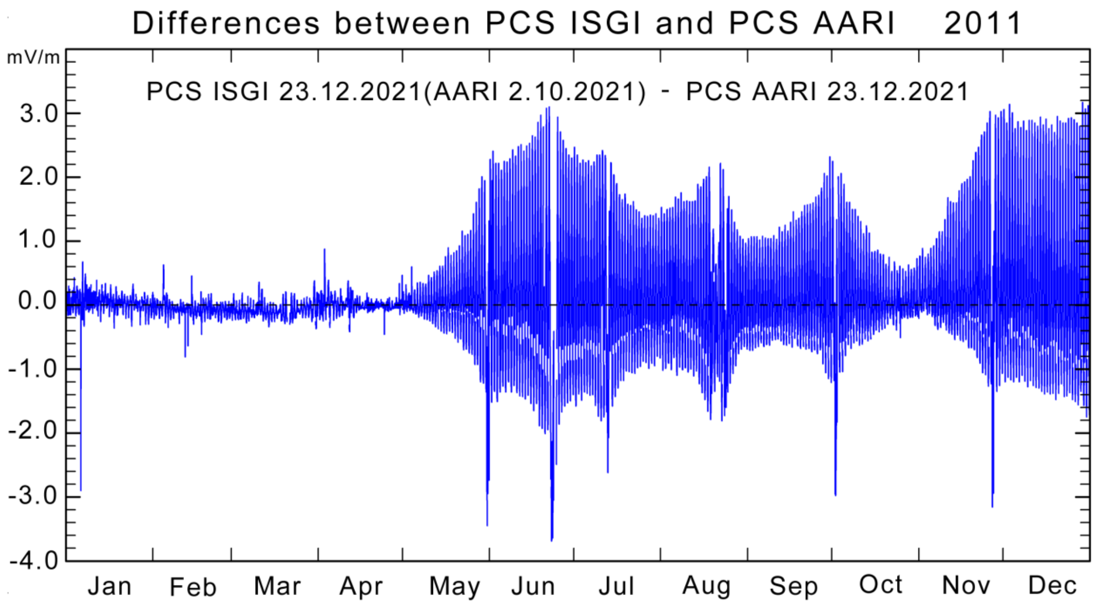

Fig. 8. Differences for 2011 between hourly averages of PCS values downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values downloaded from AARI https://pcindex.org on 23 December 2021.

This year (2011) is the worst but not the only year with invalid PCS indices. Further intervals of clearly invalid PCS values have been detected in:

Dec 2000

Dec 2001

Jan 2002, Dec 2002

Jan 2004, Nov 2004

Dec 2005

Dec 2006

Jan 2009, Jun 2009

May to Dec 2011 (cf. Fig. 8)

Aug 2013, Dec 2013

Jan 2014, Nov 2014, Dec 2014

The list is not necessarily complete. Intervals of invalid PCS indices could be difficult to detect during periods of disturbed conditions.

4. Discussions

The analyses in section 3 have documented differences between the PCS index values in the version issued since December 2021 from https://pcindex.org amounts to excursions from – 2 mV/m up to more than 3 mV/m over extended intervals (cf. Fig. 8 and further intervals of invalid PCS index values).

In order to judge the importance of such differences it could be noted that PC index values above 1.5 ±0.5 mV/m indicate onset of magnetic storm or substorm conditions according, for instance, to Troshishev et al. (2014).

Thus, excess PCS indices of magnitudes from -2 to 3 mV/m could be expected to generate substantial effects on the results and conclusions presented in publications. It is, in general, quite difficult for other than the authors to access the precise magnitude of the impact of using the invalid PCS indices. However, in some cases it is possible for scientists outside the group of authors at AARI to detect irregularities arising from the use of invalid PCS indices.

Figure 2 of Troshichev et al. (2020) presents the mean yearly values of PCN and PCS indices. Such yearly mean PCN and PCS values should be equal to within a few percent since both PC index versions are calibrated against the common merging electric field, E_{KL}. However, it is obvious that in 2007 and 2008 the mean PCN indices at 0.6 mV/m (blue dots) read from their Fig. 2 are larger than the mean PCS indices at 0.4 mV/m (red asterisks) by 0.1 mV/m, which is appr. 20%. In 2011 the mean of PCS indices at 0.71 mV/m in their Fig.2 are larger than the mean of PCN indices at 0.55 mV/m by 0.16 mV/m which is 37% of their mean value.

Such differences comply with the differences displayed in the illustrations provided in section 3 here. In calculations conducted at DMI on the same Vostok data and, for 2011 using also Dome-C magnetic data, there are only minor differences between mean PCN and PCS index values.

The blame for the devaluation of the above-mentioned 8 publications that join the 40 publication listed in section 5.2 of Stauning (2021c), which also suffer from having used invalid PC indices, is carried by IAGA for having endorsed the unclear Resolution #3 (2013) and neglected adhering to the requirements in par#2 of IAGA ***Criteria for endorsement of indices by IAGA (2009)***:

"*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 and the responsible institute will ensure the homogeneity of the data series over the whole time series*."

For the PCS index series there is no documentation beyond the sparse guidelines in Troshichev et al. (2006). Proper documentation would have enabled an independent examination of PCS index derivation methods and possibly enabled detection of the error in their processing software shared with DTU Space. Independent calculations of PCS indices based on Vostok (or Dome-C) data have provided values without the excessive systematic daily excursions that haunt the AARI pre-December2021 PCS index series (cf., Figs. 3, 4, and 5c)

Conclusions.

- The present work has identified the invalid PCS indices issued from the Arctic and Antarctic Research Institute (AARI) between 2013 and 2021. The invalid PCS values differ from the recently published PCS values issued in December 2021 by the same index provider (AARI) by amounts ranging between appr. – 2 and +3 mV/m.

- Noting that such differences considerably exceed the PC index values (appr. 1.5 mV/m) considered to cause onset of magnetic storm or substorm conditions, it is suggested that authors of publications that have used PCS indices issued between February 2014 and December 2021 review their submissions in order to detect and report failures that may have arrived from the use of invalid PCS indices.

- It is suggested that the authors of such publications are asked to specify, for instance in a corrigendum, that the PCS indices used in their works are provisional values which may suffer from undetected failures.

- The present work has demonstrated in a specific example from Troshichev et al. (2020) that the invalid PCS index series has generated considerable disproportions in the relations between yearly mean values of the PCN and PCS indices. Further effects are likely to appear at more extensive examinations of publications that have used PCS indices in the pre-December 2021 version.

Data availability.

An extended analysis of the PCS index could be found in "Note on examination of PCS index versions" from 27 December 2021 at Stauning, Peter: "NotePCSindexExamination-27-12-2021.pdf", Mendeley Data, V1, https://doi.org/10.17632/mphb8d7cv5.1 .

Geomagnetic data from Qaanaaq, Vostok, and Dome-C observatories were downloaded from the INTERMAGNET data service web portal at http://intermagnet.org. Spacecraft data needed to generate merging electric field values were downloaded from the OMNIweb service portal http://omniweb.gsfc.nasa.gov . QD data were downloaded from the ISGI data service portal http://isgi.unistra.fr.

The magnetic observatory in Qaanaaq is managed by the Danish Meteorological Institute, while the magnetometer instruments are operated by DTU Space, Denmark. The Vostok observatory is operated by the Arctic and Antarctic Research Institute in St. Petersburg, Russia. The Dome-C observatory is managed by Ecole et Observatoire des Sciences de la Terre (France) and Istituto Nazionale di Geofisica e Vulcanologia (Italy).

The "DMI" PC index version is documented in the report SR-16-22 (Stauning, 2016) available at the web site: http://www.dmi.dk/fileadmin/user_upload/Rapporter/TR/2016/SR-16-22-PCindex.pdf

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