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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.

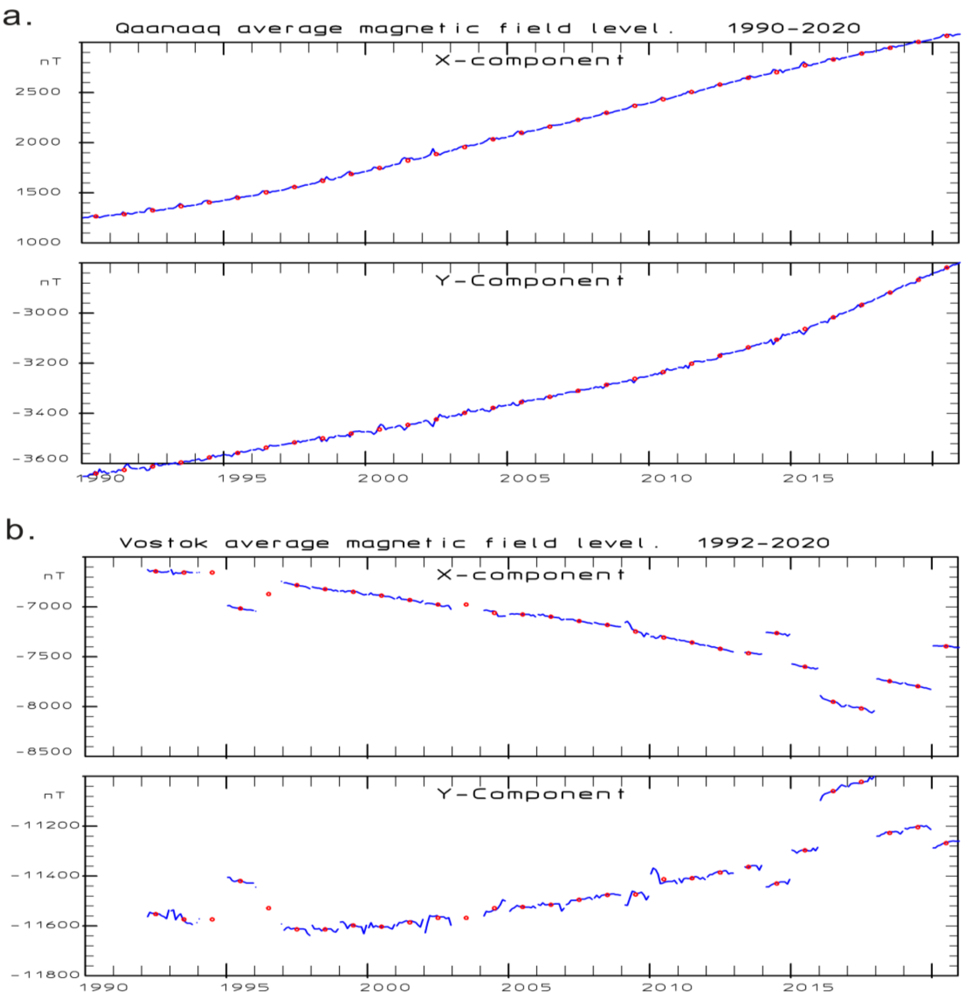

Fig. 1. Monthly (blue line) and yearly (red dots) average X- and Y-component values compiled throughout all hours of the 5 quietest days each month (http://isgi.unistra.fr). (a) Qaanaaq (THL). (b) Vostok (VOS). (data from https://intermagnet.org and http://www.wdc.bgs.ac.uk) (from Stauning, 2021a).

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).

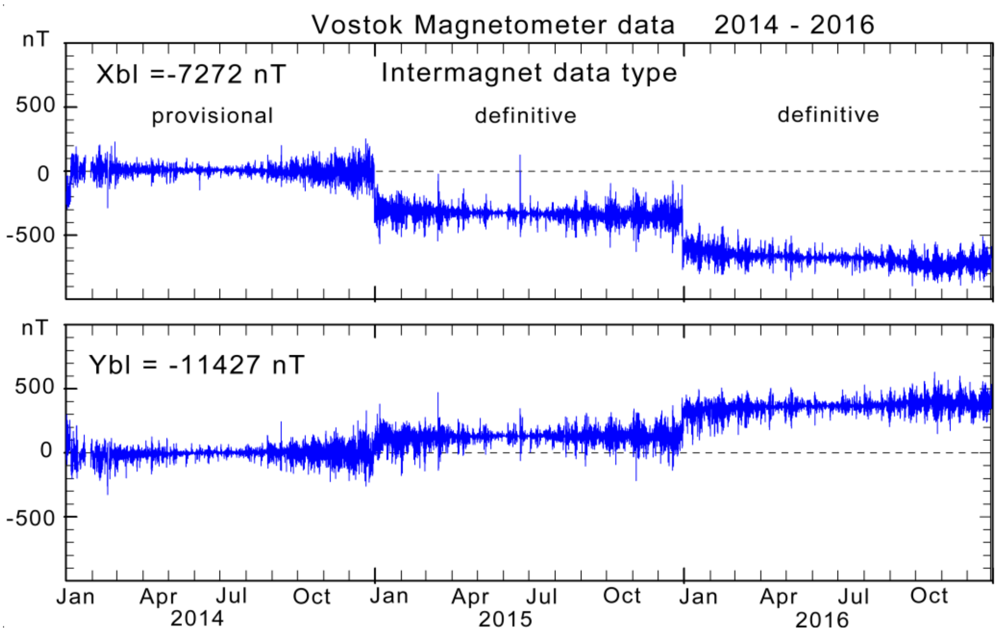

Fig. 2. Display of hourly values of the X and Y components of magnetic data from Vostok (VOS) using fixed base line levels (Xbl=-7272 nT, Ybl=-11427 nT) throughout the 3 years.

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!).

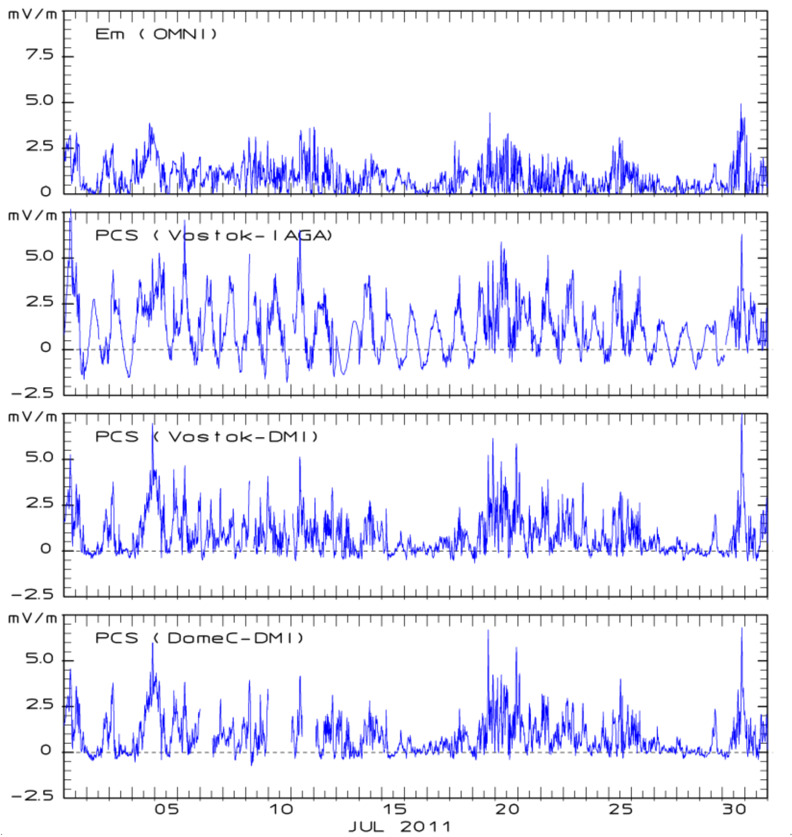

Figure 3. From top of the diagram display of (a) the solar wind merging electric field, E_M, derived from OMNIweb data, (b) PCS index values (http://pcindex.org) derived from Vostok magnetic data by the IAGA-endorsed procedure, (c) PCS index values derived from Vostok data and (d) PCS values derived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

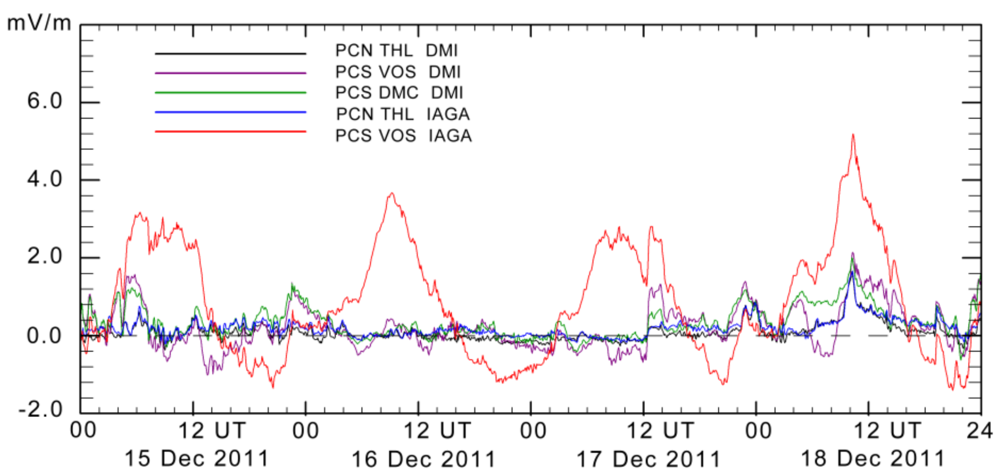

Figure 4. Display of published PCN (blue line) and PCS (red) values from 15-18 December 2011. PCN values (black) from Qaanaaq data, PCS from Vostok (magenta) and Dome-C (green) data derived by a different method (DMI, Stauning, 2016) have been added to the diagram. (from Stauning, 2020)

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)

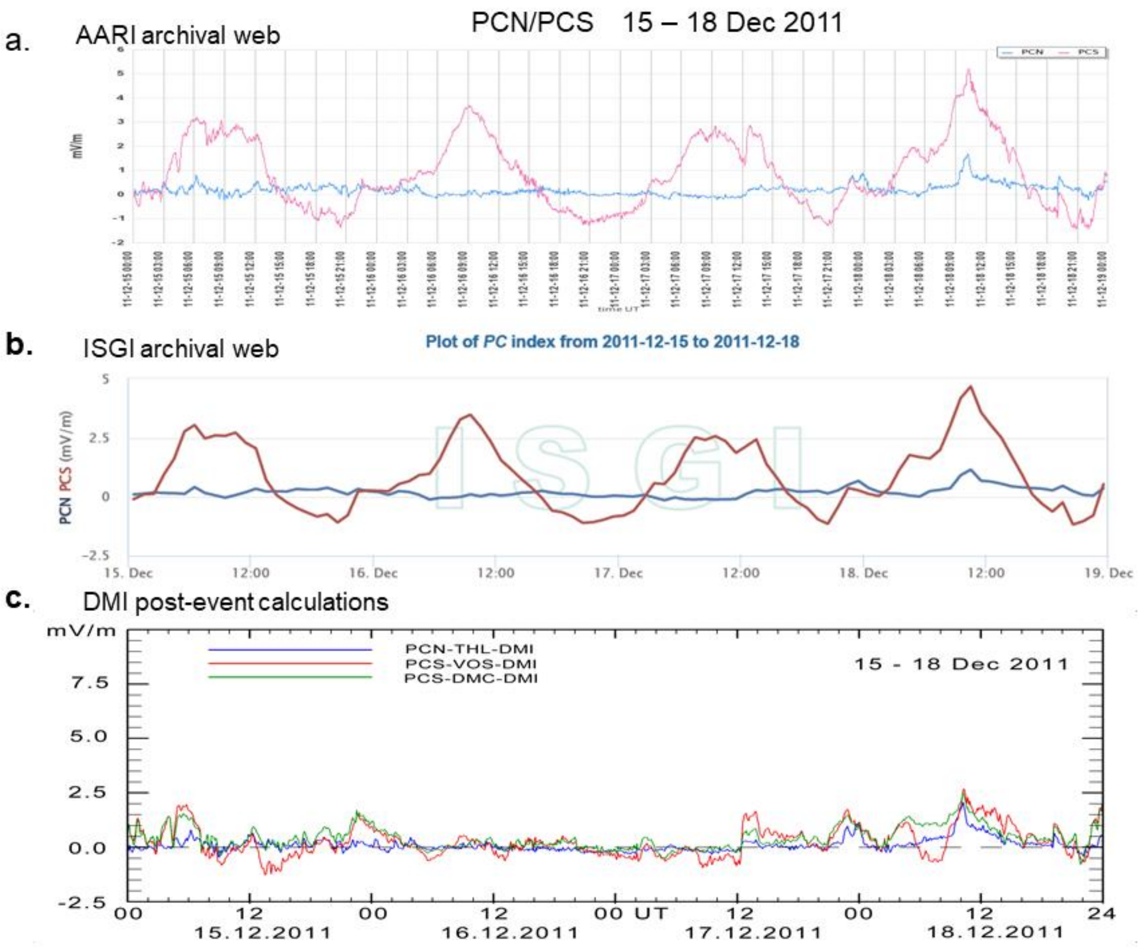

Fig. 5. Display of PCN and PCS values throughout 15 to 18 December 2011 in (a) AARI (pcindex.org), (b) ISGI (isgi.unistra.fr), and (c) DMI PCS versions (from Stauning, 2020)

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.

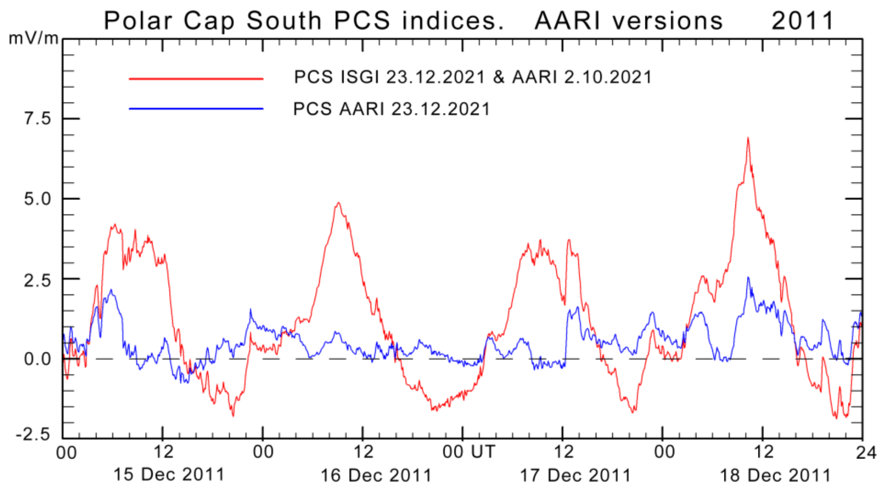

Fig. 6. Differences for 15-18 December 2011 between PCS values in red line downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values in blue line downloaded from AARI https://pcindex.org on 23 December 2021.

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.

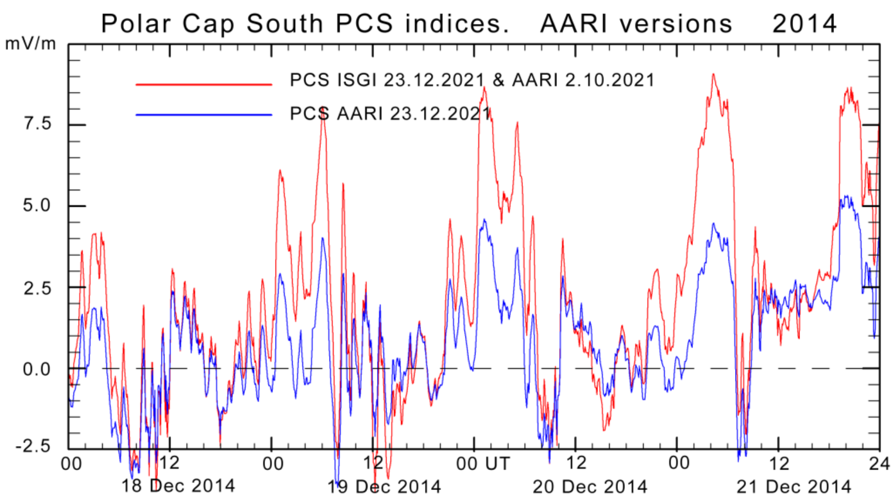

Fig. 7. Differences for 18-21 December 2014 between PCS values in red line downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values in blue line downloaded from AARI https://pcindex.org on 23 December 2021.

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.

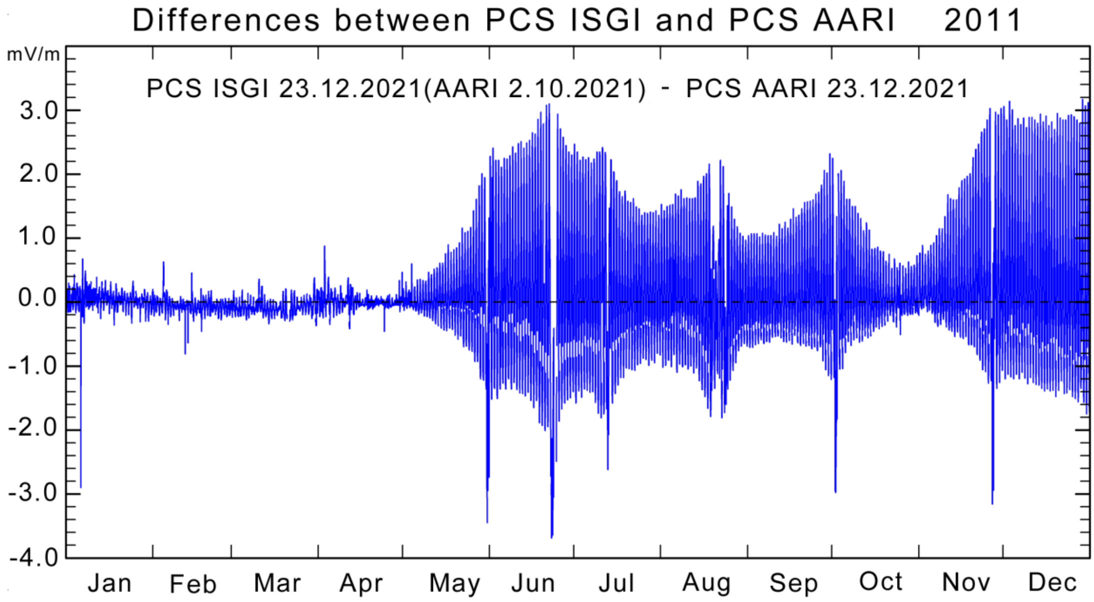

Fig. 8. Differences for 2011 between hourly averages of PCS values downloaded from AARI web http://pcindex.org on 2 October 2021 (identical files downloaded from http://isgi.unistra.fr on 23 December 2021) and PCS values downloaded from AARI https://pcindex.org on 23 December 2021.

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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