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Comment on "The PC index: review of methods", by McCreadie and Menvielle (2010)

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Abstract. The Polar Cap (PC) index is a controversial topic within the IAGA scientific community. Since 1997 discussions of the validity of the index to be endorsed as an official IAGA index have ensued. The article: "The PC index: review of methods", written by two members of the IAGA PC index committee, H. McCreadie and M. Menvielle, holds a critical review of some aspects of the methods used to derive PC index values. However, a number of incorrect statements and factual errors have been found and shall be called attention to and discussed in this commentary. Further critical comments concern the Corrigendum issued by the same authors and published in Ann. Geophys., 29, 813–814, 2011.

Keywords. Ionosphere (Polar ionosphere)

1 Introduction

The comments in the present note address the article "The PC index: review of methods" by H. McCreadie and M. Menvielle (Ann. Geophys., 28, 1887–1903, 2010) and its Corrigendum (Ann. Geophys., 29, 813–814, 2011)). The initial version of the comments were submitted to Annales Geophysicae on 8 December 2010.

Basically, the PC index represents polar cap magnetic variations, ΔF_{PROJ}, associated with the transpolar part of the DP2 current system driven mainly by the merging (or geoeffective) electric field, *Em*, of the solar wind-magnetosphere dynamo (Kan and Lee, 1979). The relation between the parameters is assumed to be of a linear form: $\Delta F_{\mathrm{PROJ}} = \alpha Em + \beta$. For obvious reasons, α is termed "slope" while β is termed "intercept". From measured values of the magnetic variation, $\boldsymbol{\Delta F}$, and subsequent projection to the "optimum direction" perpendicular to the mean transpolar DP2 current, the expression may be inverted to provide a proxy for the merging electric field, which is then the PC index, i.e.: $\mathrm{PC} = (\Delta F_{\mathrm{PROJ}} - \beta)/\alpha$ ($\sim Em$). The coefficients, α and β, and the optimum direction angle, ϕ, are found by statistical analyses of related values of *Em* and $\boldsymbol{\Delta F}$ over an epoch long enough to provide substantiated values. They are usually provided in tables, by which values at all times through every day of the year can be derived. The same set of coefficient values are used through the years, among other, over the solar cycle. Details of the derivation may be found in the referenced literature (e.g., Troshichev et al., 1988, 2006; Vennerstrøm, 1991; Stauning et al., 2006).

The PC indices are derived from ground based geomagnetic measurements in the northern and southern Polar Caps. The PCN index is based on data from Thule (Qaanaaq) in northern Greenland while the PCS index is based on data from Vostok in Antarctica. The PC index in its present form was first formulated by Troshichev et al. (1988) following a series of publications by Troshichev and other scientists on the relations between conditions in the solar wind, magnetic variations in the polar caps, and substorm occurrences (see references in McCreadie and Menvielle, 2010).

PCN indices have been supplied from the Danish Meteorological Institute (DMI) since 1991, while PCS indices have been supplied from the Arctic and Antarctic Research Institute (AARI) in various versions. In an important development not mentioned in the article, DMI at the end of 2009 stopped the production of the version DMI#2 PCN index values, which were based on the procedure developed by Vennerstrøm (1991). The production and publication of

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this index has been taken over by the Danish National Space Institute (DTU Space) and is supervised by Jürgen Matzka. This version of the PCN index is supplied, among other, to the OMNIweb data base system (http://omniweb.gsfc.nasa.gov). In the "comments" column of Table 1 on the PCN (DMI#2) index it should be mentioned that this index is now the official DTU Space PCN index. Hence, for the discussions of the various current PC indices, there are now the three separate versions, PCS (AARI#3), PCN (DMI#4), and PCN (DTU Space).

2 General comments

This section discusses the major issuess of the article's review of methods for deriving PC index values and makes comments where the descriptions provided by McCreadie and Menvielle are found to be incomplete or incorrect. In most cases the text segment to be commented is written verbatim in italics first and our comment follows in normal style. The comments are numbered C1, C2, …… Figures and equations in the present commentary article are marked by an asterix.

These issues are:

1. The parameters of the basic expression for the PC index.
2. Decomposition of the magnetic field in geographic and magnetic coordinate systems.
3. The projection angle.
4. Regression methods.
5. The derivation of the quiet reference level at AARI.
6. The derivation of the quiet reference level at DMI.
7. PC index sampling less frequent than the data sampling.

2.1 Parameters of the basic expression for the PC index

In order to help the reader to follow the discussion we first sum up the fundamental definitions. The basic concept of the PC index is derived from an assumed linear relation between the "geo-effective" (or "merging") electric field, *Em*, in the solar wind encountering the Earth and ΔF_{PROJ}, the polar cap horizontal magnetic variation (at ground) projected to the so-called optimum direction

$$\Delta F_{\mathrm{PROJ}} = \alpha Em + \beta \qquad (1^*)$$

The optimum direction is the horizontal direction perpendicular to the average DP2 transpolar equivalent current direction and makes an angle ϕ to the dawn-dusk direction. The projection serves the double purpose of converting the magnetic variation vector into a scalar quantity and focusing on the part of the magnetic variation that is most directly coupled to solar wind conditions.

The merging electric field is defined by:

$$Em = V_{\mathrm{SW}} B_{\mathrm{T}} \sin^2(\theta/2) \qquad (2^*)$$

where V_{SW} is the solar wind velocity, B_{T} is the transverse component of the interplanetary magnetic field (IMF) ($B_{\mathrm{T}} = \sqrt{(B_{\mathrm{Y}}^2 + B_{\mathrm{Z}}^2)}$, while θ is the polar angle between the Z-axis of a Geocentric Solar-Magnetospheric (GSM) coordinate system and the transverse IMF component.

The Eq. (1*) is inverted to give a definition of the PC index by equivalence:

$$\mathrm{PC} = (\Delta F_{\mathrm{PROJ}} - \beta)/\alpha (\sim Em) \qquad (3^*)$$

The scaling parameters used to derive the polar cap (PC) index from geomagnetic variations comprise the optimum direction angle, ϕ, and the regression coefficients, α and β. They are found from statistical analyses based on an ensemble of concurrent values of the merging electric field, *Em*, and the polar cap horizontal magnetic variation vector, $\boldsymbol{\Delta F}$ counted from the quiet level, $\boldsymbol{F}_{\mathrm{QL}}$. The basic unit for the PC index is the one used for the merging electric field (e.g., $\mathrm{mV\,m^{-1}}$). A re-scaling quantity, ξ, (e.g., $1\,\mathrm{m\,mV^{-1}}$) could be added to the expression in Eq. (3*) to change the unit (e.g., to make the index dimensionless).

2.2 Decomposition of the magnetic field in geographic and geomagnetic coordinate systems

Some comments to the presentation in McCreadie and Menvielle (2010) are:

C1. Figure 5, p. 1895, used as a reference to define the resolution of the disturbance vector in magnetic element pairs is erroneous. If $\boldsymbol{F}$ is the total magnetic field vector then its horizontal component, $\boldsymbol{H}$, is not necessarily situated in the magnetic meridian in the northerly direction. The same error is repeated in the Corrigendum. The vector $\boldsymbol{D}_H$ is misplaced. The quantity named D is really the geographic Y-component.

C2. The definition of D in p. 1894, and the resolution in (H, D_H) components in p. 1894 and in the caption to Fig. 5 added in the corrigendum are incorrect.

Figure 1* has been added here (to replace Fig. 5, p. 1895) in order to provide an illustration of the decomposition of the magnetic field into its basic components in local geographic and magnetic coordinate systems. The magnetic field vector, $\boldsymbol{F}$, in Fig. 1* makes an inclination angle, I, to the horizontal plane. $\boldsymbol{F}$ can be resolved in a vertical component, Z, and a horizontal vector, $\boldsymbol{H}$. The vertical component axis (downward in the Northern Hemisphere, upward in the Southern) is the same in geographic and magnetic systems. The horizontal vector, $\boldsymbol{H}$, can be resolved in the components X (northward) and Y (eastward) in a geographic coordinate system, or in the components H (magnetic north) and D (magnetic east) in a magnetic coordinate system. The declination, D_E, is the angle between the geographic north axis and the horizontal field vector. The basic declination angle between geographic and geomagnetic north directions is here denoted $D_{E,0}$.

The components could be defined through:

$$
\begin{aligned}
Z &= |\boldsymbol{F}|\sin(I) \qquad (4^*)\\
|\boldsymbol{H}| &= |\boldsymbol{F}|\cos(I)\\
X &= |\boldsymbol{H}|\cos(D_E) = |\boldsymbol{F}|\cos(I)\cos(D_E)\\
Y &= |\boldsymbol{H}|\sin(D_E) = |\boldsymbol{F}|\cos(I)\sin(D_E)\\
H &= |\boldsymbol{H}|\cos(D_E - D_{E,0}) = |\boldsymbol{F}|\cos(I)\cos(D_E - D_{E,0})\\
D &= |\boldsymbol{H}|\sin(D_E - D_{E,0}) = |\boldsymbol{F}|\cos(I)\sin(D_E - D_{E,0})
\end{aligned}
$$

In the above expressions and in Fig. 1*, please note the difference between scalar and vector symbols. (It is unfortunate that the same symbols are traditionally used for multiple quantities in geomagnetism.)

2.3 The projection angle

C3. In Eq. (7) in p. 1892 the notation F_k is introduced for the k-th value of the quantity ΔF_{PROJ} through the statement:

"*The current PC index is defined as*

$$PC = \xi(F_k - \beta_k)/\alpha_k \qquad (7)$$

where F_k is the magnetic disturbance vector."

However, F_k in Eq. (7) is a scalar quantity not a vector; it is the projection of the horizontal magnetic disturbance vector to the optimum direction.

C4. Prior to Eq. (10) in p. 1892 it is stated that "*The rotation angle γ is defined as:*"

The angle γ defined in Eq. (10) should be termed "projection angle" since it is used in the projection (not rotation) of the horizontal magnetic disturbance vector onto the optimum direction (assumed perpendicular to the DP2 transpolar current) in order to obtain the scalar disturbance parameter used for the PC index calculation. The confusion between rotation and projection is evident in Sect. 2.3 of the article where much (unnecessary) effort goes to describe rotation (e.g., Figs. 2, 3 and 4) and rotation transform matrices (e.g., Eqs. 11, 12, and 13). Further, another similarly unclear statement is found in p. 1893: *2.3 Description of projection plane angle. The projection plane angle is simply the rotation of the geographic coordinate system into the local time (LT) coordinate system, which is invariant with respect to the DP2 current system.*"

In order to clarify the projection angle issue a new figure is added here (to replace Figs. 2 and 3, p. 1893, and Fig. 4, p. 1894). Figure 2* displays a plot in geographical coordinates (latitude, local time) of the northern polar region. The varying position of Thule observatory through a day is shown by a circle at the latitude. Local time is indicated by hour marks as the station rotates counter clockwise around the North Pole during the day.

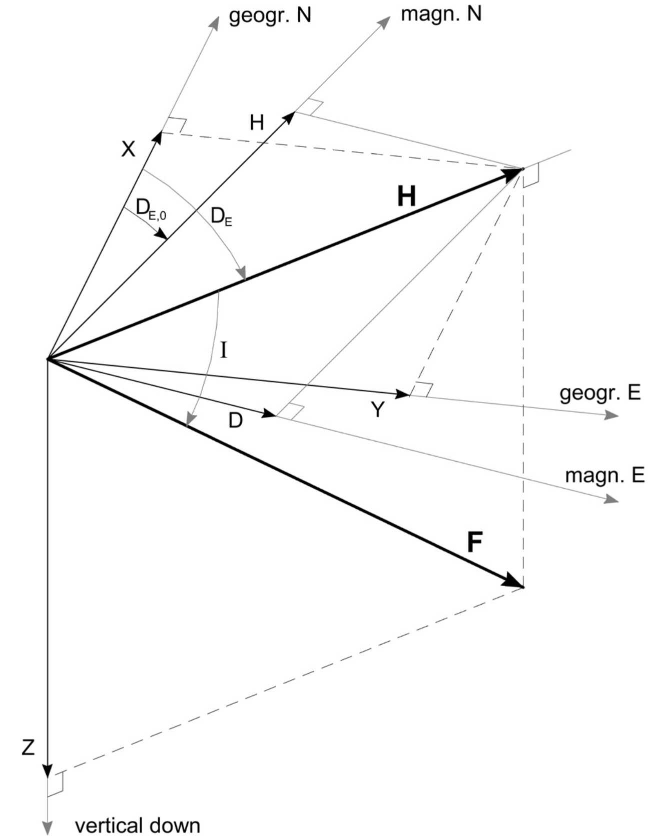

Fig. 1*. Basic resolution of a magnetic field vector, $\boldsymbol{F}$, in its horizontal vector component, H, and its components (X, Y, Z) in a geographic and (H, D, Z) in a magnetic coordinate system (figure applies to Northern Hemisphere).

Based on the definition provided by Troshichev et al. (1988), the projection of the magnetic variation vector to the optimum direction is defined by the expressions:

$$\Delta F_{\mathrm{PROJ}} = \Delta H \cdot \sin(V'_{\mathrm{PROJ,GM}}) \pm \Delta D \cdot \cos(V'_{\mathrm{PROJ,GM}})$$
in geomagnetic components (H, D) (5a*)

and

$$\Delta F_{\mathrm{PROJ}} = \Delta X \cdot \sin(V''_{\mathrm{PROJ,GG}}) \pm \Delta Y \cdot \cos(V''_{\mathrm{PROJ,GG}})$$
in geographical components (X, Y) (5b*)

The value of the projected variation vector, of course, is the same in the two equations. The projection angles in the two cases are:

$$V'_{\mathrm{PROJ}}(\gamma_{\mathrm{gm}}) = \mathrm{Longitude}(\lambda) + \mathrm{UTh}\cdot 15^\circ \pm \mathrm{Decl}(\delta) + \text{Optimum Direction Angle } (\phi) \qquad (6a^*)$$

and

$$V''_{\mathrm{PROJ}}(\gamma_{\mathrm{gg}}) = \mathrm{Longitude}(\lambda) + \mathrm{UTh}\cdot 15^\circ + \text{Optimum Direction Angle } (\phi) \qquad (6b^*)$$

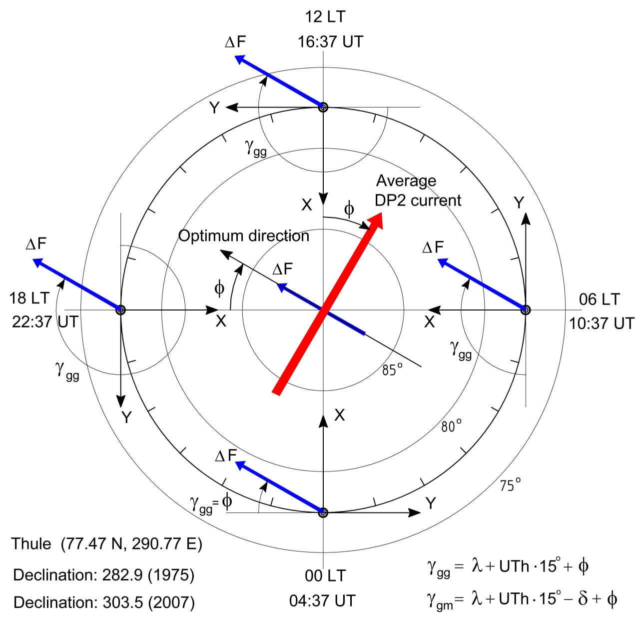

Fig. 2*. Illustration of projection angles for various hours (00:00, 06:00, 12:00, 18:00 LT) of the day for a station (Thule) in the northern polar cap.

Here, the greek letters often used for these quantities are indicated. The optimum direction angle, ϕ, is the angle between the dawn-dusk meridian and the average DP2-related disturbance vector direction or, equivalently, the angle between the direction to the Sun and the average DP2 transpolar current. UTh is the UT time in decimal hours. Decl is the local magnetic declination. The $\pm$ signs in the equations are used such that the $+$ sign is applied for the Southern Hemisphere while the $-$ sign is used for the northern regions. Equations (5a*) and (6a*) are defined from the established convention (e.g., Troshichev et al., 1988; Vennerstrøm, 1991) while Eqs. (5b*) and (6b*) are established by equivalence. In the latter case the local declination is not needed, which is an advantage particularly for Thule, where the declination changes by around 1° a year.

The optimum direction angle and the projection angle are defined from the geographic coordinate system in Fig. 2*. In the figure the red arrow indicates the average direction of the transpolar part of the DP2 (equivalent) current system. The magnetic disturbance, $\boldsymbol{\Delta F}$, at ground is perpendicular to the DP2 current and is indicated by the blue vector placed at the geographic North Pole. Assuming a uniform DP2 current system within the central polar cap, the polar cap observatory, Thule, would experience the same disturbance vector, $\boldsymbol{\Delta F}$, regardless of the time of day.

The diagram in Fig. 2* indicates the position of Thule observatory at 00:00, 06:00, 12:00, and 18:00 LT. With the longitude $\lambda = 290.77°$ for Thule, local time is LT = 00:00 (midnight) at UT time 04:37. The optimum direction making an angle, ϕ, with the dawn-dusk direction is indicated. The geographic projection angle, γ_{gg}, is indicated for each of the four LT positions shown in the figure. At 00:00 LT the projection angle γ_{gg} equals the optimum direction angle, ϕ.

The corresponding geomagnetic projection angle, γ_{gm}, can be defined in this coordinate system by tilting the Thule coordinate axes (X,Y) by the declination, δ, to arrive at the geomagnetic (H,D) component system and then define the angle, γ_{gm}, between the negative D-axis and the optimum direction indicated here by the $\boldsymbol{\Delta F}$ vector. The projection angle could also be defined in a geomagnetic latitude-local time (MLT) coordinate system. In any event, the optimum direction angle, ϕ, being the angle between two directions in space, e.g. the direction to the Sun and the DP2 current direction, remains the same regardless of the terrestrial coordinate system used for its definition.

The value of the optimum direction angle, ϕ, varying with UT time of the day and day of the year, is found by optimizing the correlation between the merging electric field, *Em*, and the projected magnetic disturbance, ΔF_{PROJ}, letting the angle, ϕ, vary through a range of possible values (usually, $0 < \phi < 90°$).

C5. The formula for the correlation coefficient used in the derivation of the optimum angle depicted in Eq. (18), p. 1895, has now the correct appearance in the corrigendum. It should be noted, that contrary to the comment in p. 1895 stating: *"…(reader please note, Eq. 18 is not the linear correlation coefficient, see Aitken, 1947)….*. the product-moment correlation coefficient in Eq. (18) is quite the same as the formula (2) for the linear correlation coefficient (also called "Pearsonian coefficient of correlation") found in Sect. 48, Chapter V, of Aitken (1962).

2.4 Regression methods

C6. The regression methods are explicitly mentioned in Table 1. The methods are divided into "*linear*" and "*orthogonal*" regression. The "*orthogonal*" regression method (Vennerstrøm, 1991) is specified in Eq. (6). However, both methods are linear since they are based on the assumption of a linear relation between the merging electric field and the projected magnetic variation. Both are based on least squares deviation from a regression line. One method uses the (1-D) deviation in one component only, while the other claims to use least squares deviations in both components (2-D).

C7. In the column *"Normalisation Coefficients"* and for the rows *"DMI#1"*, *"DMI#2"*, *"DMI#3"*, *"DMI#4"* it is stated *"Orthogonal Coefficients – smoothed ($\alpha_\perp$, $\beta_\perp$) Eqs. (5, 6)"*.

The statement is incorrect for the DMI#4 procedure that uses 1-D regression of ΔF on *Em* (ΔF taken to be a function of *Em*) by least squares minimizing the deviation in ΔF_{PROJ} from the regression line. By the terms defined in Eq. (6), the regression line has the slope $\alpha = S_{\mathrm{xy}}/S_{\mathrm{y}}$.

C8. The so-called "*orthogonal*" regression method as depicted in Eqs. (5) and (6) is inconsistent. The equations quoted from Vennerstrøm (1991), who used a formula from Hald (1968), are reproduced in Fig. 3* here.

A survey of the units of the terms used in Eq. (6) illustrates the problem. The term "S_x" is the mean squared variation in the magnetic component, "F_s", (left hand term of Eq. 5) that has the unit Tesla (or nanotesla). The term "S_y" is the mean squared variation in the merging electric field, *Em*, that has the unit $\mathrm{V\,m^{-1}}$ (or $\mathrm{mV\,m^{-1}}$).

Thus, the expression in Eq. (6) (numerator): "$S_y - S_x$" (i.e.: $[\text{nanotesla}]^2 - [\text{mV m}]^{-2}$), makes no sense. If the calculations are carried out using numerical values then the result depends on whether one or another unit (e.g., *Em* in $\mathrm{V\,m^{-1}}$, $\mathrm{mV\,m^{-1}}$, or $\mathrm{\mu V\,m^{-1}}$) is implied.

It might be assumed that Vennerstrøm (1991) and Papitashvili et al. (2001), who have used these equations, have inserted the numerical values of these terms using the traditional units (nT, $\mathrm{mV\,m^{-1}}$). However, typical corresponding values of *Em* and F are $1\,\mathrm{mV\,m^{-1}}$ and $\sim$50 nT. Thus, in Eq. (6) the terms S_x, S_{xy}, and S_y have the ratios $\sim$2500:50:1.

In Vennerstrøm (1991) the choice of sign in front of the square root term is not specified. However, the sign must be a plus, since S_{xy} is positive, the square root term is larger than the other term in the numerator, and the slope must be positive. Furthermore, in Vennerstrøm (1991) it is not specified whether S_x designates the magnetic or the electric variance term. The choice in Eq. (6) is made by the present authors.

If S_x designates the magnetic term as indicated in Eq. (6), then the corresponding result, using the approximation $(1+\delta)^{1/2} \sim 1 + 0.5\delta$ for small values of δ, would be:

$$\alpha_\perp \approx S_{xy}/S_x \tag{7a*}$$

The approximate value of this quantity is: $\alpha_\perp \approx 1/50$ which is unreasonably small for the slope defined in Eq. (5). (Actually, this quantity is the 1-D regression slope for the inverse relation: $Em = \alpha F + \beta$.)

If S_x designates the electric term (as probably used in Vennerstrøm, 1991), then S_x as well as S_{xy} in the numerator terms could be neglected giving in a very close approximation the result:

$$\alpha_\perp \approx S_y/S_{xy} \tag{7b*}$$

The approximate value of this quantity is: $\alpha_\perp \approx 50$, which is a reasonable amount. However, it should be noted that this quantity, basically, is the reciprocal value of the 1-D regression slope for the relation: $Em = \alpha F + \beta$.

Thus, the expression in Eq. (6), p. 1891, resorts to the one-dimensional least squares regression by minimizing the deviation of the electric field quantities from the regression line. This regression line, by the way, actually gives larger values of the slope, α, and more negative values of the intercept, β than the regression of F on *Em* used in the other 1-D index procedures quoted in the article.

$$F_{s,\phi} = \alpha_\perp E_{m(s)} + \beta_\perp \tag{5}$$

$$\alpha_\perp = \frac{S_y - S_x \pm \left((S_y - S_x)^2 + 4S_{xy}^2 \right)^{1/2}}{2S_{xy}}, \text{ and} \tag{6}$$

$$\beta_\perp = \overline{E_m} - \alpha_\perp \bullet \overline{F_{s,\phi}}$$

where

$$S_x = \frac{1}{N-1} \sum_s \left(F_{s,\phi} - \overline{F_{s,\phi}} \right)^2 \quad ;$$

$$S_y = \frac{1}{N-1} \sum_i \left(E_{m(s)} - \overline{E_m} \right)^2$$

$$S_{xy} = \frac{1}{N-1} \sum_s \left(F_{s,\phi} - \overline{F_{s,\phi}} \right) \left(E_{mi} - \overline{E_m} \right)$$

Fig. 3*. Set of defining orthogonal regression equations from McCreadie and Menvielle (2010).

In other words, the "orthogonal" regression, apart from the inconsistency involved in the parameter units, is really a one-dimensional (and linear) regression method. The difference from the other cited regression methods used to derive the coefficients α and β is only in the choice of parameter, whether F or *Em*, selected for the least squares minimizing.

This lengthy comment also serves to document that the fundamental basis for the derivation of "DMI#1_1991", "DMI#2_2001", and "DMI#3_2001" PCN index series is questionable.

2.5 Derivation of the quiet reference level at AARI

C9. In Table 1, p. 1888, it is stated in the "Baseline" column for AARI#3_2006: "*Daily quiet level (Hd, Dd) computer derived: filtered mean of each preceding 30 day period; minute vaules calculated daily*". In Sect. 2.3.2., p. 1896, it is stated: "*The quiet level is different each day and is dependent on the quiet level in the previous 30 days from the point of calculation. The method is very useful for online calculations*"

These descriptions are inconsistent with the procedures explained in Janzhura and Troshichev (2008). Two QDC variants emerge from their running QDC method. One QDC variant is intended for on-line use. The other is applied in the calculations of final PC index values, which are the ones to be considered for IAGA approval. The method use magnetic data from Vostok recorded by a flux-gate magnetometer. The raw H (magnetic north) and E (magnetic east) component values are counted from the instrument's baselines.

1. The quiet segments used to build a QDC are selected on basis of the variability in the components. The variability should be held within specified limits if the magnetic recordings through intervals of 20 min at a time are to be included in the superposition of data forming the basis for QDC construction. If the first approach fails to produce enough samples then the variability limits are raised, the interval extended to 1 h, and the weight of the sample reduced. In the reference it is stated (in p. 965) that the assembly of weighted quiet segments for a 30 days interval defines the QDC for one day within the 30-days interval: "*and this day may not be quiet. For example, the mean daily variation shown in Fig. 1* (superposition of quiet segments through the 30 days in June) *faithfully reproduced the QDC for 13 June*".

2. The procedure then shifts the 30-days interval forward by one day at a time and repeats the QDC calculation for the new interval. After many successive shifts of the 30 days interval a number of QDC's are defined through one month. Then (p. 966) "*two-dimensional bicubic interpolation with subsequent Savitzky-Golay smoothing*" is employed to define a proper QDC for each day of the month (including days that did not obtain an individual QDC in the first step).

3. Typically, data from half a month preceding and half a month following the month in question are needed to complete the QDC calculations, that is, to provide a QDC for each day of the month. In extreme cases, data from up to one month (29 days) preceding and following the month in question are needed.

4. A feature not directly explained in Janzhura and Troshichev (2008) is the definition of the "solar sector correction" of the baseline. However, this feature was explained very detailed in the manuscript by Oleg Troshichev: "Description_2009_Heather.doc" (private communication). The corrected baseline for the H-component is presented in Fig. 7 of the manuscript and explained as "*the 3 days-averaged median value of H-component referred to the midpoint of 3-days interval.*" A similar procedure is applied to the D-component. At the end of this section (Sect. 3.1.2) it is stated "*After the SS effect estimation, it is automatically excluded from variations of geomagnetic field while the QDC deriving*." This formulation implies, that the SS effects are excluded from the observed values, and that the corrected magnetic variation values are used both for calculations of coefficients and for calculation of PC index values.

5. The procedure calculate on-line QDC values by extrapolation of the 30 days continuous sequence of QDCs found after completion of above step 3 by the around extra 15 days needed for the calculations. In addition, the SS corrected baselines are also extrapolated on basis of the values from the preceding 3 days in order to apply to the current day instead of the day in middle of three consecutive days.

In summary, the method requires typically 2 months, in extreme cases up to almost 3 months, of data (not 30 days) for QDC calculations. The preliminary QDCs are automatically turned into final QDCs at a latency of one to two months. In addition to the published description, the method relies on the calculation of the solar sector correction. For on-line calculations the method (any QDC method) is quite vulnerable to data gaps.

2.6 Derivation of the quiet reference level at DMI

The descriptions im McCreadie and Menvielle (2010) of the QDC procedure used at DMI is incomplete and holds incorrect statements. One statement is corrected in the Corrigendum. Further questionable statements are listed below:

C10. Statement in p. 1896: "*DMI#4 2006 calculate the quiet level in two steps. A baseline is determined (basic geomagnetic field intensities (Table 3.1 in Stauning et al., 2006). How this is determined in unclear but at least one year of data are required*."

1. The DMI qwnl baseline procedure was established by O. Rasmussen and E. Friis-Christensen to derive the field from "internal sources" and relies on examination of quiet winter night recordings where the "external" contributions to the magnetic field are at minimum.

2. The prediction of the qwnl baseline values one year ahead is quite precise. Hence, there is no need for waiting one year to calculate PC index values for this reason.

C11. It is stated in p. 1896: "*…then weighted means method is used to determine the daily variation which is static over one month. A linear interpolation is used between months*."

1. The QDCs are calculated for each day.

2. Quadratic interpolation is used to derive QDC values with finer than one hour time resolution (e.g., 1-min samples).

C12. "*The method for obtaining the quiet level is stated in Stauning et al. (2006) but is not clear. The weights used are not explicitly given*."

The weights are given by the product of well-defined power, exponential and cosine functions. The combined weight function for solar rotation phase and proximity is displayed graphically in the reference.

The QDC calculations at DMI are explained in the referenced DMI report (Stauning et al., 2006, rev. 2, 2007). The method use X- and Y-component data from Thule with absolute scaling, i.e., total field values. The method builds on superposition of a selection of quiet segments to build a QDC for any given day. The samples are weighted according to the variability, as well as on their proximity and the relative solar rotation phase compared to the day in question. The calculations are performed in the following steps:

1. In the initial step the Quiet Winter Night Level (qwnl) baseline values (represent "internal field" levels) interpolated to the day in question are subtracted from the recorded data.

2. Hourly average samples are defined and given weights on basis of the actual variability in the magnetic field vectors in order to give preference to the quietest segments of the recordings.

3. In the superposition of quiet recordings from different days, further pre-tabulated weight functions are applied to give preference to intervals close to the QDC day in question (through an exponential function) and to intervals where the same face of the sun is directed towards the Earth (through a cosine squared function of half the relative solar rotation angle). The solar rotation weight factor takes into account the regular variations in the solar UV radiation, the solar wind velocity and the IMF sector structure.

4. For each hour of the QDC day, every corresponding (same UT) hourly sample within an interval of 40 days preceding and following the day in question is multiplied by a product of weight parameters relating to its variability, proximity, and relative solar rotation phase. The weighted samples are added and divided by the sum of weights to provide an hourly QDC value for the selected day.

5. The procedure is fully automatic and a quality parameter (the sum of weights) is provided for each hourly QDC value to enable a warning for poorly defined QDC values. It was applied to all Thule data recorded during 1975–2008 in a single program run to provide hourly QDC values for each day of the epoch without any misses.

6. Quadratic interpolations are used to provide QDC values with finer than one hour time resolution (e.g., 1-min samples).

7. For possible on-line calculations of the QDC, the same program is applied. The built-in check of data availability ensures that only data from the preceding 40 days are used. The differences between on-line calculations and the final QDC calculations give deviations between the on-line preliminary PCN index values and the final index values of around 0.1 (RMS) to 0.3 (peak) units. The on-line QDC procedure is vulnerable to major data gaps.

It might be noted that the automatic handling of the QDC variations related to the solar rotation (e.g., solar UV irradiance and solar wind sector structures) is the most significant difference between the above Stauning et al. (2006) QDC procedure and the Janzhura and Troshichev (2008) procedure that uses a separate solar wind sector (SS) correction of the primary data.

2.7 PC index sampling less frequent than data sampling

This section concerns the derivation of PC index values for time intervals longer than the data sampling intervals as expressed in Eq. (8), p. 1892, that defines the F_k value.

C13. Statement in p. 1894: "*Also note there is confusion surrounding the exact coordinate axes presented here and that noted in Troshichev et al. (1979):*"

1. It is not clear why the expressions presented in Troshichev et al. (1979) shall again be discussed in context of the Sect. 2.2.1: *Definition of the current PC index*.

2. It is inappropriate to talk about "confusion" since the definitions of the signs and directions of the terms included in the description of the magnetic variations in Troshichev et al. (1979) are perfectly clear.

C14. The defining expression for F_k in Eq. (8), p. 1892, and the subscript as well as the subscript ranges are incorrect. The corrected version of Eq. (8) found in the Corrigendum is also incorrect.

With Eq. (8), apart from the confusion in indices and summation ranges, the basic problem resides with the concept of the quantities δM_i and δN_i. The formula appears to be inherited (cf. comment C17) from part of the definition of the PC(Bz) index in Troshichev et al. (1979). However, there the corresponding quantities are defined (in Eq. 3) as the differential component variations from one data interval to the next. For the present case, the equivalent quantities should have been defined like: $\delta M_i = M_i - M_{i-1}$ and $\delta N_i = N_i - N_{i-1}$.

However, the terms δM_i and δN_i are actually defined here in Eq. (9) to be components of the (presumably much larger) total disturbance vector. Thus, with 1-min magnetic data, the quantity F_k and subsequently the PC index in 15-min versions of Eqs. (7), (8) and (9) would be much larger than the proper value.

If a formula like Eq. (8) is to be used with the definitions of terms in Eqs. (7) and (9), p. 1892, then the expression should read:

$$F_k = (1/n) \sum_{i=(k-1)\cdot n}^{k\cdot n} (\delta M_i \sin\gamma_i \mp \delta N_i \cos\gamma_i) \tag{8*}$$

where subscript i designates the data sample identifier, k the PC index sample identifier, while n is the number of data samples used in the summation for each PC index sample. It might be noted, that all current PC index versions use 1-min magnetic data to derive 1-min PC index values.

3 Further comments

In addition to the points listed above there are some statements presented in the review (McCreadie and Menvielle, 2010), which we want to comment. These statements shall be addressed in order of appearance. The comments are numbered in continuation of the preceding section and there are references to the related pages in the article.

C15. Statement in p. 1887: *The next major contribution to the index derivation came from Papitashvili et al. (2001) who, after fixing a programming error in the PCN index showed a recognisable daily variation which is comparable to the seasonal variation and a solar cycle variation within the index.*

Comment: The recognisable daily variation was present in the index values before (not "*after*") the programming error was fixed. The problem was actually detected by Kalevi Mursula (University of Oulu), who communicated an unusual daily variation in the PCN index to V. Papitashvili then working at DMI. Papitashvili found the error in the programming code used to derive the angle and coefficients for calculation of PC index values from magnetic variations. According to Papitashvili (2001) the error "*forced only a single value of each parameter (that is, the optimal direction angle, slope and intercept) to be taken for calculations of the index through the entire UT day.*

In consequence, among other, of the error in the PCN index series DMI#1 (issued from 1991 to 2000) the disagreement between DMI index values (DMI#1_1991) and PCN (and PCS) values calculated at AARI (AARI#2_1991) became quite substantial at this time (cf. Lukianova et al., 2002) resulting in poor conditions for the unification of index procedures.

C16. Table 1, pp. 1888–1889 and statements in Sect. 2.1. in p. 1890:

The two upper rows in Table 1 are presented as two former "*PC index*" types. However, they are both principally different from present PC indices. The present authors fail to clearly state the meaning of the indices and mix the PC(P_Z) and MAGPC indices. Here, a brief clarification follows:

1. In the source article for the "PC$_L$" index (Kuznetsov and Troshichev, 1977) it is clearly stated (in p. 19) that: "*We propose a new index PC$_L$ characterizing the changeability of the geomagnetic field*". Thus, the PC$_L$ index is a "variability" index (like the K indices) not at all equivalent to the present PC "level" index (like the Dst or AE indices).

2. The "MAGPC_1979 index listed in the second row of the table appears to be the "PC(B_Z)" index defined in Troshichev et al. (1979). Here it is stated (p. 219) that $PC(B_Z) = F_\Sigma(B_Z)F'_\Sigma(B_Z)$ i.e., the product of the variation level and the variability in the dawn-dusk component of the magnetic field. The physical meaning of the term $F_\Sigma(B_Z)$ is close to the present PC index except for the scaling with respect to the merging electric field, Em, while the term $F'_\Sigma(B_Z)$ is of the same character as the PC$_L$ index (a variability index).

3. In the source for the "MAGPC" index (Troshichev and Andrezen, 1985) it is stated (p. 415) that the MAGPC index is the magnitude (in nT) of the 15-min samples of the magnetic variation in the direction of the 03:00–15:00 MLT meridian.

4. The reference to the MAGPC index should have been MAGPC_1985 (not 1979). The defining expression in the second last column of Table 1 (and Eq. 3) applies to the PC(B_Z) index and is, furthermore, in error for this index.

C17. Statement in p. 1890: "*Also the magnetic elements chosen were not the same as the Troshichev team (see Table 1)*."

The magnetic elements used by Vennerstrøm (1991, p. 7); Vennerstrøm et al. (1991); Papitashvili et al. (2001, p. 6) and by the Troshichev team (in AARI#1, AARI#2, and AARI#3) were quite the same, namely the horizontal variation components in the magnetic north and magnetic east directions.

C18. Statement in p. 1892: "*The normalisation coefficients α and β, and the angle ϕ are defined in a table for each UT hour and calendar month. To obtain the values for times between defined elements a linear relation is assumed*."

1. Troshichev's team defines the coefficients and the angle in tables for every minute of the year; interpolation is not needed

2. Stauning et al. (2006) uses a table for each UT hour and calendar month but use quadratic interpolation for values calculated at times between defined elements.

C19. Statement in p. 1894: "*The value of D_E does not change with time in the calculations so magnetic secular variation is not considered*."

Actually, the value of D_E for Thule does change significantly (by around 1°/year) over the years considered in the calculations of the PC index. In an in-depth review this problem should be mentioned.

From the Vennerstrøm (1991) calculations of coefficients based on data from 1977 to 1980 and to present time the declination for Thule has changed from 284.3° (1978) to 306.5° (2010), i.e., by more than 22 degrees, which is equivalent to 1.5 h UT change in the entry to the tables of projection angle from 1991 used in the DMI#1, DMI#2, DMI#3, and still now in the DTU PC index procedures. The DMI#4 procedure does not use the declination value in the expression for the projection angle and thus avoids the problem.

C20. Statement in p. 1896: "*Now that the angle ϕ has been found the coefficients α and ß are then calculated using orthogonal correlation analysis (see Eq. 6 and Table 1).*"

In the DMI#4_2006 procedure, the angle ϕ is found by correlation analysis while the coefficients α and ß are calculated using 1-D least squares regression analysis.

C21. Statement in p. 1896: "*Papitashvili et al. (2001) were unable to locate the coefficients used by Vennerstrom (1991) and, therefore, recomputed these coefficients following Vennerstrom's method and used them for DMI#2 2001*."

The coefficient set derived and used by Vennerstrøm (1991) has been available all the time (the original data and calculations are gone). The DMI#2_2001 published (now by DTU Space) PC index values use the original coefficients.

C22. Statement in p. 1897: "*The normalisation coefficients are a scaling factor to make the location where the PC index is derived independent within the polar cap*"

The daily and seasonally varying normalisation coefficients help to make the PC index values independent of location within the northern and southern central polar caps as well as making them refer to solar wind conditions independent of UT time-of-day and season of the year.

C23. Statement in pp. 1897–1898: "*Thus a major difference between DMI#2 2001 and the comparative AARI#2 1991 are the quiet level determination. The DMI index takes the quiet night time field only whereas the AARI index has a daily magnetic variation included in it*."

1. The DMI#2_2001 PCN index (as well as the DMI#1_1991 and DMI#3_2001 PCN indices) uses the quiet winter night levels (qwnl) interpolated through the days of the year as the reference level from which the magnetic variations are counted.

2. The epoch-average daily magnetic variations (projected QDC) are implied in the DMI#2_2001 intercept coefficients. Hence for average solar activity levels there should not be any major difference between the two sets of index values (the large actual differences have other causes; cf. Sect. 2.4 and comment C15).

4 Conclusions

The topics for the article in question (McCreadie and Menvielle, 2010) and its corrigendum (McCreadie and Menvielle, 2011) comprise important issues in the development of an approved polar cap PC index. The discussion presented in these papers and in the present article, hopefully, clarifies several aspects in the procedures used for the PC index derivation. It is clear, however, that the best approach to inform the future generation about the pros and cons of the PC index would be writing a new independent article about this topic.

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