Generation and applications of real-time Polar Cap (PC) indices

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Abstract.

The Polar Cap (PC) indices, PCN (North) and PCS (South), are based on geomagnetic observations from Qaanaaq (Thule) and Vostok, respectively (e.g., *Troshichev et al*., 2006). In real-time versions the indices could be useful a.o. for power grid protection by enabling warning an hour or more ahead of violent events of geomagnetically induced currents (GIC) that may threaten high-voltage power lines in the vicinity of the auroral zones (*Stauning*, 2013). The PC indices in the real-time version endorsed by IAGA, and made available at http://pcindex.org, display excessive excursions that seriously deteriorate their usefulness for Space Weather applications. The problems are illustrated here and alternative real-time PC index derivation methods are suggested. Furthermore, the potential use of alternative locations in the northern and southern polar caps to provide reliable data for PC indices are considered.

PC index 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:

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

A basic issue for PC index calculations is the derivation of the quiet reference level (QL) from which the magnetic variations should be counted. For the IAGA endorsed PC index version based on the methodology presented in *Janzhura and Troshichev* (2011), hereafter *J&T2011*, the QL is defined by

$$\mathbf{F}_{QL} = \mathbf{F}_{BL} + \mathbf{F}_{QDC,SS} + \mathbf{F}_{SS} \qquad (3)$$

Here, $\mathbf{F}_{SS}$ is a solar wind sector (SS) term derived from the daily median values of the horizontal magnetic components. In the index version used for archival data, the SS term is derived by smoothing the daily medians over 7 days with the actual day at the middle. Such smoothing is not possible in real time and is replaced by Cubic Spline extrapolation from four previous 3-days medians.

However, rather than generating smoothly varying solar sector terms, the *J&T2011* procedure, as shown in *Stauning* (2018b), generates excessive variability in the QL components. This is shown in Fig. 1 based on the H-component median values and the procedure presented in *J&T2011*.

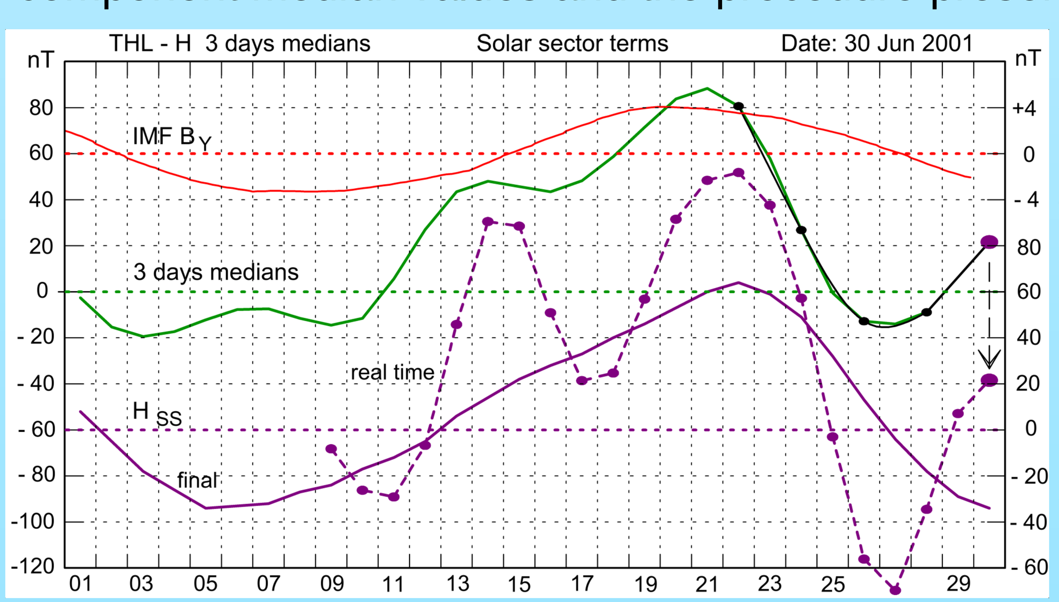


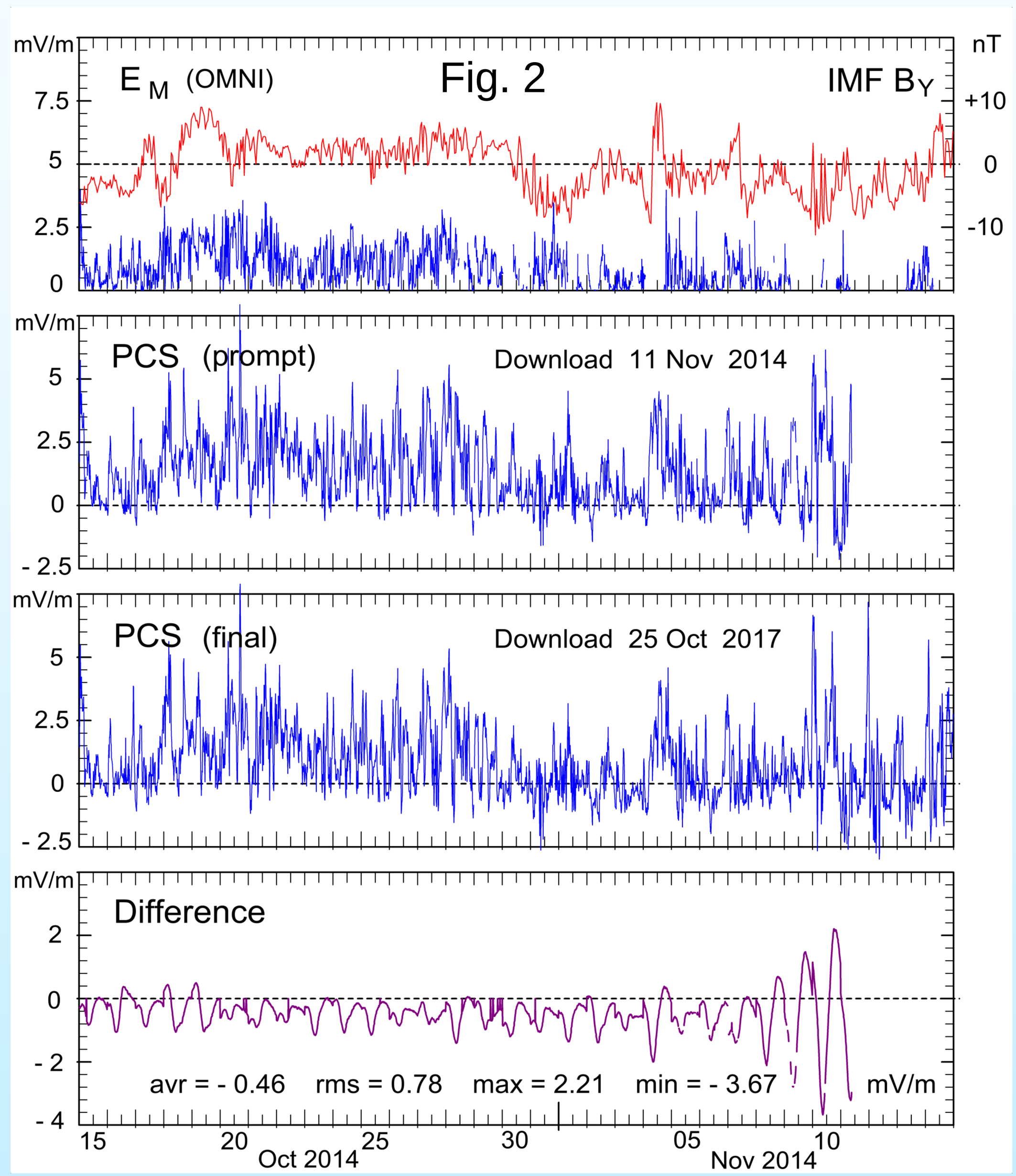
Fig. 1. 3-days median values (green line) and H_{SS} values (magenta) from *J&T2011*. Four 3-days average median values marked by black points are used for Cubic Spline extrapolation to give H_{SS} = 21 nT on 30 June. For clarity the point is displaced downward by 60 nT (all H_{SS}) points.

In Fig. 1 the 3-days median values presented in the green line were read-off from Fig. 6 of *J&T2011*. From consecutive 4 points the H_{SS} values were derived by Cubic Spline extrapolation one day ahead and marked by a large dot. The points were subsequently displaced by 60 nT downward and connected by the broken magenta line to be contrasted with the smoothed H_{SS} values on the same scale (to the right).

Downloads from http://pcindex.org

The large differences between the Cubic Spline "real-time" and the "final" smoothed $\mathbf{F}_{SS}$ values included in the QL derivation, as shown for the H-component in Fig. 1, could be expected to generate large differences between the "real-time" and the "final" PC index values.

Fig. 2 is based on download on 11 Nov 2014 of a month's worth of "prompt" PCS data up to the real-time value, and download of the same interval of "final" PCS values on 25 Oct 2017.



In **Fig. 2** the upper field displays values of the merging electric field, E_M, (blue line) and IMF B_Y (red). The next lower fields display the prompt PCS data up to the real-time value and the final PCS values from a later download. The bottom field displays the differences between the final and the prompt values. The average, rms, max and min differences are noted at the bottom of the diagram. The max difference is 3.67 mV/m. (*Stauning*, 2018b)

The differences are displayed more detailed in Fig. 3

Fig. 3

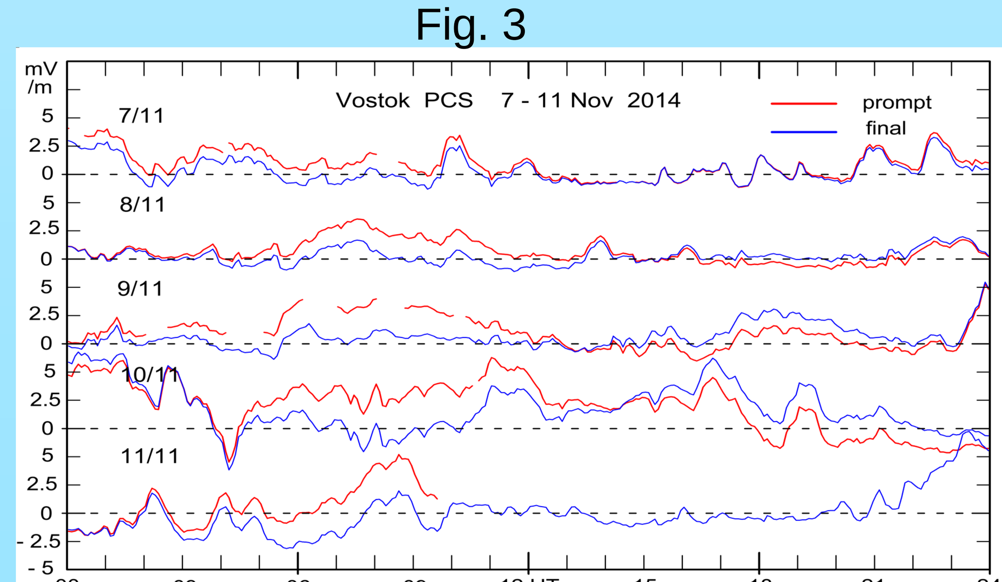
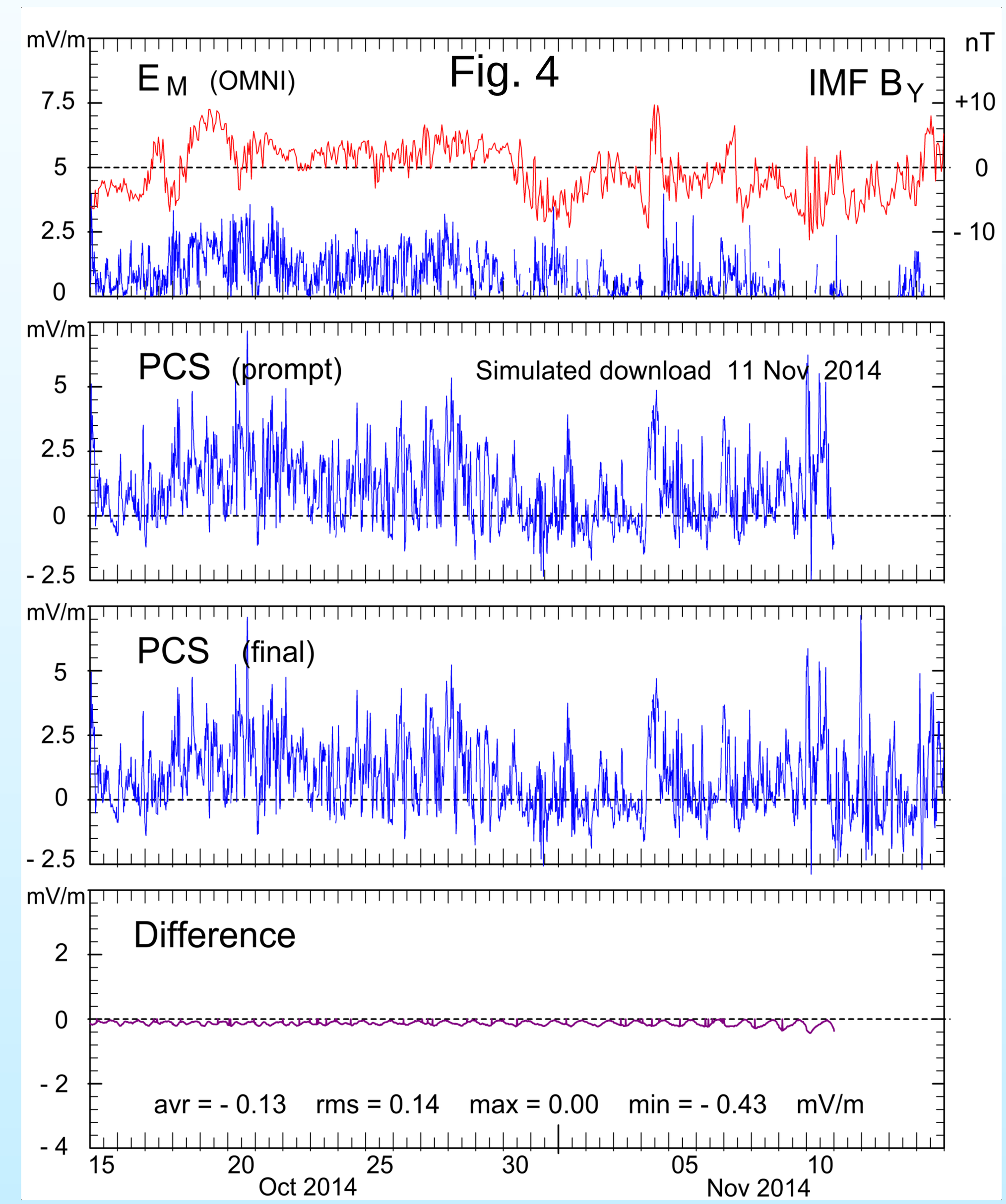


Fig. 3. "Prompt" PCS indices from a download on 11 Nov 2014 at 09:41 UT (red line). "Final" PCS indices from a download on 25 Oct 2017 (blue line). (from *Stauning*, 2018b)

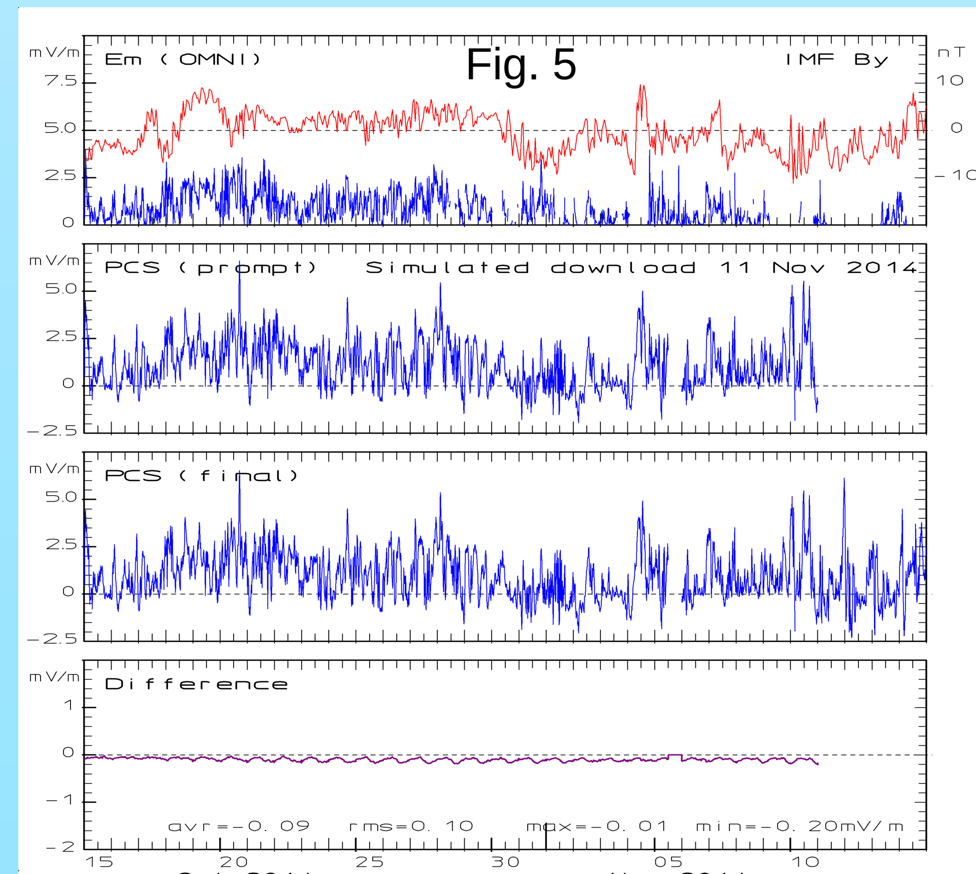
The DMI PC index calculations

As shown in Fig. 4, the differences between the prompt (real-time) and the final PC index values need not be that large. In Fig. 4, the PCS values have been derived by the "DMI" procedures from the same Vostok data as those used for Figs. 2 and 3. The reference QL was derived by the "solar rotation weighted" (SRW) method (*Stauning*, 2011) from quiet samples only. QL for the "prompt" PCS values were derived from data prior to the simulated download time only.



In **Fig. 4** the format and the E_M and IMF B_Y data are the same as those used in Fig. 2. The prompt and final PCS values were derived by the DMI methods. With this method the max difference between prompt (real time) and final PCS values were just 0.43 mV/m. (from *Stauning*, 2018b)

Similar results are obtained by using the DMI metods on magnetic data from Concordia Dome C as shown in **Fig. 5**. Max difference=0.2 mV/m



Protection of Power Grids

One of the potential applications of real-time PC indices is the protection of power grids against damage caused by excessive geomagnetically induced currents (GIC) related to violent substorms. From a study of disruptions of high voltage power lines in Sweden related to GIC's it was found that such disturbances were preceded by PCN values exceeding 10 mV/m (alert level) for 2-3 hours. In the strongest cases, the PCN index exceeded 15 mV/m (red alert) during most of the previous hour.

Fig. 6

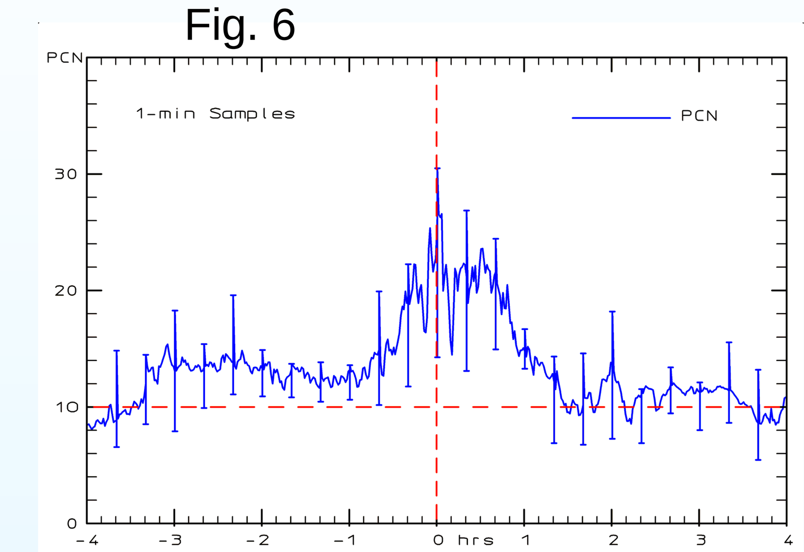


Fig. 6. PCN index values during 4 hours before and after power line disruptions in Sweden. (from *Stauning*, 2013)

Fig. 7

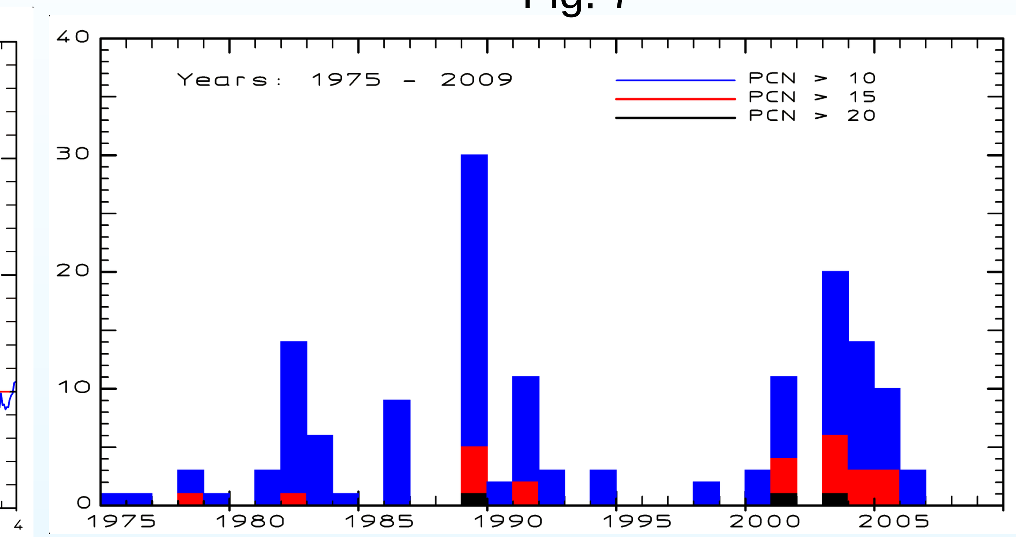


Fig. 7. Yearly occurrences of hourly PCN index values above specified 10, 15, and 20 mV/m levels. (from *Stauning*, 2013)

Advance GIC warning

Usually, substorm activities start within an hour, when the PC index exceeds 2 mV/m. However, it takes some time with a consistent high level of the polar cap plasma convection (and PC index) to widen the open Polar Cap enough to cause a substantial equatorward displacement of the auroral regions. The displacement is needed to enable substorms hitting sub-auroral latitudes where power grids are really vulnerable to GIC events. Thus, the PC indices are very well suited to provide advance warning of major GIC events that may seriously threathen electric power grids. Fig. 8 displays an example where the PCN indices based on magnetometer data from Resolute Bay (a local source in Canada) could have given 6 hours of advance warning, including 2 hours of "red alert" immediately preceding the major power outage on 13 March 1989

Fig. 8

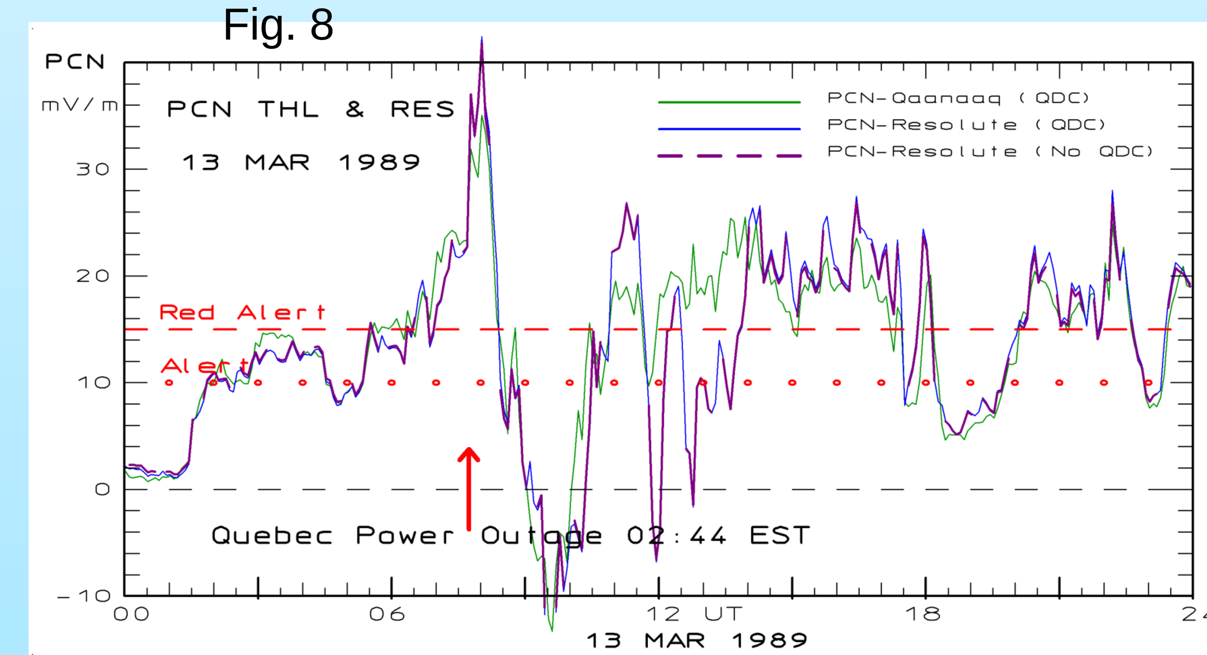


Fig. 8. PCN indices based on Thule and Resolute data in final versions (with QDC), and in a real-time version (no QDC) based on Resolute data. Alert level (10 mV/m) is indicated by red dotted line. Red alert (15 mV/m) by red dashed line. (from *Stauning*, 2018a)

Conclusions

- Real time PC indices in the version approved by IAGA resolution no. 3 (2013) and made available at http://pcindex.org display excessive variability compared to the final values.
- For Space Weather applications it is suggested to use the DMI derivation methods (*Stauning*, 2016) to calculate real time PC indices.
- In order to ensure credibility and oprational reliability of PC indices used for Space Weather services it is suggested to include alternative sources of index data.

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.

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