

Comments to paper Stauning, P. (2022) The use of invalid Polar Cap South (PCS) indices in publications. *Journal of Geophysical Research: Space Physics*, 127, e2022JA030355

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Abstract. Declaration (Stauning, 2022) on “invalid *PCS* index” is based on the following arguments: *PCS* index is calculated with use of incorrect procedure (Janzhura and Troshichev, 2011), as a part of the unified *PC* derivation (Troshichev et al., 2006) method; *PCS* index used in analyses is a preliminary index, which was not approved by IAGA and, therefore it cannot be regarded a correct index; *PCN* and *PCS* indices demonstrate, from time to time, large difference in value, which should be treated as evidence of the *PCS* index invalidity. The paper presents comments to these arguments. (1) Procedure (Janzhura and Troshichev, 2011) was never applied in the unified *PC* derivation method (Troshichev et al., 2006), which is used for calculation of “correct” *PCN* index and “invalid” *PCS* index”. (2) IAGA approved the *PC* index and method of the index derivation in 2013, when the definitive *PCN* and *PCS* indices have not been produced. Definitive *PCN* and *PCS* indices were approved by IAGA in 2021. (3) Difference between *PCN* and *PCS* indices reached the maximum in solstice periods is natural phenomenon related to the *PC* seasonal variation ($PC_{summer} > PC_{winter}$) explained by peculiarities of the field-aligned currents closure in the winter and summer polar caps. Conclusion is made that criticism of the *PCS* index, presented in Stauning (2022), is based on groundless arguments.

Introduction

Paper (Stauning, 2022, thereafter St2022)] is designated to demonstrate the invalidity of the Polar Cap South (*PCS*) index and, correspondingly, the results of numerous analyses (their list is given in St2022, section 4) fulfilled with application of the *PCS* index. A number of assertions is given in St2022 to motivate the *PCS* erroneousess. Below we shall examine these assertions in order of their mention in St2022 to display the unfounded character (to put it mildly) of the presented arguments. The assertions presenting direct quotations from St2022 are marked by Arial.

1. Comments to section 1. Introduction (St2022)

1.1 “The Polar Cap (*PC*) indices, *PCN* (North) and *PCS* (South) indices were developed through the pioneering works of Troshichev and Andrezen (1985) and Troshichev et al. (1988). Further *PC* index developments were made by Vennerstroem (1991), Troshichev et al. (2006), Stauning et al. (2006), and Stauning (2007, 2011, 2016, 2018c, and 2021c)”.

Index of the polar cap (*PC*) magnetic activity, elaborated in the Arctic and Antarctic Research Institute (AARI, Saint-Petersburg) (Troshichev & Andrezen, 1985), has been put into the practical use in cooperation with Danish Meteorological Institute (DMI, Copenhagen) (Troshichev et al., 1988). The 15-min *PC* index was calculated independently for Northern and Southern polar caps by data of magnetic observations at the near-pole stations Quanaak (Thule) in the Greenland (*PCN*) and station Vostok in the Antarctic (*PCS*) since 1998. However, the procedures of the *PCS* and *PCN* indices derivation adopted, correspondingly in the AARI and in DMI, turned out to be different in detail. As a result, when the 1-min *PCN* and *PCS* values were brought into practice (1999) the inconsistency between the indices turned out to be a regular phenomenon, especially

during the disturbed periods. To resolve the problem the unified method of *PC* index derivation, approved by both sides, was required.

In 2008 the IAGA Division V-DAT appointed a special Task Force to resolve the long-standing *PC* index issue. Three competing methods for the *PC* index derivation were presented to Task Force team for consideration: the official DMI method (Vennerstroem, 1991), the unified method (Troshichev et al., 2006, thereafter JS2006) and the method of Dr. Stauning, published later in (Stauning, 2011, thereafter St2011). After comprehensive analysis fulfilled by the Task Force team (see McCreadie and Menvielle, 2010), these methods were examined by the IAGA Division V-DAT at the working meeting at Vienna in May 2010, and the TJS2006 method was recommended, as the best one, for the IAGA endorsement. In 2010 the Space Research Institute of Danish Technical University (DTU-Space) became responsible for magnetic observations at Thule station. During next two years the AARI and DTU teams got agreement on all details of the *PC* derivation procedure. The corresponding documentation was prepared and submitted to IAGA in 2013 (Matzka and Troshichev, 2014). In 2013 the *PC* index, derived by the unified TJS2006 method, was approved by IAGA as a new international index of magnetic activity, characterizing the solar wind energy that enters into the magnetosphere [XXII IAGA Assembly, Mexico, 2013, Resolution N3]. In 2014 all series of the *PCN* and *PCS* indices for previous years were recalculated in accordance with the unified *PC* derivation TJS2006 method.

As answer to the IAGA (2013) decision approving the *PC* index derived by the unified TJS2006 method, Dr. Stauning published in subsequent years a number of papers, where the IAGA-endorsed *PC* index was claimed as invalid index (Stauning, 2013a, 2013b, 2015, 2016, 2018a, 2018c, 2020, 2021a) with reference to advantages of St2011 method above the TJS2006 method. It is not quite clear, why the St2011 method rejected by IAGA-2013, can be announced (Stauning, 2022) as “further developments of the *PC* index”?

Quality of the *PCN* and *PCS* indices, produced by the unified TJS2006 method, was checked by IAGA in 2021. Making allowance for good consistency between the definitive and preliminary *PCN/PCS* indices observed during 22 years (1997–2019) the IAGA ultimately approved the *PC* index and recommended the index for use by international scientific community (IAGA 2021, resolution №2).

It should be noted that Dr. Stauning has modified his criticism after the IAGA 2021 decision. In the previous publications (Stauning, 2013a, 2013b, 2015, 2016, 2018a, 2018c, 2020, 2021a) the IAGA-endorsed *PC* index was announced as “invalid”. At present (St2022) the *PCS* index (calculated in AARI) is only claimed (St2022) as “invalid”, whereas the *PCN* index (calculated in DTU) is regarded as correct, although both indices are derived by the same unified TJS2006 method. To justify this transformation, it is alleged (St2022) that the IAGA 2013 approval was related only to *PCN*, but not to *PCS* index. But this new approach means that the IAGA endorsed *PC* index derivation method is judged in (St2022) as correct met. On the other side, the definitive *PCS* indices, approved by IAGA in 2021 (IAGA Resolution № 2 (2021): Polar Cap (*PC*) index), turned out to be consistent with preliminary *PCS* indices

1.2 The resolution was later in 2013 endorsed by IAGA Executive Committee (EC). Note the unclear text: “the *PC* index” and “serves as a proxy for energy that enters into the magnetosphere” and “use of the *PC* index”. Actually, there is no “*PC* index” but *PCN* and *PCS* indices. The unclear formulation opens for misunderstanding or misuse of the resolution.

It should be reminded that the unified TJS2006 method ensured conformity between the *PCN* and *PCS* indices in their response to the solar wind influence, regardless of polar cap where the magnetic activity is observed. As results (Troshichev et al., 2022) have demonstrated, there is

perfect harmony in response of the *PCN* and *PCS* indices to the solar wind E_{KL} changes during 23/24 solar activity cycles, as well as in relationships between the *PCN/PCS* indices and magnetic disturbances (*AL*, *Dst* indices). Does Dr. Stauning believe that *PCN* and *PCS* indices, as proxies of the solar wind influence effects in the southern and northern polar caps, should be derived by different methods and should be endorsed by separate IAGA decisions?

1.3 *PCS* indices were never derived in definitive versions.....

The other (new) *PCS* version has been issued since December 2021 from the “definitive” link of the AARI portal, <https://pcindex.org>

The real state of things is the following. According to the IAGA rules, the “provisional” (preliminary) indices, obtained by data of current magnetic observations, should be then verified with allowance for all possible faults of observational, technical and computer-assisted origin, to produce the “definitive” indices, which will be valid for ever. This work was fulfilled in AARI in 2021 with application of the restructured and harmonized code (Nielsen & Willer, 2019). The *PCN* and *PCS* indices were finally approved by IAGA in 2021 taking into account conformity between the corresponding provisional and definitive *PCS* indices as well as agreement between the definitive *PCN* and *PCS* indices. After December 2021 the AARI portal <https://pcindex.org> presents the definitive *PCS* indices for 1997-2019, as well as the provisional *PCS* indices for period from 2020 to current days and the quick-look *PCS* indices for current days.

1.4 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 standard”.

The Vostok (VOS) station is a member of INTERMAGNET - the global network of observatories, monitoring the Earth's magnetic field. INTERMAGNET is associated with IAGA and the World Data System ICSU. The INTERMAGNET programme exists to establish a global network of cooperating digital magnetic observatories, adopting modern standard specifications for measuring and recording equipment, in order to facilitate data exchanges and the production of geomagnetic products in close to real time. Annual definitive data from all INTERMAGNET magnetic observatories (IMOs) are carefully prepared and checked for quality and compliance in a three stage process before they are accepted and published (<https://www.intermagnet.org/>).

2. Comments to section 2. Polar Cap (PC) Indices (St2022)

2.1 The *PC* index derivation methods have been questioned and modifications suggested in Stauning (2013a, 2013b, 2015, 2018a, 2020, 2021a).

What is advantage of the unified *PC* derivation *TJS2006* method? It is well known that magnetic activity in the polar caps is dependent on the electric field generated by the solar wind and on ionospheric conductivity affected by regular and irregular solar UV irradiance as well as by the solar proton injections in periods of solar proton events (SPE). Therefore, to estimate correctly the polar cap magnetic activity, related to the solar wind action, it is necessary to separate this activity from the geomagnetic alterations, related to the solar UV irradiation effect. The problem was resolved in AARI (*TJS2006* method) taking into account not only regular daily and seasonal UV variations, but also the irregular UV irradiation rises related to solar flares, which duration is much longer (several days) than the typical duration of the electric field E_{KL} changes produced by the geoeffective solar wind (from minutes to hours). Consideration of the solar flares UV effect as a long-term factor in comparison with the short-term solar wind E_{KL} factor made it possible to distinguish the irregular UV effects related to solar flares and to incorporate them in QDC, which is used as a level of reference to account off the solar wind effect.

Critique of the unified *PC* derivation *TJS2006* method is mainly based on comparison of the SS effect derivation method suggested by Stauning (2011) and the IMF By identification method suggested by Janzhura and Troshichev (2011, thereafter *JT2011*). The *JT2011* method is erroneously regarded by Stauning as a part of the QDC derivation procedure in *TJS2006* method. In actuality the *JT2011* method was never used in the QDC calculation procedure (see, as example, description of software applied for the *PC* index calculation (Nielsen & Willer, 2019)). Indeed, the QDC derivation procedure in *TJS2006* takes into account the data for the 5 quietest days, which are selected from 30 previous days, the SS effect having been subtracted previously. In contrast, the *JT2011* method concerns with median values for 9 days preceding to the current day, which are subjected to 3-days running average, and then the interpolation procedure is applied to these smoothing averages. Nevertheless, the *JT2011* method is repeatedly criticized in papers (Stauning 2013a, 2015, 2016, 2018a, 2018c, 2020, 2021a) as an integral and incorrect part of the unified *PC* derivation *TJS2006* method, with corresponding conclusion that “*the IAGA recommended near-real time indices highly unreliable and thus unsuitable for space weather applications*”.

The competitive *St2011* method, named as a solar rotation weighted (SRW) method, emphasizes the regular 27-days periodicity (“sector structure”) in magnetic activity and levels off the irregular effects being about 180° out of phase with 27-periodicity. As a result, the effects of irregular UV variations related to solar activity occurred to be attributed to the solar wind effects. For this reason the SRW method was rejected by the IAGA Division V-DAT in May 2010,

2.2 The magnetic observations from Vostok suffer, among others, from the observatory position on the unstable ice sheet and the extreme climatic conditions, which imply that the observational quality would not enable the characterization “definitive” for the data and the derived PCS indices; they are only “provisional” (or “preliminary”). These concerns have been brought forward in a proposal to establish an alternative PCS index based on data from the French-Italian research station, Dome Concordia (Dome-C).

It is very strange statement. For the first time I am hearing that status of geomagnetic data, “definitive” or “preliminary” is determined by the observatory position. In this connection it should be indicated that both stations, Vostok and Dome C, are located at the Antarctic Ice Dome under the similar climatic and ice conditions. Indeed, the ice sheet drift at Dome C station (~ 10 cm/year) is much lesser than that at the Vostok station (~ 100 cm/year) and South Pole station (~ 1000 cm/year). However, everybody knows that instability of the main geomagnetic field, observed at the stations, is determined first of all by drift (10 - 15 km/year!) of the Sought magnetic pole.

3. Comments to Section 3. PCS Index Quality (St2022)

The AARI PCS index 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 Figure 8 of Stauning (2018b).

It was indicated above that “provisional” (preliminary) *PCS* indices, derived by data of current magnetic observations, were recalculated in 2021 making allowance for possible faults of observational, technical and computer-assisted origin. The preliminary and definitive *PCS* indices turned out to be in good agreement, as well as the definitive *PCN* indices and *PCS* indices. The high correspondence between the definitive *PCN* and *PCS* indices provides evidence of high quality *PCS* and *PCN* indices as itself.

Figure 1 shows, as example, courses of daily values of the definitive *PCN* (blue) and *PCS* (red) indices and their difference (*PCN-PCS*) for 4 years related to various epochs of solar activity:

2000 (maximum), 2008 (decay), 2011 (growth) and 2019 (minimum). One can see that *PCN* and *PCS* indices synchronously increase and decrease, irrespective of epoch of solar activity. But value of difference between *PCN* and *PCS* values is dependent on season: *PCS* index is totally large than *PCN* index in November/December/January/February, whereas *PCN* index is larger in May/June/July/August, the indices being leveled in equinox (March/April and September/October). The difference between the daily values of *PCN* and *PCS* is the highest (> 1 mV/m) in epochs of solar activity maximum suggesting that that difference between the hourly values of *PCsummer* and *PCwinter* indices in these periods can be much higher. In the quiet periods the difference is minimal (< 0.5 mV/m). Exceeding of the *PCsummer* index values over the *PCwinter* values is a common peculiarity of the *PC* index, which is conditioned not by quality of the *PCN* or *PCS* index as such, but by physics of the solar wind – magnetosphere coupling (see Troshichev and Janzhura, 2012; Troshichev et al., 2022). It should be reminded that the *PCwinter* index is the better indicator of substorms development, irrespective of hemisphere (*PCN* or *PCS*) (Troshichev et al., 2014).

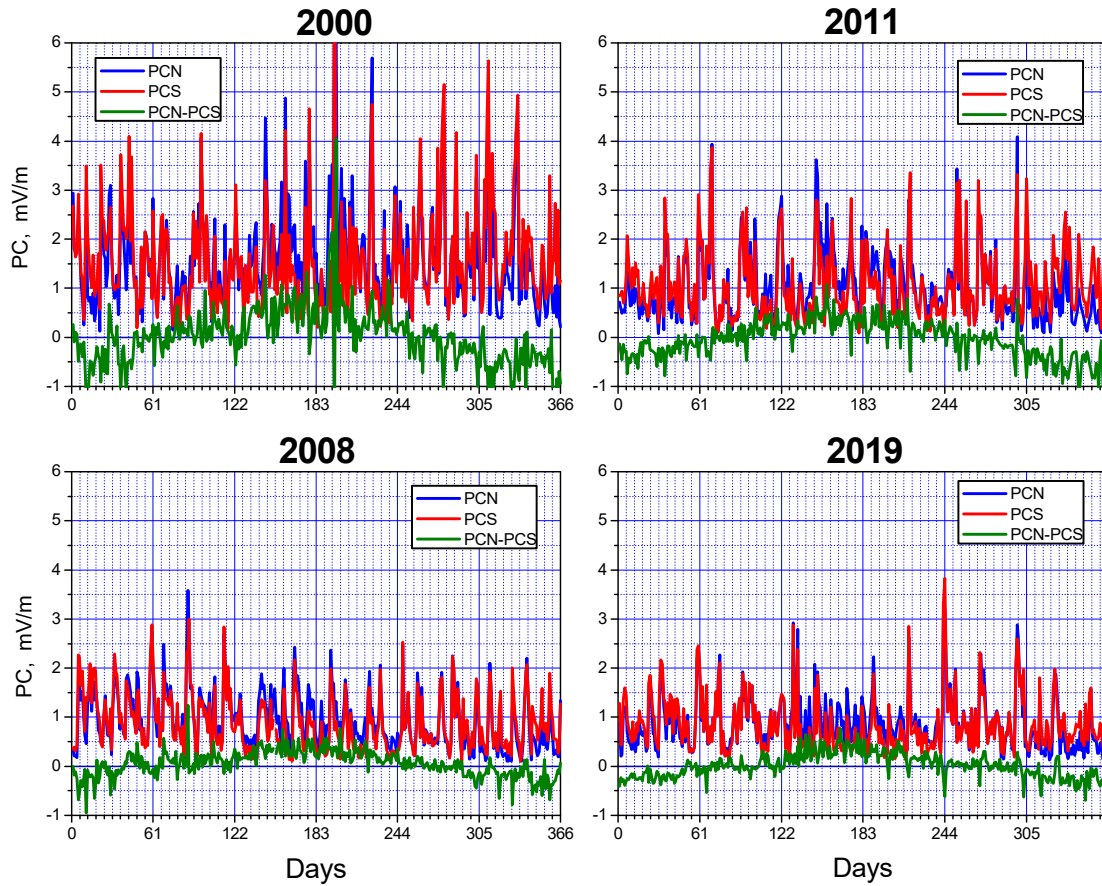


Figure 1. Courses of daily values of the *PCN* (blue) and *PCS* (red) indices and difference (*PCN-PCS*) (olive) in 2000 (epoch of solar maximum), 2011, and 2008, 2015 (epoch of solar minimum).

In this connection it should be noted that examples of discrepancies between the *PCN* and *PCS* indices, used as argument of bad quality of the *PCS* index (Stauning, 2022), are related just to 2011, when the evident problem with quality of absolute observations at Vostok station took place. (These problem have been resolved while producing the definitive *PC* index, see example in Figure 1). As Table 1 shows, correlation between the 1-min preliminary and definitive *PCS* indices over period 1997-2019 exceeded, as a rule, level 0.95, being so high as $R>0.98$ during 20 years from 22. Correlation fell down $R=0.822$ only in 2011 being the worst ($R<0.6$) in June and December of this

year (Table 2). Just preliminary *PCS* indices for these unfortunate periods are given in all publications of Stauning, as example of the *PCS* index inaccuracy, although these events present the evident exception to the rule in history of magnetic observations at Vostok station. Is it trustworthy to present the exclusive cases as regularity typical of station? It should be noted that after 2014, when the on-line *PCS* index production started, the *PCS* index quality does not evoke criticism.

Table 1. Correlation between the 1-min preliminary and definitive *PCS* indices in different years over the period 1997-2019.

Year	1997	1998	1999	2000	2001	2002	2004	2005	2006	2007	2008
Correlation	0.981	0.997	0.996	0.997	0.999	0.995	0.981	0.997	0.994	0.987	0.997
Year	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Correlation	0.988	0.996	0.822	0.995	0.982	0.953	0.981	0.983	0.988	0.988	0.984

Table 2. Correlation between the 1-min preliminary and definitive *PCS* indices in different months of 2011.

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Correl.	0.987	0.993	0.986	0.987	0.904	0.430	0.665	0.831	0.912	0.895	0.755	0.534

4. Comments to Section 4. The Use of *PCS* Indices in Publications (St2022)

4.1 Resolution #3 “recommends use of the *PC* index by the international scientific community in its “near-real time and definitive forms”. However, it should be noted that IAGA would endorse “definitive” indices only. It should also be noted that the recommendation mentions “the *PC* index”, while there are separate *PCN* and *PCS* indices, of which only the *PCN* indices could be generated in definitive versions.

Definitive version of *PCN* index could appear only after 2014 when the *PCN* index has been recalculated by the “unified *PC* derivation” TJS2006 method according to the IAGA Division V-DAT recommendation and the IAGA 2013 Decision. According to quotation from paper (Stauning, 2018c): “Controlled and verified index values are usually termed “definitive” by the data centres. However, the *PCN* values available since 1975 and the *PCS* index values available since 1994 are presently termed “provisional” by the International Service of Geomagnetic Indices (ISGI) as reported at their web site, <http://isgi.unistra.fr>.

4.2 The *PCS* indices were not and could not possibly be made definitive as their data basis is not “observatory standard”.

See our remark in section 1.4.

4.3 In addition, the derivation methods were never published thereby violating the requirements in par.#2 of IAGA Criteria for endorsement of indices by IAGA (2009).

The competing *PC* index derivation methods (TJS2006, Vennerstroem, 1991 and unpublished method of Dr. Stauning), submitted for examination of Task Force team, were described in detail in (McCreadie and Menvielle, 2010). Description of the TJS2006 method, which was endorsed by IAGA in 2013, was given by Matzka and Troshichev (2014). Contemporary software treated for the *PC* index calculation is presented in (Nielsen & Willer, 2019). The equivalency of the derivation procedures described in (Matzka & Troshichev, 2014 and Nielsen & Willer, 2019) is evidenced by conformity of the preliminary and definitive *PCS* indices, which were calculated, correspondingly, before and after 2021.

5. Discussions

According to Stauning (2022), “the use of the provisional PCS indices may have caused invalid features and incorrect conclusions in the affected publications” (Troshichev et al., 2014-2021). Let us examine the use of PC indices in these publications and the main results of the studies.

1. (Troshichev et al., 2014) Study of relationships between the *PC* index and substorms with use of the *PCN* and *PCS* indices in case of substorm events ($N=1798$) of different types. It was found that the substorm development is better related to changes of the *PC* index in winter season (*PCwinter*) than in summer season (*PCsummer*). Correlation between *PCwinter* and *AL* indices turned out to be so high as $\sim 0.9 \pm 0.05$, being dependent on substorm type regardless of hemisphere (*PCN* or *PCS*).
2. (Troshichev and Sormakov, 2015). Examination of the solar wind electric field E_{KL} behavior in course of substorms showed that *PC* index (*PCN* and *PCS*) strongly follows the E_{KL} field variations.
3. (Troshichev et al., 2018). Analysis of relationships between the field-aligned currents and *PC* index during the substorm growth phase showed the evident connection between the FAC intensity and *PC* index irrespective of hemisphere (*PCN* or *PCS* index), the FAC intensity in the summer polar cap was about twice higher than in the winter polar cap.
4. (Troshichev and Sormakov, 2018). Study of relationships between the magnetic storms ($N=249$) and *PC* index (1-min *PCN*, *PCS* indices, and their mean value *PCmean*) showed linear connection between the storm intensity (*SymHmin*) and maximum value of *PC* in the previous period (*PCmax*), the steady value of $PC > 1.5$ mV/m being a necessary condition for the storm development.
5. (Troshichev and Sormakov, 2019a). Analysis of relationships between the solar wind dynamic pressure (P_{SW}) impulses and *PC* index with use of the 1-min *PCmean* index showed that the *PC* and *AL* indices correlate (increase or decrease) with the P_{SW} changes if the P_{SW} impulses (leaps or drops) are accompanied by the corresponding changes in the solar wind E_{KL} field,.
6. (Troshichev and Sormakov, 2019b). Analysis of relationships between the electric field E_{KL} and *PC* index (1-min *PCN*, *PCS*, *PCmean* and *PCwinter*) showed that the *PCwinter* index demonstrates the best correlation with E_{KL} field. As this takes place, the correlation between E_{KL} and *PC* was low or even negative in about 20% of examined substorms ($N=1194$) testifying that solar wind fixed in the Lagrange point does not contact with the magnetosphere in about of 1/5 of the time history.
7. (Troshichev et al., 2021). Analysis of alteration of the annual values of *PC* index, solar wind parameters and magnetospheric disturbances during 22-23 solar cycles (1998-2019). It is shown that all versions of the average annual *PC* index (*PCN*, *PCS*, *PCmean*, *PCwinter*) altered during 24 years in good agreement to one another. The annual *PC* values perfectly correlate with the solar wind parameters V_{SW} , $|B|$ and E_{KL} , as well as with annual values of *AE* and *Dst* indices.
8. (Troshichev et al., 2022). Analysis of relationships between E_{KL} field and indices of magnetic activity *PC*, *AL* and *Dst* in course of 23/24 solar activity cycles. It is displayed invariability of these relationships irrespective of solar activity epochs and cycles. The *PCsummer* index is commonly larger than the *PCwinter* index, but *PCwinter* index better correlates with the solar wind E_{KL} field.

One can see that analyses of Troshichev et al. (2014-2021) were fulfilled with application of the preliminary or definitive *PCN* indices and preliminary *PCS* indices, which were derived by one and the same “unified PC derivation” TJS2006 method. The results of analyses demonstrated the same regularities for *PCN* and *PCS* indices, the seasonal peculiarities (*PCwinter* or *PCsummer*) being taken into account. Inaccuracies taken place in the *PCS* index derivation in 2011, were of accidental character and did not have any influence on the results of analyses of Troshichev et al (2014-2021). Remark made by Stauning (2022) “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 electric field E_{KL} ” is indicative of author’s misunderstanding of nature of phenomenon. Indeed, if the active period falls on the summer season in northern polar cap, the yearly mean value of *PCN*

will be larger than the value of PCS, and opposite regularity will takes place when the active period coincides with winter season in the northern polar cap.

6. Conclusions

Statement on invalid PCS index, made by Stauning (2022), is based on three main arguments, which are presented below in conjunction with our assessments:

1. *PCS index is calculated with use of incorrect JT2011 procedure, as a part of the unified PC derivation TJS2006 method.* This allegation is not in conformity with a real state of things. Besides, the same TJS2006 method is used for calculation of the “correct” PCN index.
2. *PCS index used in analyses is a preliminary index, which was not approved by IAGA and, therefore it cannot be regarded a correct index.* The same statement should be applied also to the PCN index. Besides, the preliminary PCS indices turned out to be consistent with the definitive PCS indices and they have been approved by IAGA in 2021.
3. *PCN and PCS indices demonstrate, from time to time, large difference in value, which should be treated as evidence of the PCS index invalidity.* PCN and PCS indices demonstrate regular seasonal variation ($PC_{summer} > PC_{winter}$), why the difference between the PCN and PCS values observed in solstice periods should be treated as evidence of the PCS index invalidity? It is natural phenomena explained by peculiarities of the field-aligned currents closure in the winter and summer polar caps.

Thus, our conclusion is that criticism of the PCS index, presented in Stauning (2022), is based on groundless and artificial arguments, and has no relation to reality.

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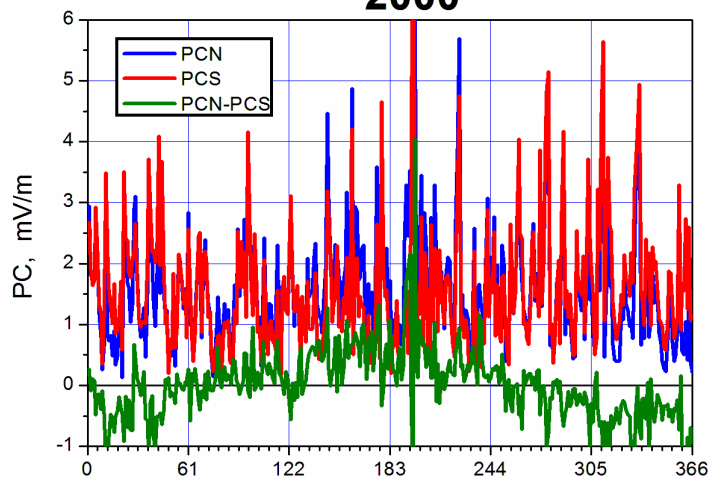
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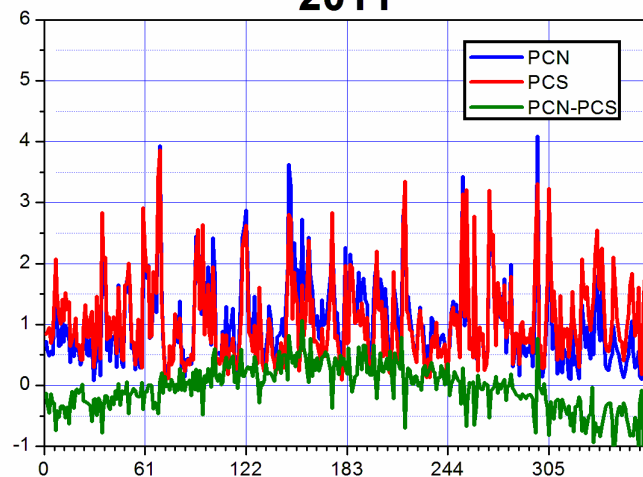
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Figure 1.

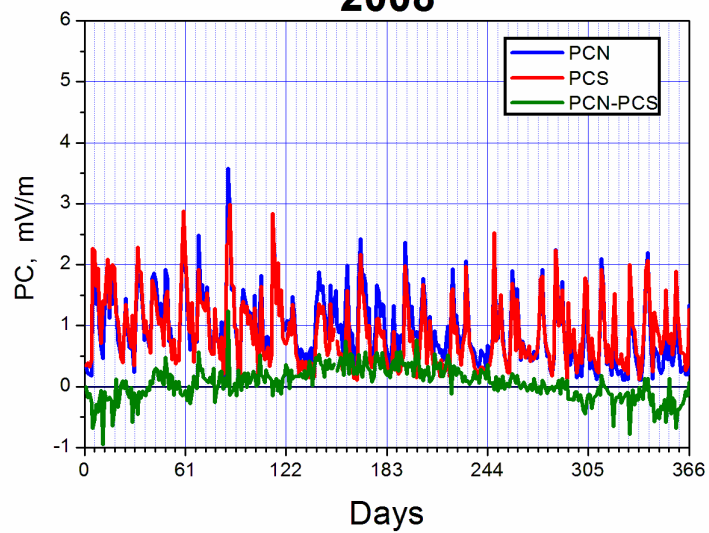
2000



2011



2008



2019

