EGU General Assembly 2018 · Vienna | Austria 8-13 April 2018

Critical assessment of the IAGA-endorsed Polar Cap (PC) indices

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Abstract.
The IAGA assembly by its resolution no. 3 (2013) endorsed the Polar Cap (PC) indices, PCN and PCS, in the versions presented jointly by the Arctic and Antarctic Research Institute (AARI) and the Danish Space Research Institute (DTU Space). In the resolution, "*IAGA …. recommends use of the PC index by the international scientific community in its near-real time and definitive forms* ". In spring 2014 the IAGA-endorsed PC indices were made available at the technically excellent web portal, http://pcindex.org. However, issues in the calculation of index coefficients, and in the determination of the reference level (QL), from which the disturbances are counted, which have not been examined and documented properly, deteriorate the general validity of the indices (*Stauning*, 2013, 2015). The archival PC index data, furthermore, comprises considerable sections of corrupted index values (*Stauning*, 2018a). In addition, the real-time index values display excessive variations with respect to the corresponding posterior index data (*Stauning*, 2018b).

Summary of shortcomings of the IAGA-endorsed PC indices

Noting that magnetic storm conditions are considered to accompany PC indices reaching levels above 1.5 ±0.5 mV/m (e.g., *Troshichev et al*., 2014), the following summary specifies the problems with the IAGA-endorsed methodology used for index derivation and demonstrates the magnitude of observed adverse effects.

1. Adverse reverse convection effects on index calibration parameters
The inclusion of reverse convection samples in the regression to derive index scaling parameters makes the slopes larger and the intercept coefficients more negative than justified. At high activity levels, the enhanced slope values reduce PC index levels and imply earlier saturation of index values (*Stauning*, 2018a). In examples of PCN calculations (*Stauning*, 2018a), the inclusion of reverse convection samples reduces PC index values by 2 to 3 mV/m at index levels between 10 and 15 mV/m. At low disturbance levels, the large negative intercept values generate unjustified contributions of 0.5 to 1 mV/m added to the index values (*Stauning*, 2015).

2. Questionable QL method used for archival (final) PC indices
The method used to determine the quiet reference level (QL) for calculations of archival (final) PC index values may generate unjustified contributions to the index values (*Stauning*, 2013, 2015). Calculations based on the data for June 2001 presented in *Janzhura and Troshichev* (2011), have documented unjustified contributions of up to 2.4 mV/m to the PC index values at local night and morning hours (*Stauning*, 2015).

3. Problematic QL method for real-time PC indices
The method used for calculations of the quiet reference level for real-time calculations of PC index values aggravates the QL problem detected for the archival index calculations. Examples based on downloads of index values from the PC index portal, http://pcindex.org, at different times gave differences between the real-time values at the download time and later downloads of the corresponding final PC index values of up to 3.67 mV/m (*Stauning*, 2018b).

4. Inadequate control and finalizing of PC indices
There is apparently no supervision of the real-time PC indices supplied from the index portal, http://pcindex.org, and no recording of the index values for posterior quality control. Furthermore, the archival (final) index values supplied from the PC index portal are not properly controlled. Recent downloads of PCS values for 2011 (*Stauning*, 2018a) showed unjustified daily oscillations between -1 and +2 mV/m superimposed on the proper index values throughout most of the year.

5. Lack of documentation of PC index derivation methods
Comprehensive documentation of the methods used for derivation of PC indices is not available. Partial descriptions found in the referenced publications, e.g., *Janzhura and Troshichev* (2008, 2011), are not in agreement with the data processing by the actual computer programs used for the index calculations

Basics.
The assumed relation between polar cap horizontal magnetic field variations projected to an "optimal direction", considered to be perpendicular to the DP2 transpolar plasma flow, and the Kan and Lee (1979) merging electric field ($E_M = V_{SW} \cdot B_T \cdot \sin^2(\theta/2)$) has the form:

$$\Delta F_{PROJ} = \alpha \cdot E_M + \beta \qquad (1)$$

where α is the "slope" (e.g. in units of nT/(mV/m)), while β (e.g. in units of nT) is the "intercept". The calibration parameters are calculated by regression from cases of measured values through an extended epoch. From equivalence with E_M, the Polar Cap Index PC is defined by:

$$PC = (\Delta F_{PROJ} - \beta)/\alpha \qquad (2)$$

Quality control
The basic PC index quality control comprises the verification demands in the description "Polar Cap (PC) indices" by *Troshichev* (2011) available at http://pcindex.org
- PCN and PCS indices should be consistent with the interplanetary electric field, E_M.
- PCN and PCS indices should be in close agreements with each other irrespective of season and UT time.
- Indices should not demonstrate seasonal variation.
- Indices should not demonstrate regular daily variation (i.e. dependence on UT-time).

Effects of reverse convection samples on slope and intercept coefficients.

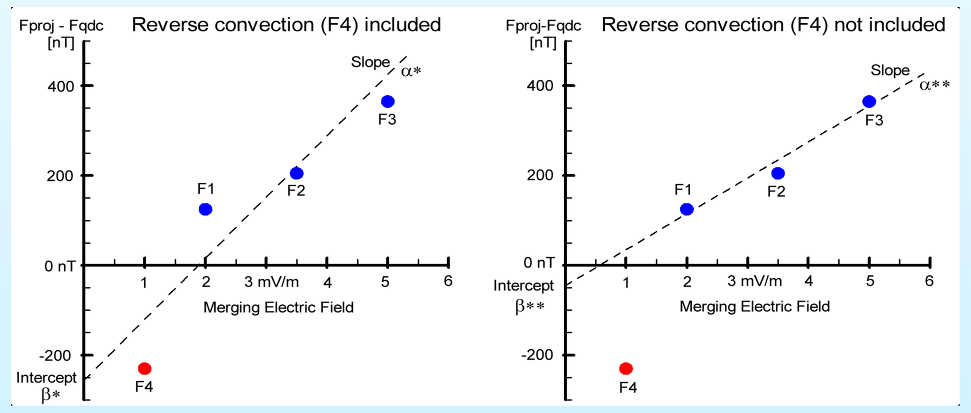

Fig. 1. (a) Reverse convection sample, red point F4, (ΔF_{PROJ} <0) is included in the regression. (b) Regression based on forward convection cases (ΔF_{PROJ} >0) only. Note larger slope and more negative intercept in (a) compared to (b). (From *Stauning*, 2013)

Reverse convection (DP3) events occur mainly at local times near local noon, in the summer season, and within a limited latitude range between the Cusp and the magnetic Pole (e.g., *Stauning*, 2002). In the regression, their narrow distributions in time and space are conveyed to the PC calibration parameters and index values and counteracts the quality demands.

Fig. 2. **Reverse convection effect**. Due to increases in slope from reverse convection events, the winter night PCN index samples (black squares in left diagram) have different relations to the merging electric field compared to the summer day samples (right diagram). Note that in the range E_M = 10 – 15 mV/m, the average PCN values are 2 – 3 mV/m smaller in summer days compared to winter nights. (from *Stauning*, 2018a)

Fig. 2a

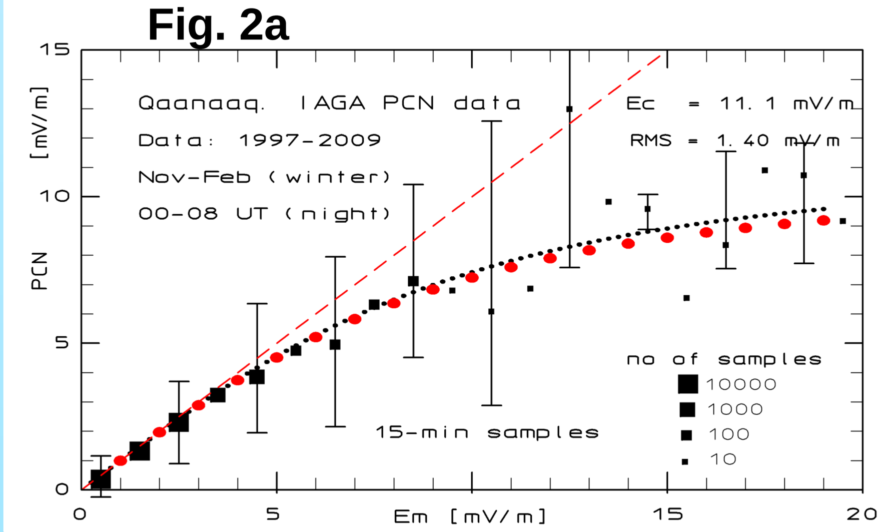

Fig. 2b

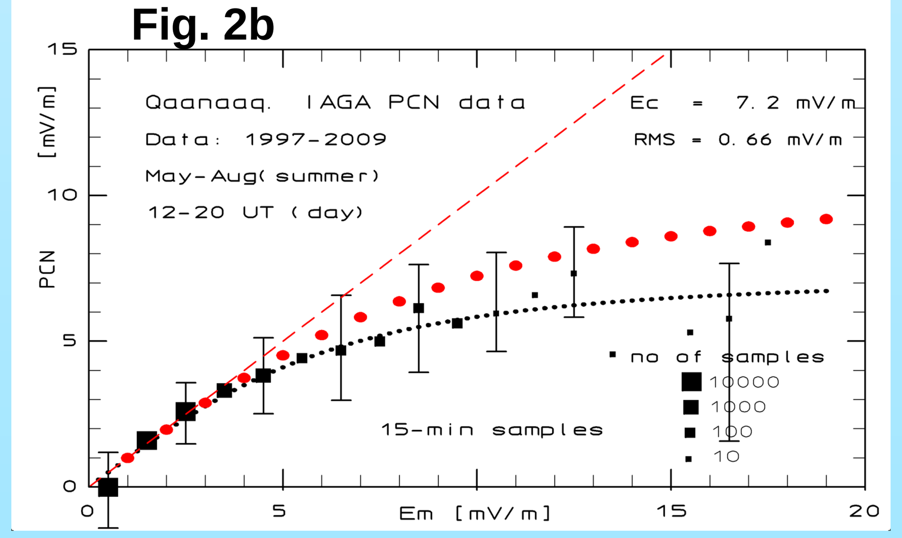

Fig. 3

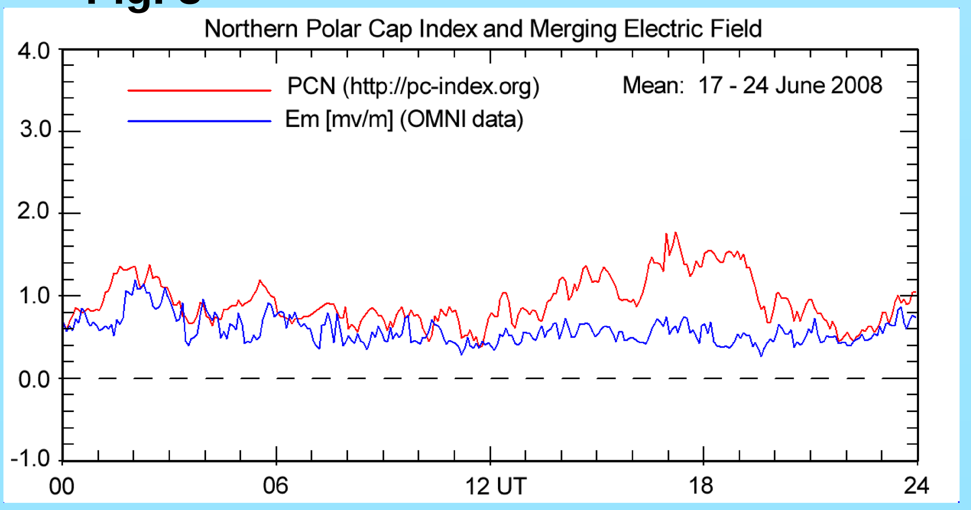

Fig. 3. Reverse convection effect. The increased intercept values caused by including reverse convection samples in the regression generate an unjustified "hump" (0.5-1.0 mV/m) in the PCN indices at around local noon (~16 UT).

The data in Fig. 3 have been averaged through 8 days in order to suppress statistical fluctuations. (*Stauning*, 2015)

Solar Wind sector effects on quiet reference level (QL)
The IMF B_Y component of the interplanetary magnetic field (IMF) affects the transpolar plasma convection patterns and intensities and thus the PC index values beyond the effects related directly to the solar wind merging electric field.
In an attempt to compensate for such irregular effects, *Troshichev* (2011) and *Janzhura and Troshichev* (2011) introduced a solar sector term, $\mathbf{F}_{SS}$=(H_{SS},D_{SS}) or (X_{SS},Y_{SS}), to be included in the determination of the quiet reference level (QL) from which the magnetic variations, **ΔF,** used for the PC index are counted. Thus:

$$PC = (\Delta F_{PROJ} - \beta)/\alpha = ((\mathbf{F}_{OBS} - \mathbf{F}_{BL} - \mathbf{F}_{QDC,SS} - \mathbf{F}_{SS})_{PROJ} - \beta)/\alpha \qquad (3)$$

In the version for archival (final) PC index values, the sector term is derived from the daily median component values smoothed over 7 days with the actual day at the middle. However, the use of the solar sector term is based on the incorrect assumption that the IMF B_Y effects on the magnetic field level are the same day and night. In an example based on data presented in *Janzhura and Troshichev* (2011), it was shown in *Stauning* (2015) that the solar sector term generated unjustified modifications of the PCN index by up to 2.45 mV/m.

Excessive excursions in real time PC indices
In the real-time version, the adverse effects from the solar sector term are aggravated. Following Janzhura and Troshichev (2011), Cubic Spline extrapolation of four previous 3-days average median values replaces the smoothing in the calculations of the solar sector term. Fig. 4 displays the PCS index values in their "prompt" version (red line) ending in the "real-time" value, from a download on 11 Nov 2014, as well as the "final" values (blue line) from a download on 25 Oct 2017. The differences between the two versions reach up to 3.67 mV/m. Between 06 and 10 UT on 8 – 11 Nov, as an example, the prompt indices indicate magnetic storm, while the final values indicate quiet conditions. Thus, the PC indices in the IAGA-endorsed version are not suitable for Space Weather monitoring.

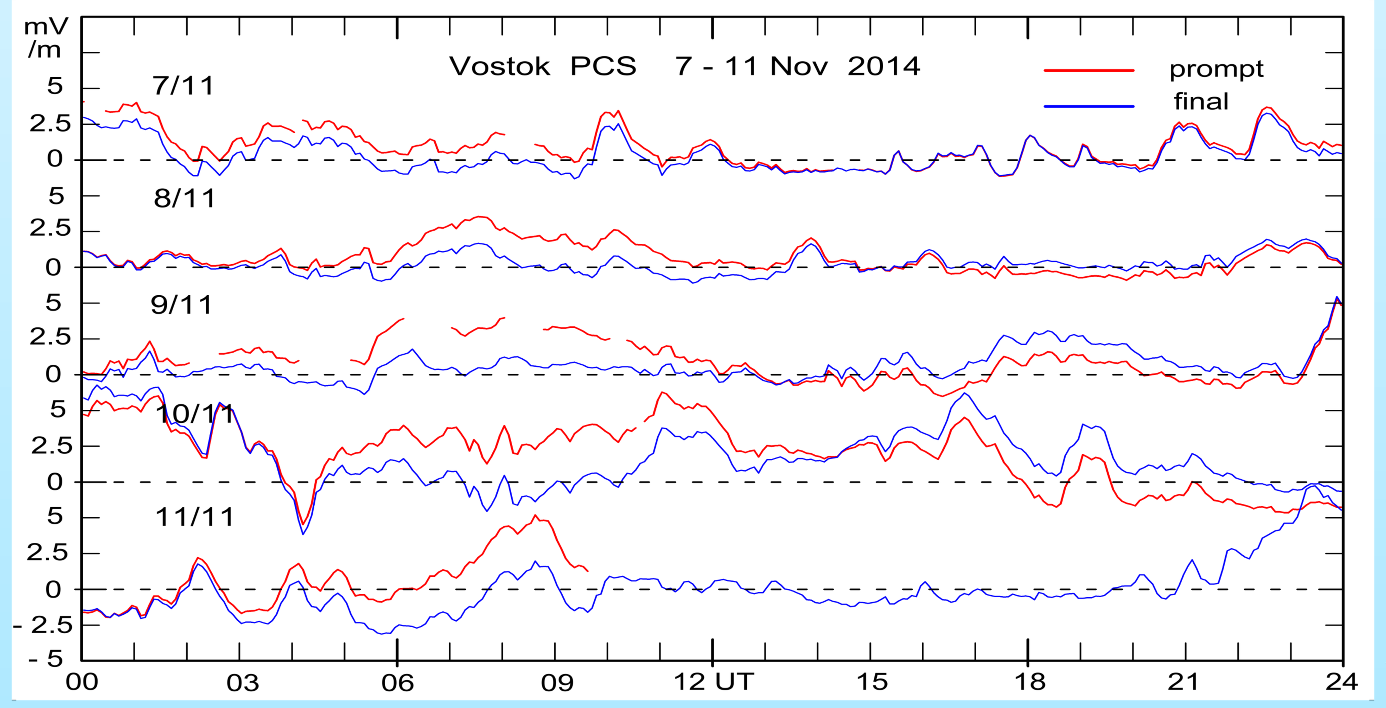

Fig. 4. "Prompt" PCS indices from a download on 11 Nov 2014 at 09:41 UT (red line). Final PCS indices from a download on 25 Oct 2017 (blue line). (from *Stauning*, 2018b)

Conclusions
-The PC indices in the present version were approved by IAGA resolution no. 3 (2013) without examination of the effects of reverse convection cases, with very little examination of the derivation of the quiet reference level (QL) and the related effects on the final index values, and without any examination of the QL effects on the real-time PC indices.
- It is suggested that IAGA forms a working group to examine PC index procedures, real-time and archived index values, and to suggest appropriate modifications.

References
Janzhura, A. and O.A. Troshichev (2011): Identification of the IMF sector structure in near-real time by ground magnetic data, Ann. Geophys., 29, 1491-1500.
Stauning, P. (2015): A critical note on the IAGA-endorsed Polar Cap index procedure: effects of solar wind sector structure and reverse polar convection, Ann. Geophys., 33, 1443-1455.
Stauning, P. (2018a): Multi-station basis for Polar Cap (PC) indices: ensuring credibility and operational reliability, J. Space Weather Space Clim., 8, A07.
Stauning, P. (2018b): A critical note on the IAGA-endorsed Polar Cap (PC) indices. (in press)
Troshichev, O. A. (2011): Polar Cap (PC) Index, available at: http://pcindex.org .