Polar Cap (PC) index now IAGA-endorsed

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Introduction. A new polar Cap (PC) index version has now been endorsed by the International Association for Geomagnetism and Aeronomy (IAGA) at the General Assembly held in 2013 and made available at http://pc-index.org. The PC indices, scaled to equal the merging electric field in the solar wind, represent the conditions that dominate the solar wind interaction with the Magnetosphere. The PC indices, PCN based on Thule magnetic data and PCS based on Vostok data, are the firsts among the ground-based indices to respond to changes in the solar wind forcing of the Magnetosphere. Most other ground-based indices, e.g., the auroral electrojet index AE (or AL), the Kp index, and the ASY-H index could be derived directly from the PC index with time delays of around 5-15 min. The ring current index, Dst, can be derived by integration of the PC index. Further indices or parameters like the Auroral Power index, the Electrojet Joule heating, and the Cross Polar Cap Potential could be associated statistically with the PC indices. Thus, the PC indices are extremely useful in Space Weather forecast and analyses. Unfortunately, there are still some unresolved issues around the new PC index version.

1. Basics. A high degree of correlation exists between polar cap horizontal magnetic field variations ΔF and the "Geo-effective" (or "merging") Electric Field, E_m, that controls the global energy transfer from the Solar Wind to the Earth's Magnetosphere (Kan and Lee, 1979):

$$E_m = V_{SW} \cdot B_T \cdot \sin^2(\theta/2) \quad (1)$$

$B_T = (B_Y^2 + B_Z^2)^{1/2}$: IMF transverse magnetic field component
θ = arctan(B_Y/B_Z) : IMF polar angle with respect to the GSM Z-axis

We may increase the correlation by projecting ΔF to an "optimum" direction in a polar cap coordinate system fixed with respect to the Sun-Earth direction. The optimum direction is perpendicular to the equivalent horizontal currents (Hall currents). It could be characterized by the angle, φ, between the current direction and the direction to the Sun and varies with local time and season.

Hence we are looking for a relation between the projected polar cap horizontal magnetic field variations ΔF_{PROJ} and the Solar Wind geo-effective electric field E_m of the form:

$$\Delta F_{PROJ} = \alpha \cdot E_m + \beta \quad (2)$$

where the proportionality constant α is the "slope" (e.g. in units of nT/(mV/m) while β (e.g. in units of nT) is the baseline shift, the "intercept". The parameters are calculated on a statistical basis from cases of measured values through an extended epoch.

From equivalence with E_m the Polar Cap Index PC is then defined by:

$$PC = (\Delta F_{PROJ} - \beta)/\alpha \quad (== E_m) \quad (3)$$

Thus, the PC index is a measure of the polar geomagnetic activity scaled to Solar Wind conditions, and thus corrected for daily and seasonal variations, but also a proxy for the geo-effective electric field E_m measured in mV/m

2. Definition of magnetic variation vector. In the calculation of magnetic variations, three variants have developed to derive the magnetic variation vector, ΔF, from the observed magnetic data, F_{OBS} , which could be described by the following defining equations:

$\Delta F = F_{OBS} - F_{BL}$ …. DTU-S (formerly DMI#2) (4a)

$\Delta F = (F_{OBS} - F_{BL}) - F_{QDC}$ …..DMI (4b)

$\Delta F = (F_{OBS} - F_{BL}) - (F_{QDC} + \Delta F_Y)$ …. AARI (4c)

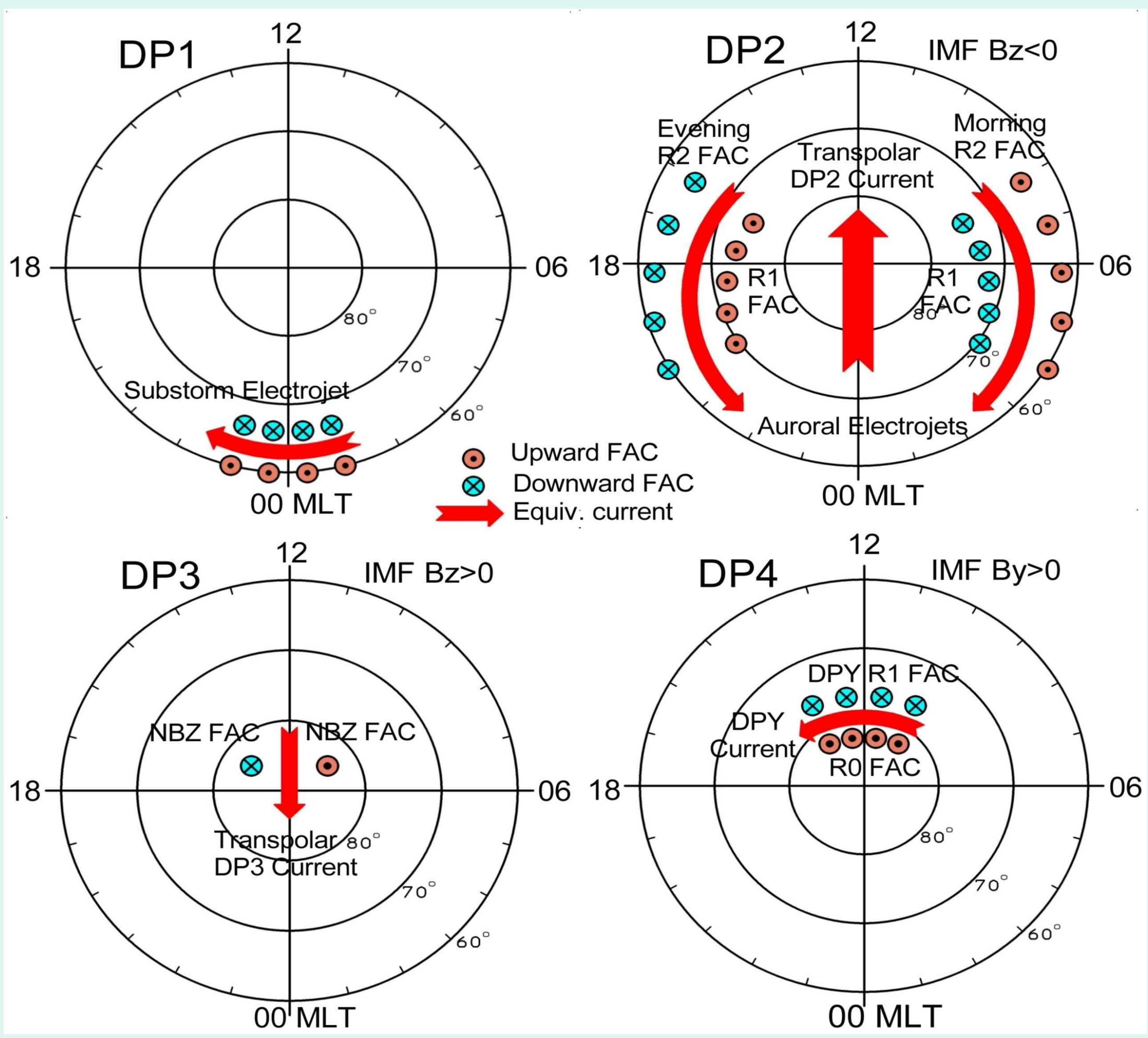
In these expressions F_{BL} is the slowly (secularly) varying baseline vector for the day in question; F_{QDC} is the quiet day (QDC) variation vector for the time in question; ΔF_Y is an IMF By-related (solar wind sector dependent) correction vector for the time in question. The terms $F_{BL} + \Delta F_Y$ could be combined.

In the present DMI method the IMF By-related (solar wind sector related) contribution is included in the calculation of the QDC vector.

In the AARI version the initial QDC is found by averaging quiet data over an interval much longer than the sector structure. An IMF By-related contribution is calculated separately and added to the QDC.

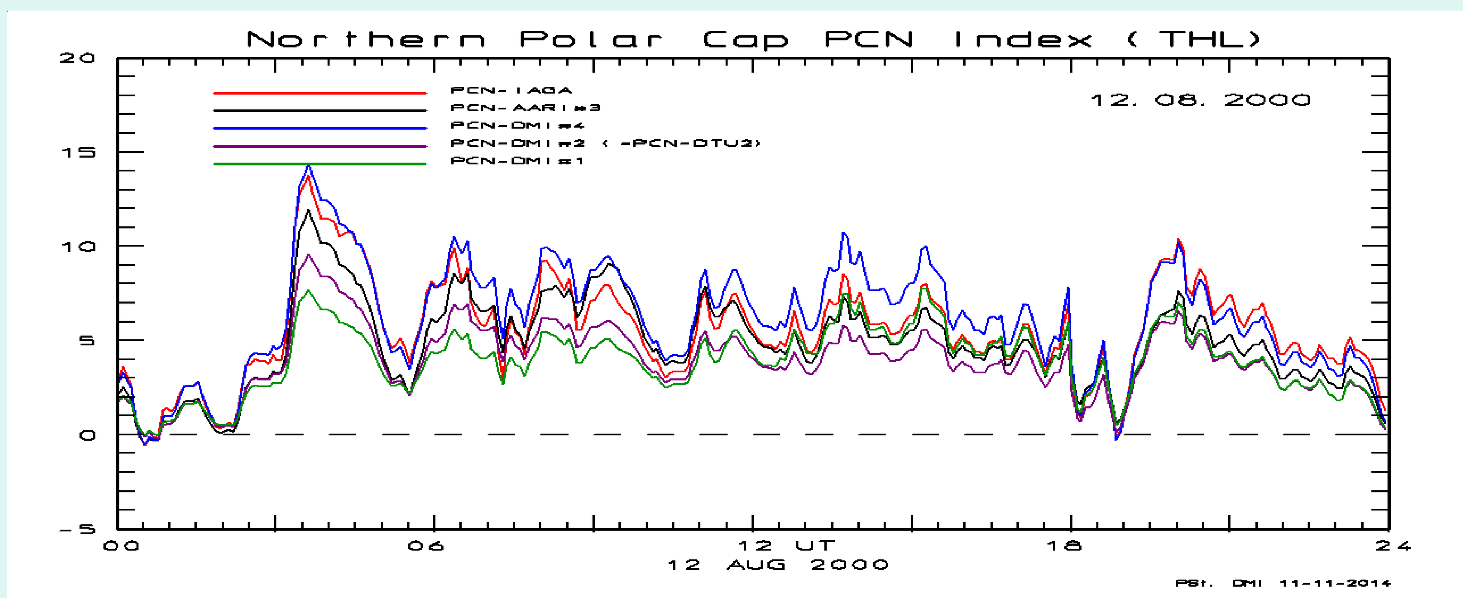
3. PC index problems. The Polar Cap index refers to the **DP2** forward convection patterns illustrated by the ionospheric currents in the upper right panel in Fig. 1 below. This mode is driven by the geo-effective electric field in the solar wind (Eq.1) related to the southward component of IMF. The **DP1** (substorm) mode is driven by instability processes in the tail region. The **DP3** (NBZ reverse convection) mode develops during strong northward IMF. The **DP4** (DPY Cusp current) mode is driven by the Y-component of IMF.
The derivation of index coefficients (slope, intercept) and reference Quiet Day level (QDC) in the geomagnetic data used for PC index calculations (Eqs. 4) should focus on DP2 conditions and minimize disturbing effects from the other modes.

Fig. 1



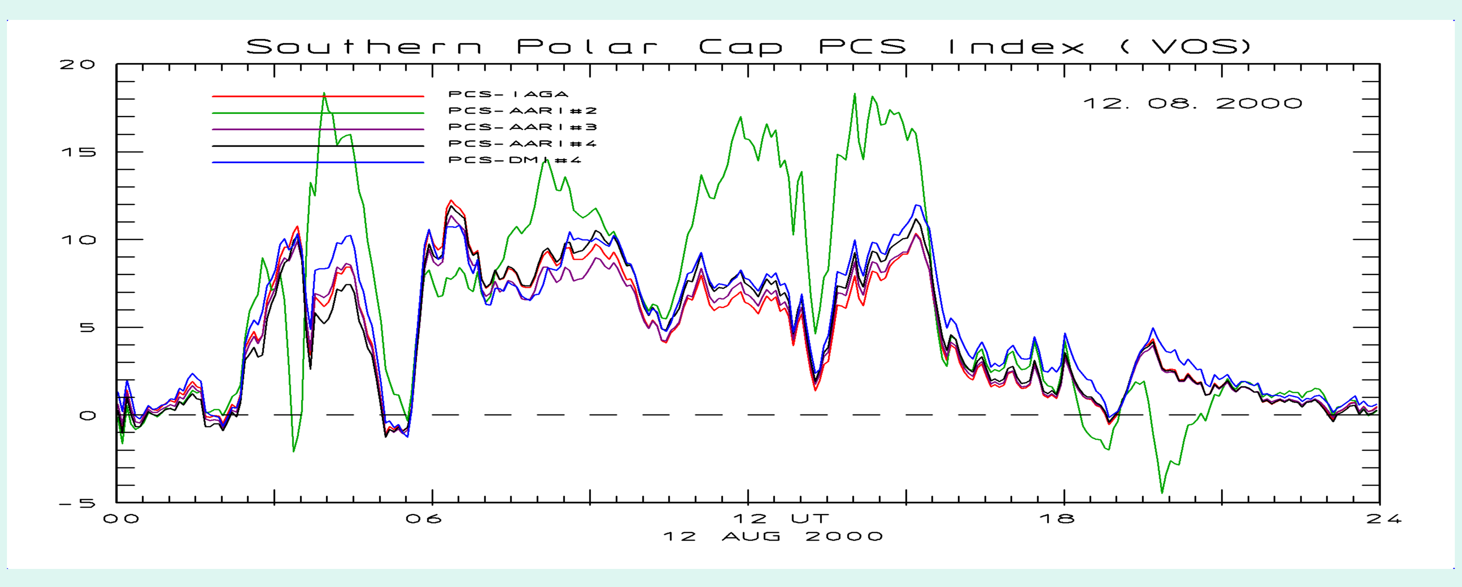
4. PC index versions. With papers discussing the relations between PC index values and other geophysical parameters it is important to settle the PC index version. The examples in Figs. 2 and 3 here shows IAGA, DMI#1, DMI#2 (=DTU-S), DMI#4, and AARI#3 PCN index values all derived from Thule data for 12 August 2000 but using different procedures. There are quite large differences between the different versions.

Fig. 2



The example in Fig. 3 below shows PCS data for 12 August 2000 supplied from AARI in versions AARI#2, AARI#3, and AARI#4. In addition, the figure displays IAGA PCS values (in red line) and DMI#4 PCS values calculated for the same day also from Vostok data.

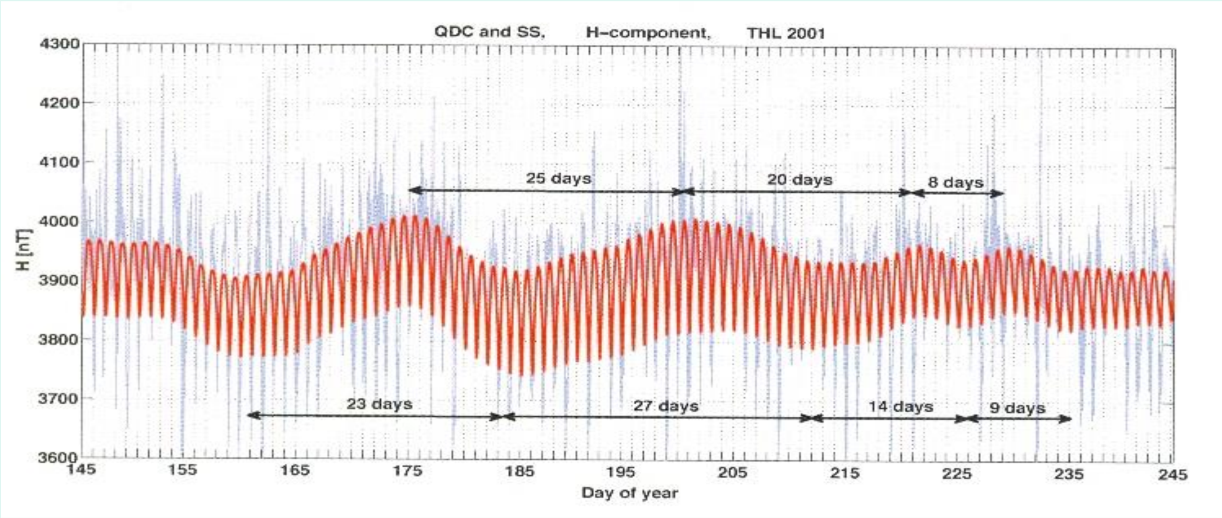
Fig. 3



The presently IAGA-adopted PC procedure fails on two important issues:
(A) The IMF-By effects on the QDC derivation are handled inconsistently.
(B) The reverse convection effects on the PC index coefficients are not excluded.

A. In the IAGA-adopted PC index procedure the IMF-By contributions to the QDC for the geomagnetic components are derived from smoothed daily mean values of the magnetic variation vectors. These values are then added to the slowly varying QDC amplitude as illustrated in the Fig. 4 below for the H-component of Thule magnetic recordings (from Janzhura and Troshichev, 2011).

Fig. 4



The basic problem here is the equal IMF-By related shifts of the top (night time) values and the bottom (day time) values of the QDC (red curve). For the real QDC there are only IMF By effects in the daytime while the nighttime QDC is not affected much by IMF By variations. This feature is illustrated in the Fig. 5 below. Thus, the IAGA-adopted QDC procedure is inconsistent.

Fig. 5

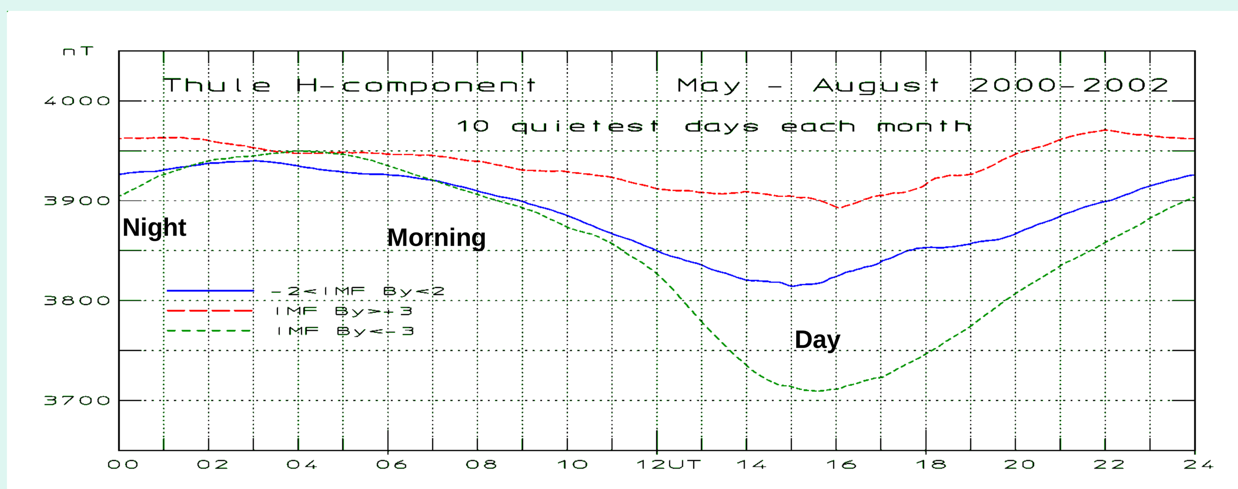
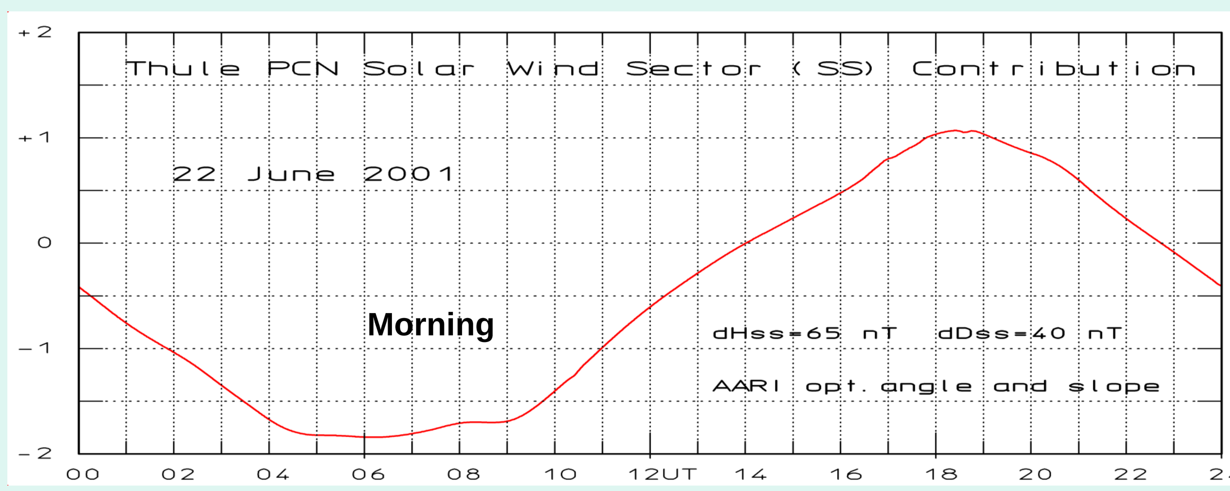


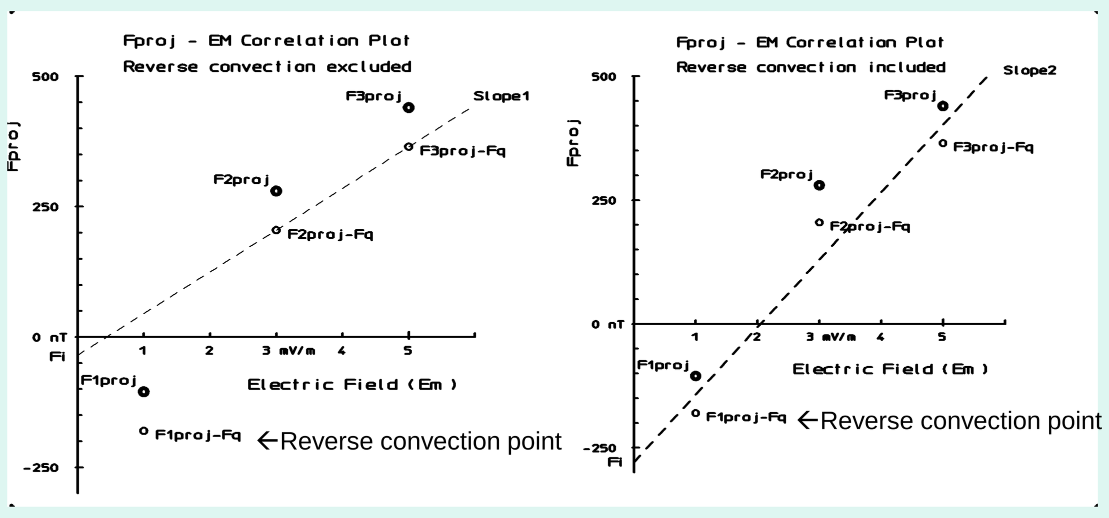
Figure 6 below presents an example of the derived IMF By (solar wind sector) addtion to the PC index. Note the contribution of ~ -2 units in the local morning sector (03 – 09 UT) at a time when the real IMF By effects are almost abscent. The figure uses values of the SS contribution and coefficients derived at AARI.

Fig. 6



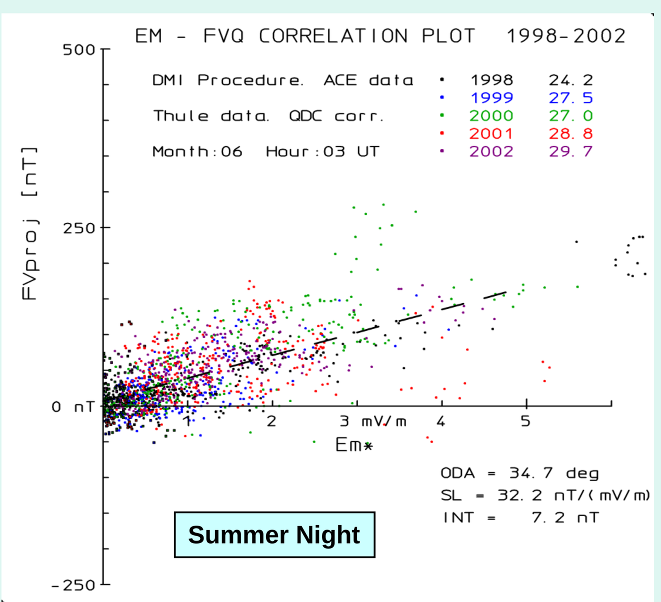
B. In the IAGA-adopted derivation of the PC slope and intercept coefficients, α,β (cf. Eq.3), all data are included without discrimination of reverse convection cases (DP3 mode). The PC index is meant to describe the forward convection (DP2 mode) and the mixing of modes in the derivation of index coefficients is inconsistent. The effects are shown schematically in the diagrams in Fig. 7 below. The reverse convection cases are characterized by large negative values of the projected horizontal magnetic component (Fproj).

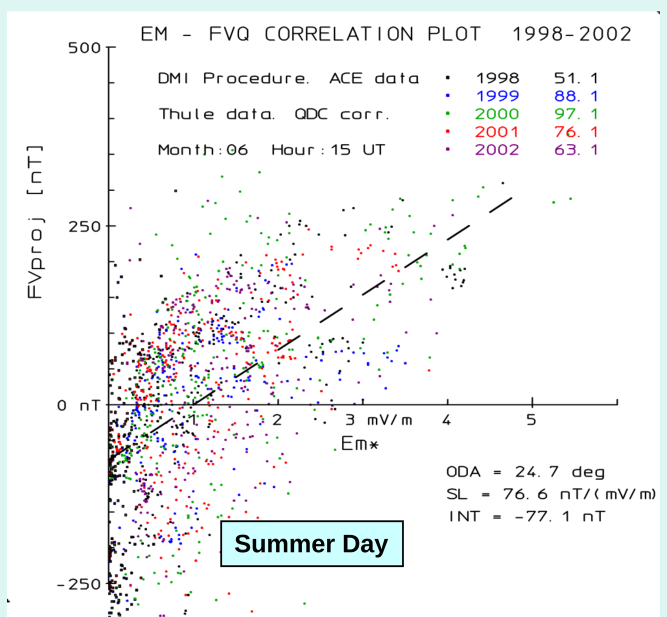
Fig. 7



It is seen from Fig. 7 above that including the reverse convection cases (right field) makes the regression line describing the relation between the magnetic deflection (Fproj) and the geoeffective electric field (Em) in the solar wind go steeper. Thus, the slope value (α) is larger and the intercept value (β) more negative than values found with omission of reverse convection cases (left field).
The effect is particularly pronounced at Thule in the summer daytime when the reverse convection cases are most frequent as illustrated in Figs. 8a,b below.

Fig. 8a,b





Among the consequences of including reverse convection data in the index calculations are smaller PCN index values (due to larger slope) at summer day hours during large disturbances and odd daytime upward humps in PC index values (due to large negative intercept values) during quiet conditions. Furthermore, the coefficient values and the derived PC index values matches poorly between Thule (PCN) and Vostok (PCS) at equivalent local time and season due to the less frequent occurrence of reverse convection cases at Vostok compared to Thule.

Conclusions. The Polar Cap index has the potential to become the World's leading ground-based magnetic index. The IAGA adoption of the PC index is an important step. The presentation of PC index values, among other in real-time, at the web site http://pc-index.org is most useful, among other for forecast (alerts) of geomagnetic storms, e.g. for power line operators and aurora watchers.

However, the IAGA PC index derivation procedures should be improved to include:
(A) Proper handling of the IMF By effects on the Quiet Day (QDC) reference values and
(B) Suppression of the adverse effects on the index coefficients of including reverse convection cases in the data base for coefficient calculations.

The PCN and PCS index values made available at the PC index web site should be marked "Preliminary values" until the derivation procedure is finally agreed upon and settled.

References:

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