DMI

The Polar Cap PC indices

Peter Stauning
Danish Meteorological Institute (DMI)

PC index status

- Presently the PCN and PCS indices are "unofficial" indices with no complete, clear and published derivation procedure.

- Unified PCS and PCN procedures (but not quite the same) are used at AARI and DMI (magnetic data corrected for QDC)

- Old PCN procedure is used at DTU Space (magnetic data not corrected for QDC, inconsistency in derivation procedure)

- At the forth-coming IAGA 12'th Scientific Assembly to be held in Yucatan, Mexico 26-31 August 2013, there should be a formal approval of the PC indices.

- One year ahead (very soon) the final procedures should be published and open for scientific discussions.

- DTU Space has agreed to change their present PCN procedure to agree with the procedure used by Oleg Troshichev at AARI.
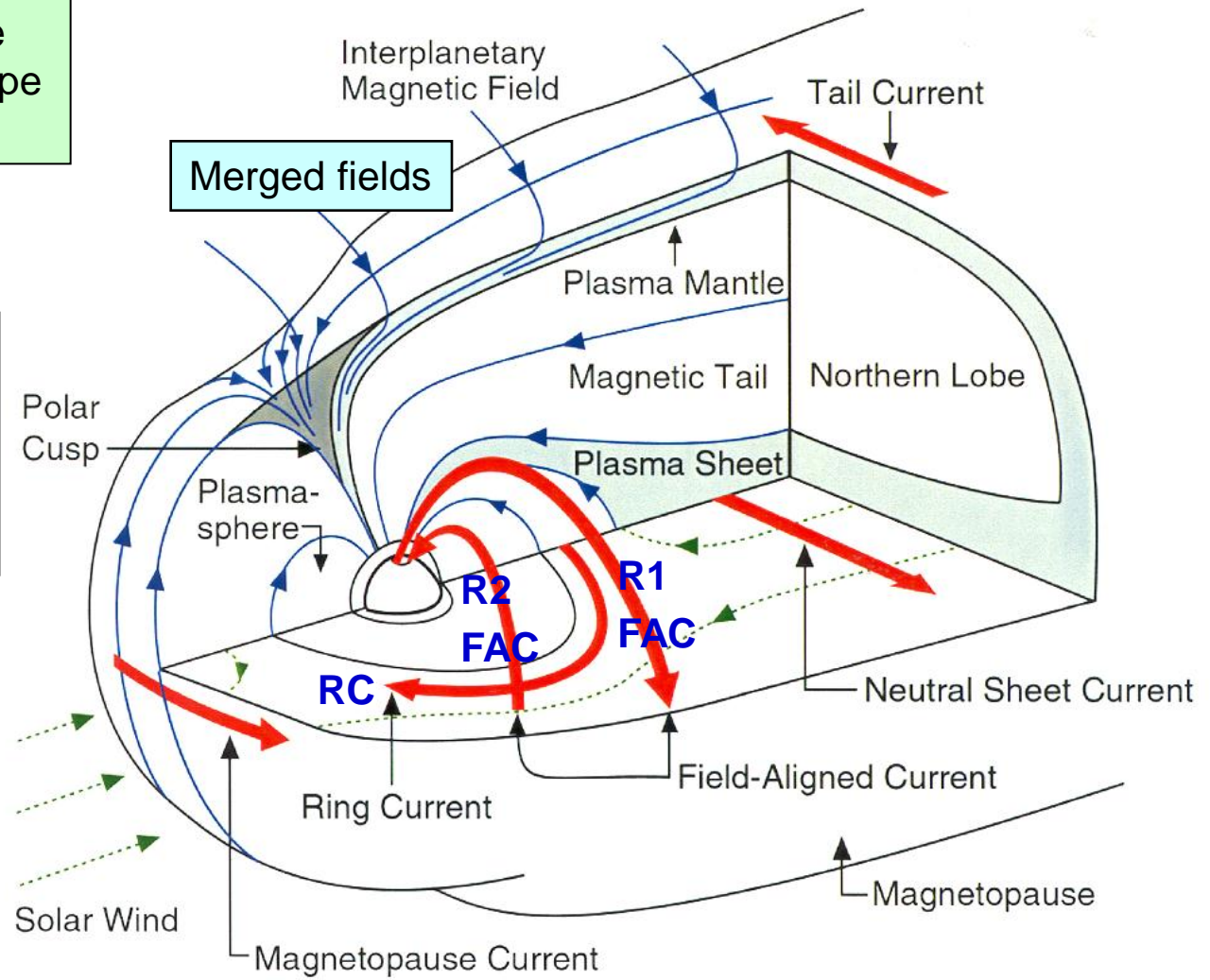
The Earth's Magnetosphere in the Solar Wind

Solar wind dynamic pressure controls Magnetosphere shape and Magnetopause currents

$$P_{SW} = D_{SW}\, V_{SW}^2$$

Solar wind electric field controls merging of IMF and geomagnetic field as well as internal FAC currents and plasma convection

$$E_{SW} = -V_{SW} \times B_{SW}$$

The convection of geomagnetic field into the tail region creates an unstable configuration that is released through substorms.

Merged fields

Interplanetary Magnetic Field

Tail Current

Plasma Mantle

Magnetic Tail

Northern Lobe

Polar Cusp

Plasma-sphere

Plasma Sheet

R2 FAC

R1 FAC

RC

Neutral Sheet Current

Ring Current

Field-Aligned Current

Magnetopause

Solar Wind

Magnetopause Current

Deriving Polar Cap (PC) Indices

- The PC indices represent polar cap magnetic variations associated with the transpolar part of the polar forward double vortex current system.

- The transpolar part of the vortex system is driven mainly by the merging electric field of the solar wind-magnetosphere dynamo acting through field-aligned currents (R1-FAC).

- 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.

Plasma flow   Hall current

Weimer, 1999
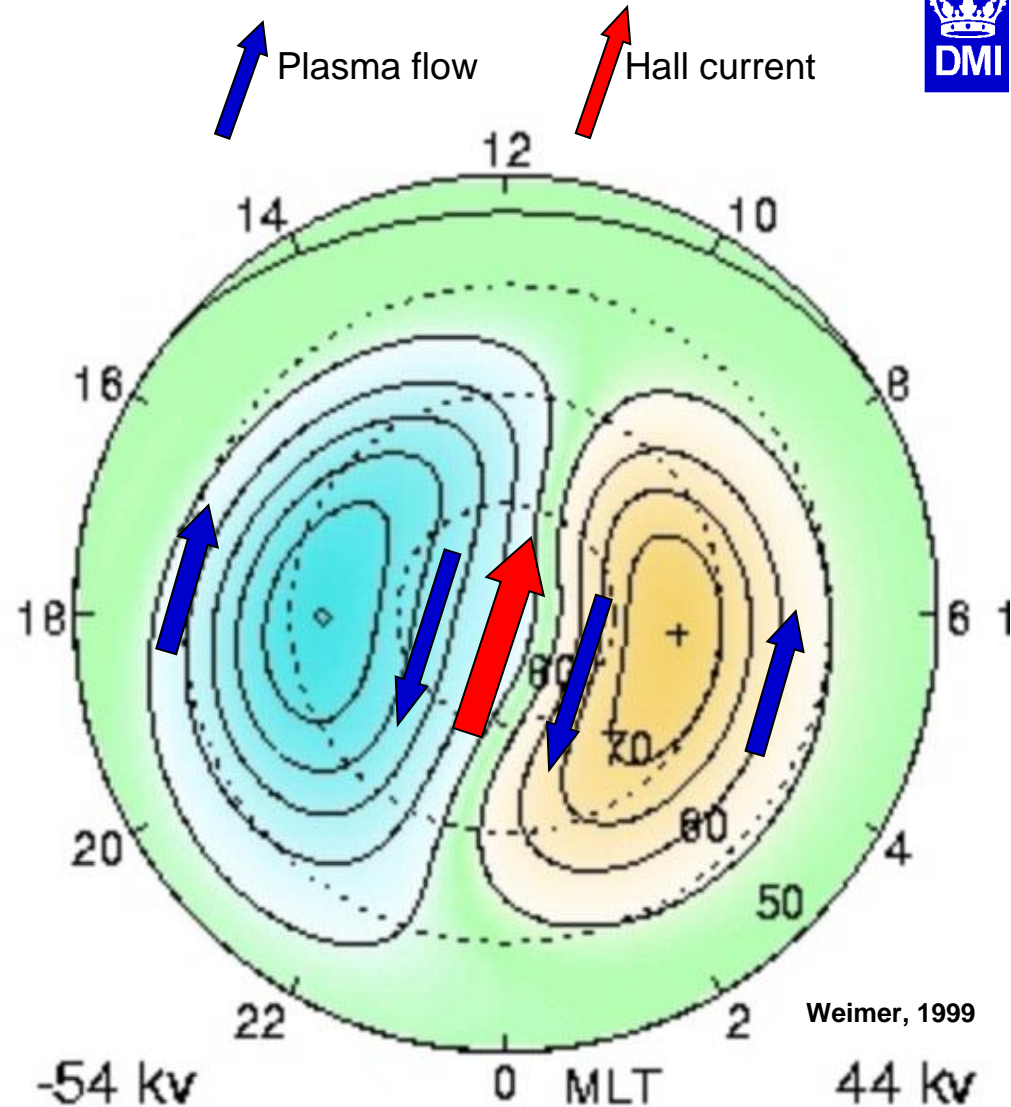
IMF B_Z = - 8 nT, V_{SW} = 450 km/s, E_M=3.6 mV/m

Basics.

The "Merging Electric Field" (or "Geo-effective Electric Field") E_M, (=MEF) controls the global energy input (Kan and Lee, 1979):

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

where:

V_{SW} : solar wind velocity, $B_T = (B_Y^2 + B_Z^2)^{1/2}$: IMF transverse magnetic field component, and $\theta = \arctan(B_Y/B_Z)$: IMF polar angle with respect to GSM Z-axis.

Polar magnetic field variations are approx. proportional to E_M. Thus:

$$\Delta F_{PROJ} = E_M \cdot \alpha + \beta$$

Where ΔF_{PROJ} (in units of nT) is the magnetic variation projected to the "optimum direction" in a polar cap coordinate system fixed with respect to the Sun-Earth direction. The proportionality constant α is the "slope" (e.g. in units of nT/(mV/m)) and the baseline shift β (nT) is the "intercept".

The dimensionless Polar Cap Index PC is derived from the magnetic variations calibrated to statistically equal the merging electric field:

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

The scaling parameters, i.e. projection angle, slope and intercept, are found from statistical analyses of corresponding polar geomagnetic observations and interplanetary satellite measurements to make PC and E_M values statistically equal. The parameters vary with local time and season but are invariant through the solar cycle.

The PC indices and further parameters

- The PC indices characterize solar wind energy input to the magnetosphere, which is the driver of most other disturbance parameters.

- Thus, PC indices can be used to monitor auroral and mid-latitude magnetic activities characterized by the AE and Kp indices.

- PC indices can also be used to derive Polar Cap potentials, as well as Joule and particle heating of the upper atmosphere.

- The PC indices can be used to derive the asymmetric ring current index ASY-H.

- The PC index can also predict the development of the symmetric ring current flowing in the equatorial regions of the magnetosphere at distances between 4 and 6 Re.

- The ring current characterized by the 1-min SYM-H or the hourly Dst indices is assumed to represent the energy stored within the magnetosphere during the course of magnetic storms. Its intensity is a balance between source and losses.

Relations between PCN and Merging Electric Field
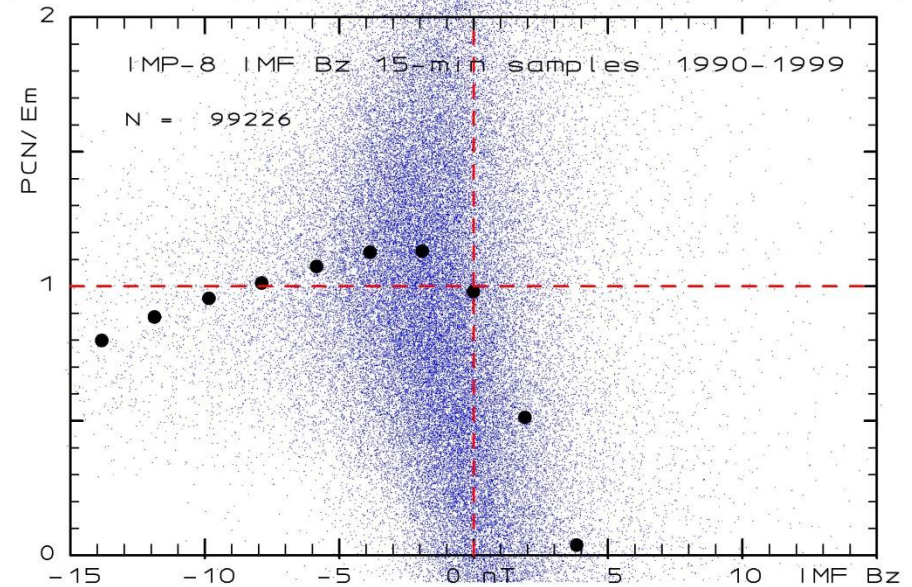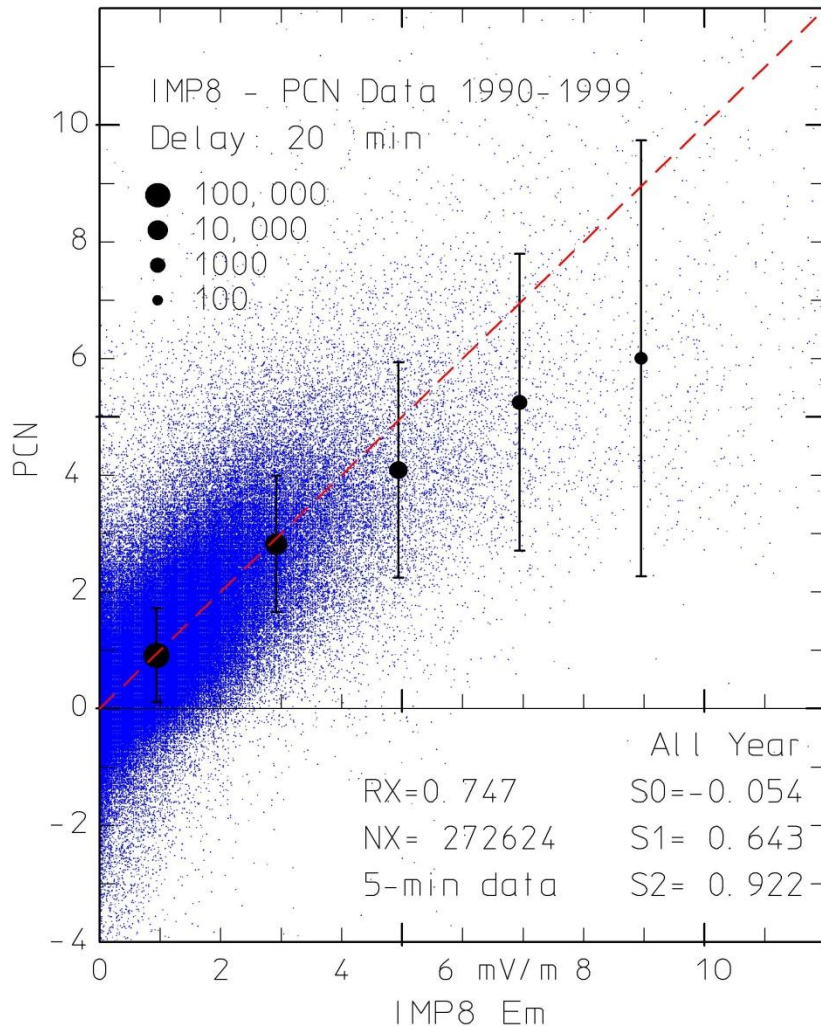
E_M is always positive while the PCN (and PCS) indices could be strongly negative when IMF Bz is strong and positive.

Negative index values are inconsistent with PC indices representing energy input.

The combined PCC index

During strong northward oriented interplanetary magnetic fields (NBZ cases) the pattern in the central polar cap may change to "reverse" convection, which gives large negative values of the PC index.

Now the close correlation between the PC index and the merging electric field is lost since E_M by definition is always positive, although numerically small in cases of northward IMF.

In NBZ cases reverse convection and associated negative PC index values occurs predominantly in the summer polar cap. The corresponding convection in the opposite (winter) polar cap is usually forward but weak such that the associated PC index here is positive but numerically small like the merging electric field.

Hence we expect better correlation between the merging electric field and a combined PCC index defined through.

PCC = (PCN if >0 or else 0 + PCS if >0 or else 0) / 2

The use of a combined PC index also solves the ambiguity problem involved in having two separate PC index series to characterize the interplanetary merging electric field and global geomagnetic activity.
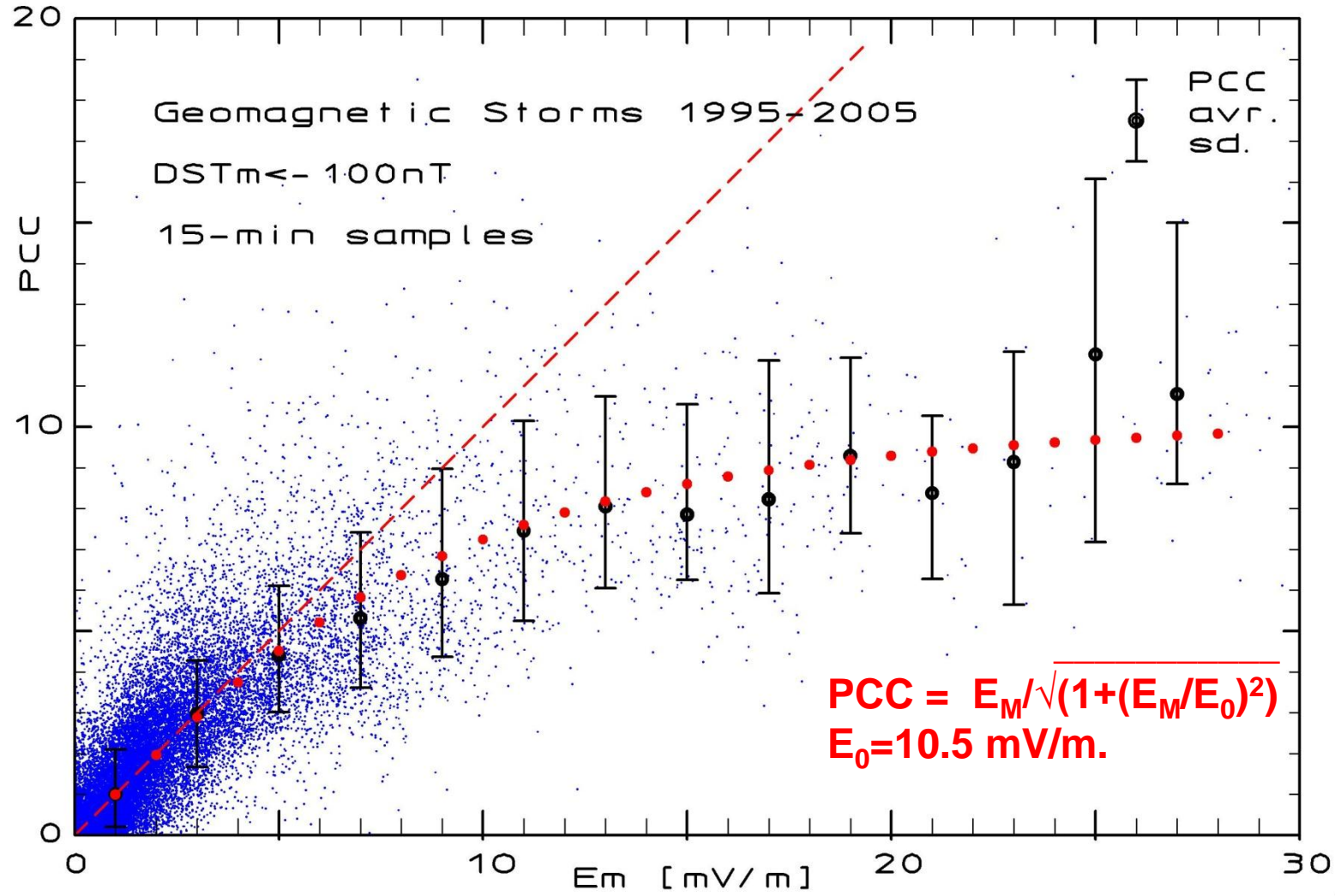
In general:

PCN is used for Northern Hemisphere topics
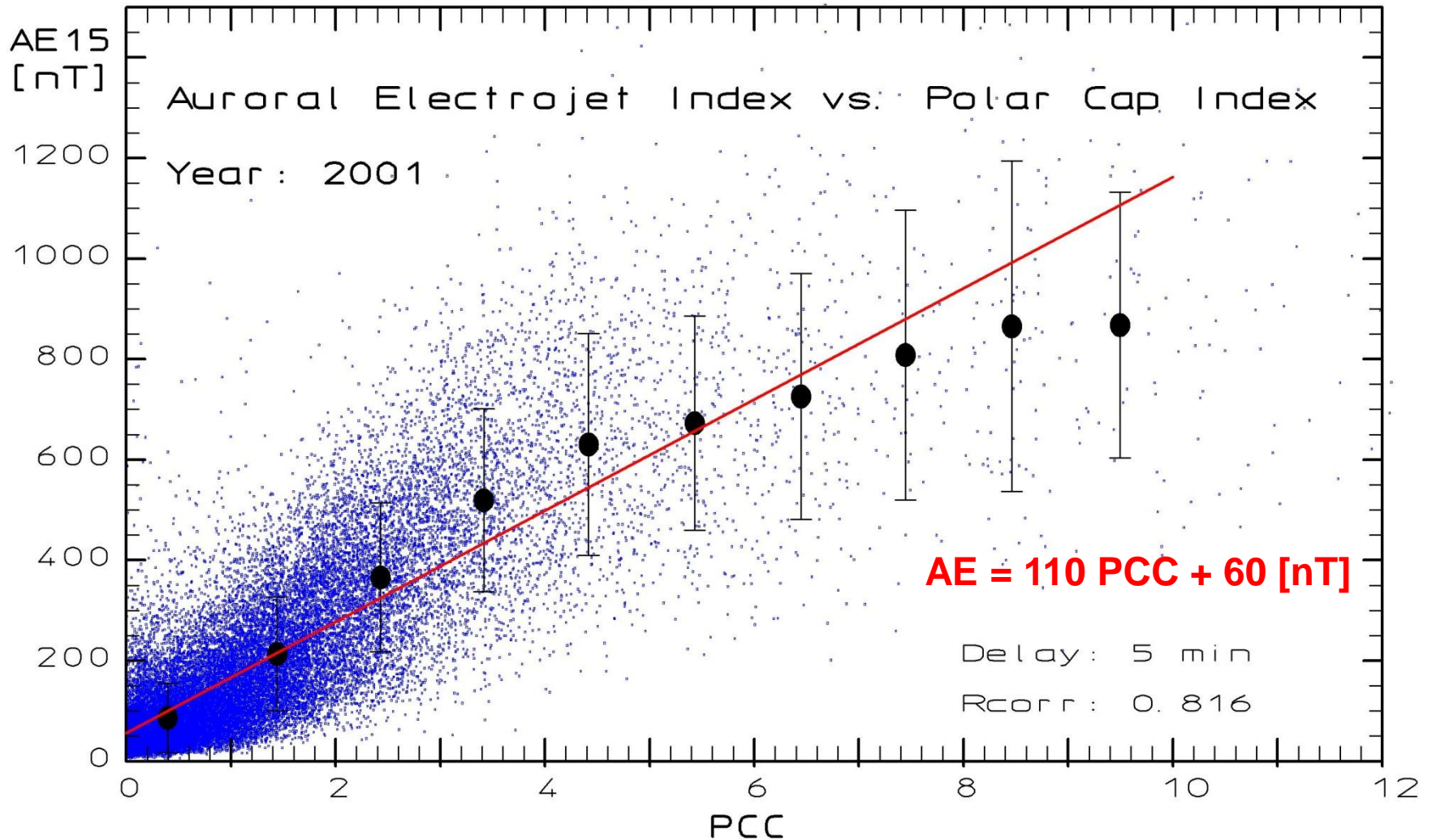
PCS is used for Southern Hemisphere topics

PCC is used for Global topics

Thus they complement each other !

Relations between PCC and Merging Electric Field

Geomagnetic Storms 1995-2005

DSTm<-100nT

15-min samples

PCC avr. sd.

$$PCC = E_M/\sqrt{(1+(E_M/E_0)^2)}$$
$$E_0=10.5 \text{ mV/m.}$$

PCC (y-axis), Em [mV/m] (x-axis)

Relations between PCC and Auroral Electrojet Indices

Auroral Electrojet Index vs. Polar Cap Index

Year: 2001

AE = 110 PCC + 60 [nT]

Delay: 5 min

Rcorr: 0.816

Relations between PC and Auroral Electrojet Indices

The relation between PC index and auroral electrojet activity is not a smooth function.

The PC index characterize the build-up of stresses in the tail region. The auroral activity, in particular substorms, characterize release of stresses.

Handy relations:
PC index < 2 → no substorm
PC index 2 – 5 → substorm onset after delay ~5-60 min
PC index > 5 → imminent substorm (delay 0-10 min)
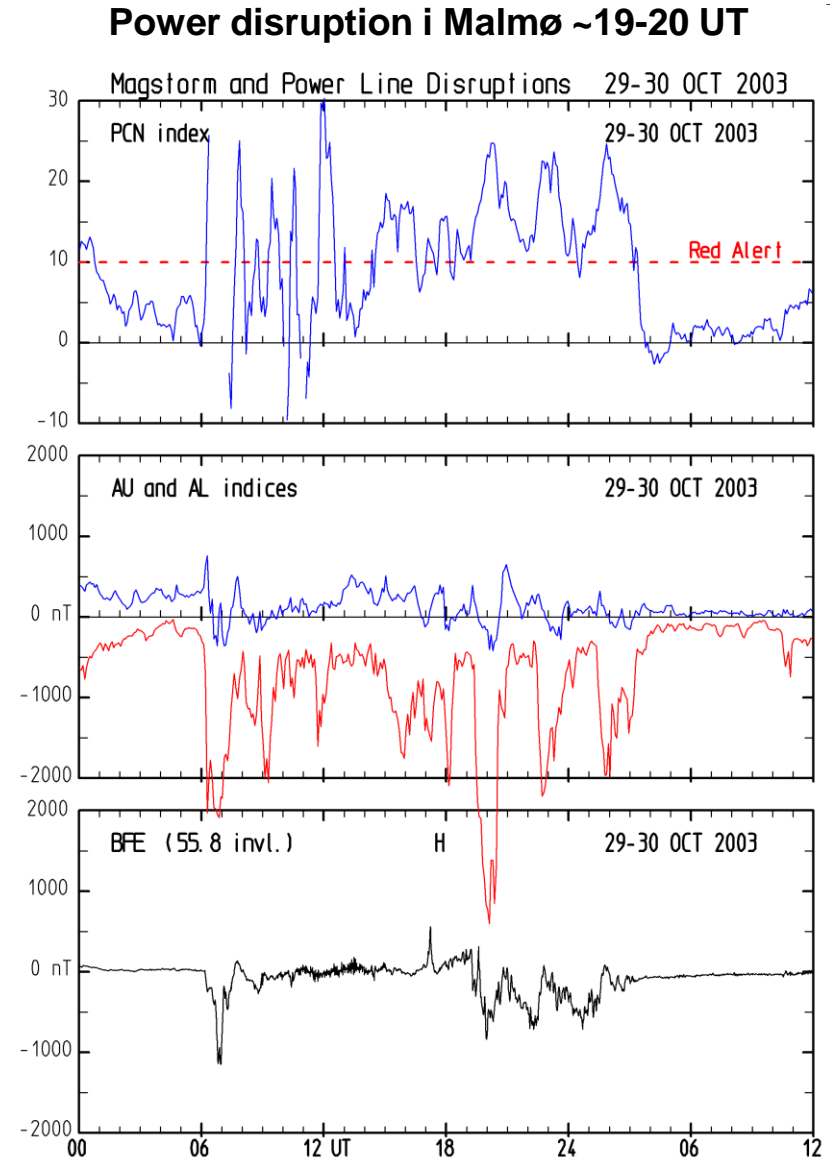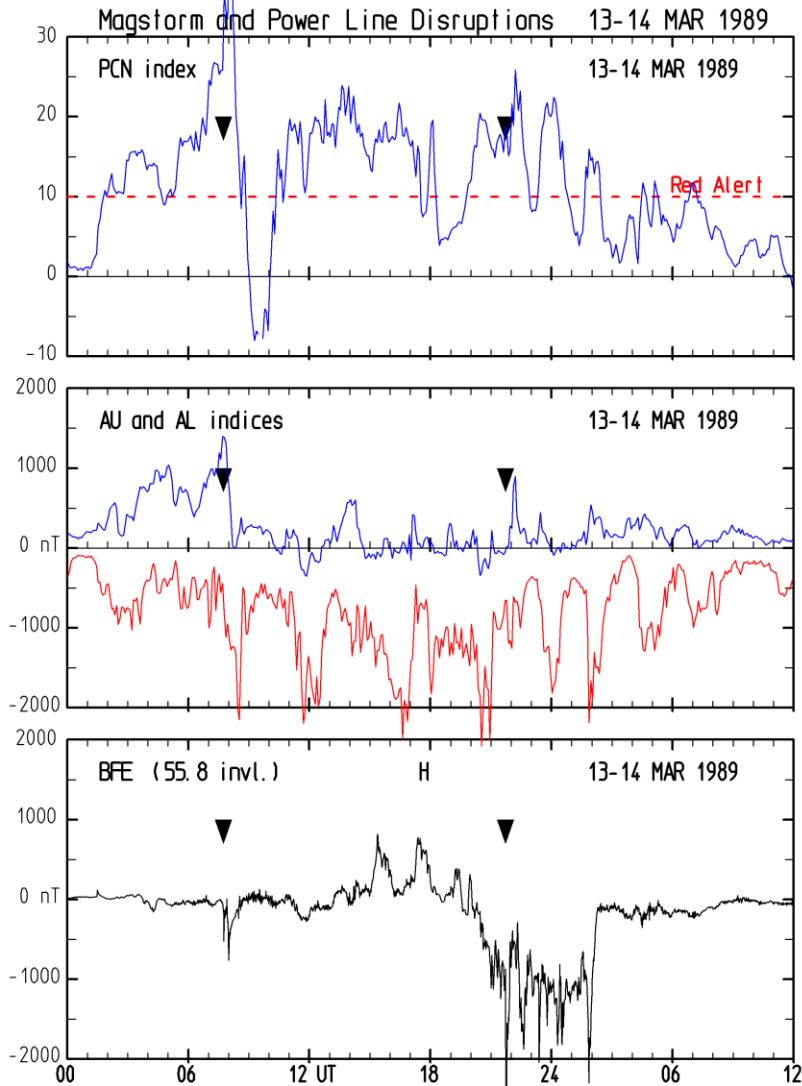PC index >10 → violent substorm activity (grave risk for power grids)

Using the Polar Cap index PCN in early warning of disruptions of Power Distribution systems
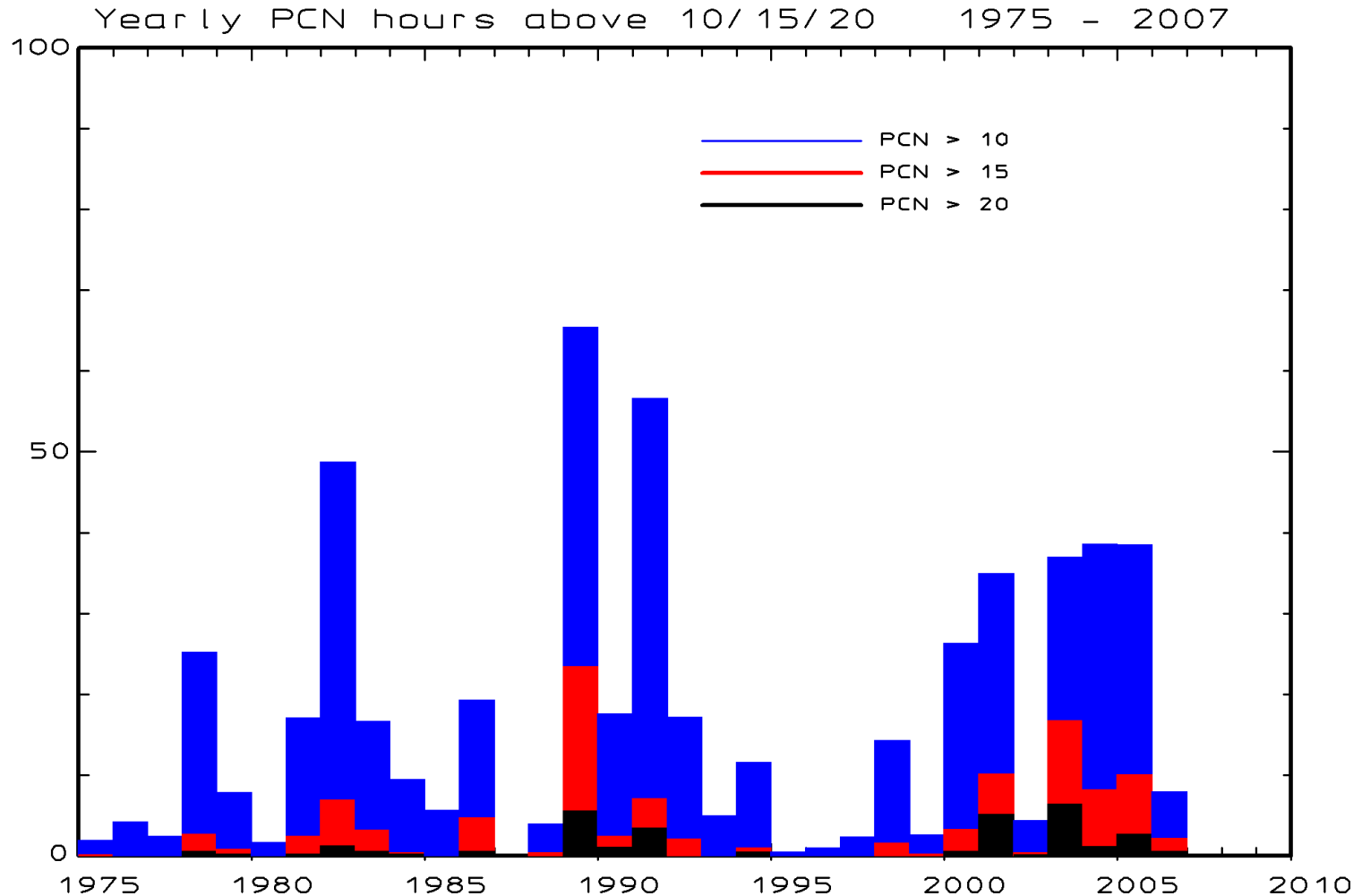
High-voltage power-line disruptions in Sweden marked by triangles
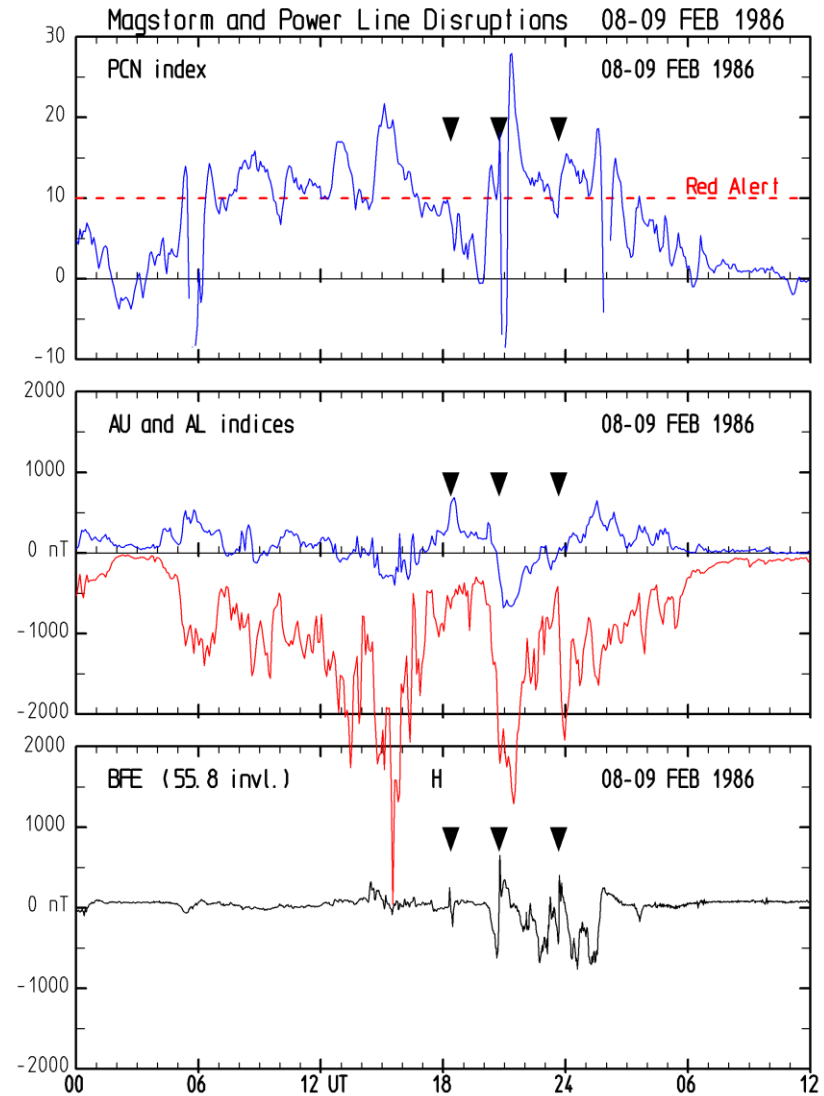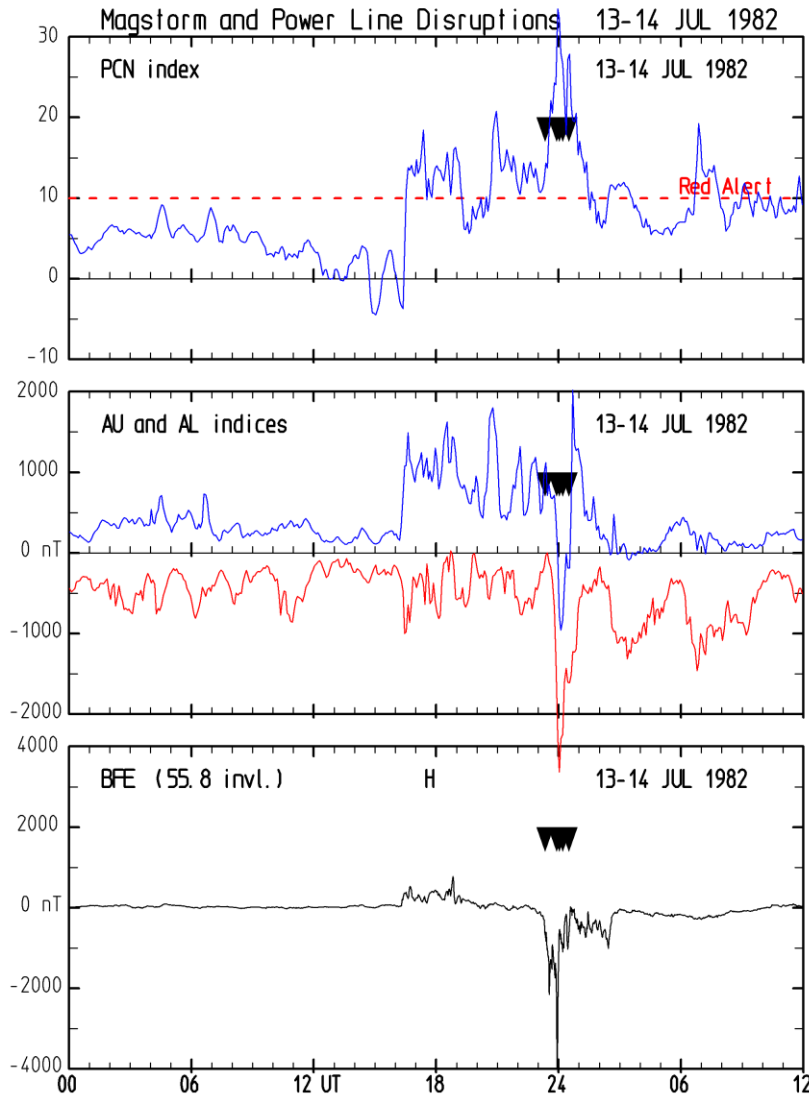
Using the Polar Cap index PCN in early warning of disruptions of Power Distribution systems

Power disruption i Malmø ~19-20 UT

Using the Polar Cap index PCN in early warning of disruptions of Power Distribution systems

Yearly PCN hours above 10/15/20   1975 – 2007

- PCN > 10
- PCN > 15
- PCN > 20

PSt. DCGA Consult & DMI 09-03-2009

Cross-Polar-Cap Potential

The cross polar cap potential data shown in Fig. 10 of Hairston et al. (2005) could well be represented by an expression involving the PCC index (Stauning, 2012) by:

$$\Phi_{PC} \approx 20 \; PCC + 15 \quad [kV]$$

Joule Heating Northern Hemisphere

From the study by Chun et al. (1999), the total Joule heating power for the northern hemisphere (JHN) was estimated and compared to the corresponding values of the polar cap index, PCN. Their result for all data is :
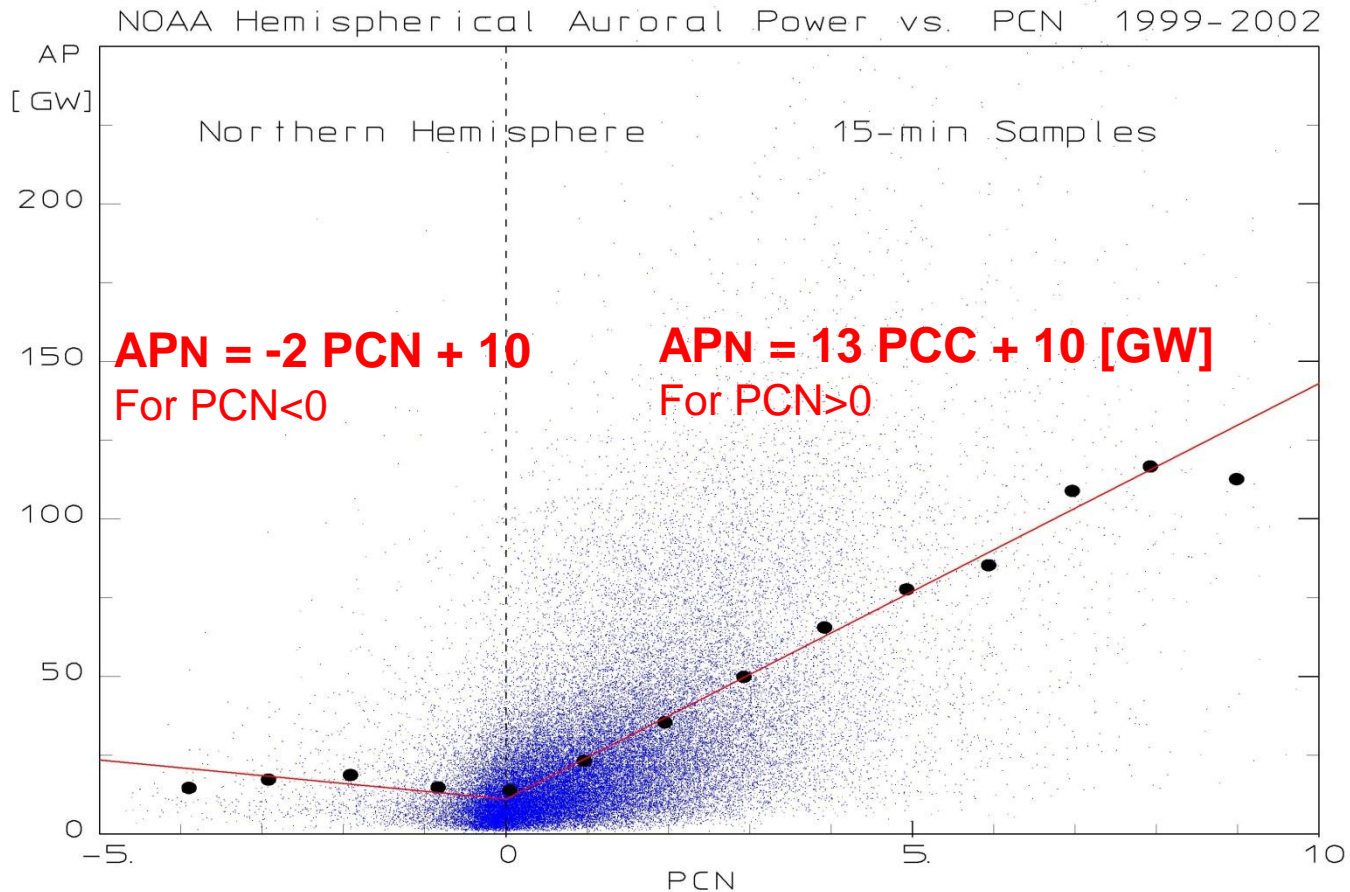
$$JH_N = 4.03 \; PCN^2 + 27.3 \; PCN + 7.7 \quad [GW]$$

NB Just consider the trend. PCN data might not be final.

15-min PCN indices and total northern hemisphere auroral power

NOAA Hemispherical Auroral Power vs. PCN 1999-2002

Northern Hemisphere — 15-min Samples

APN = -2 PCN + 10
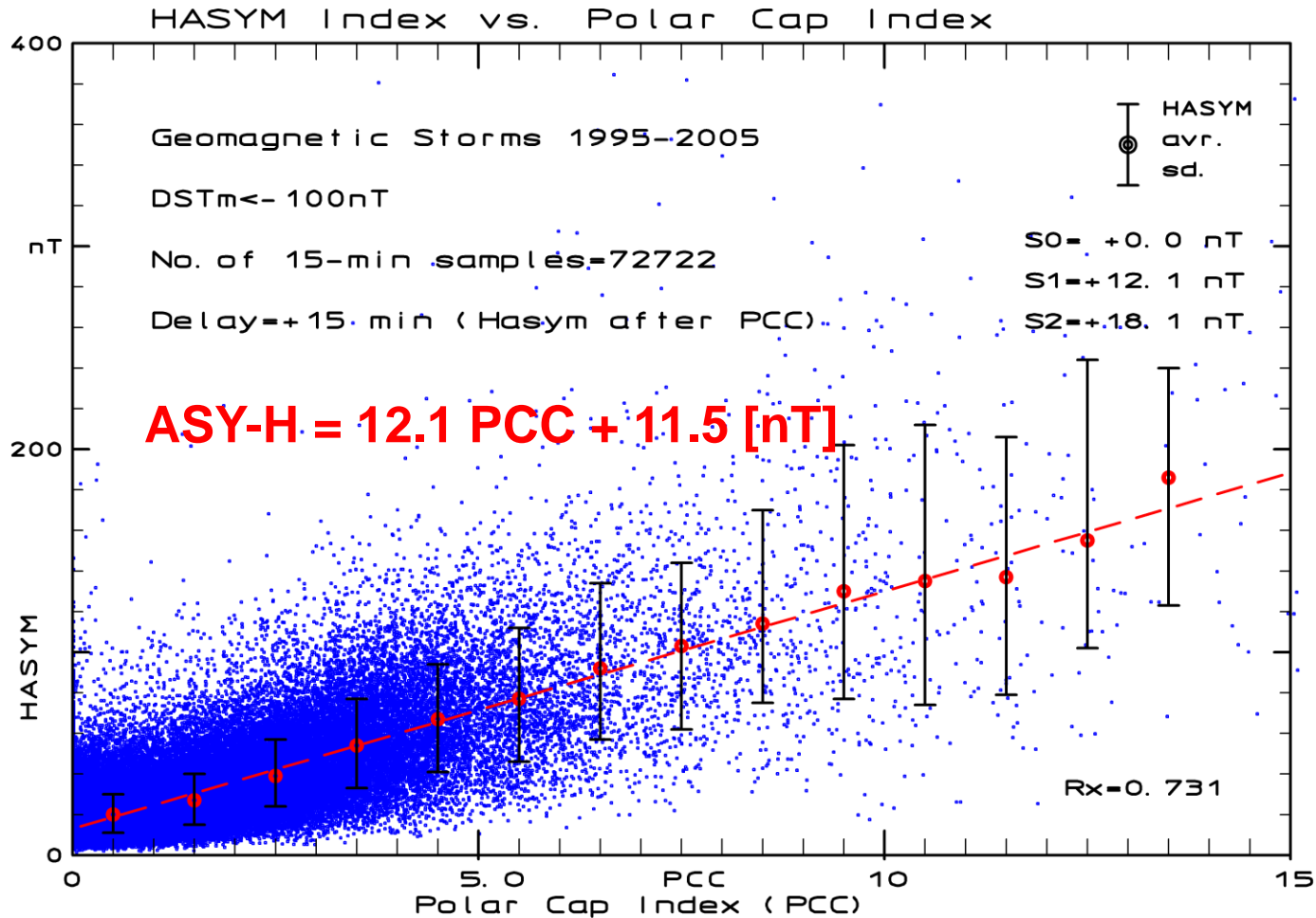For PCN<0

APN = 13 PCC + 10 [GW]
For PCN>0

Note the close average relation.

Relations between PCC and Kp Indices

Kp = 8.0 PCC + 1.0
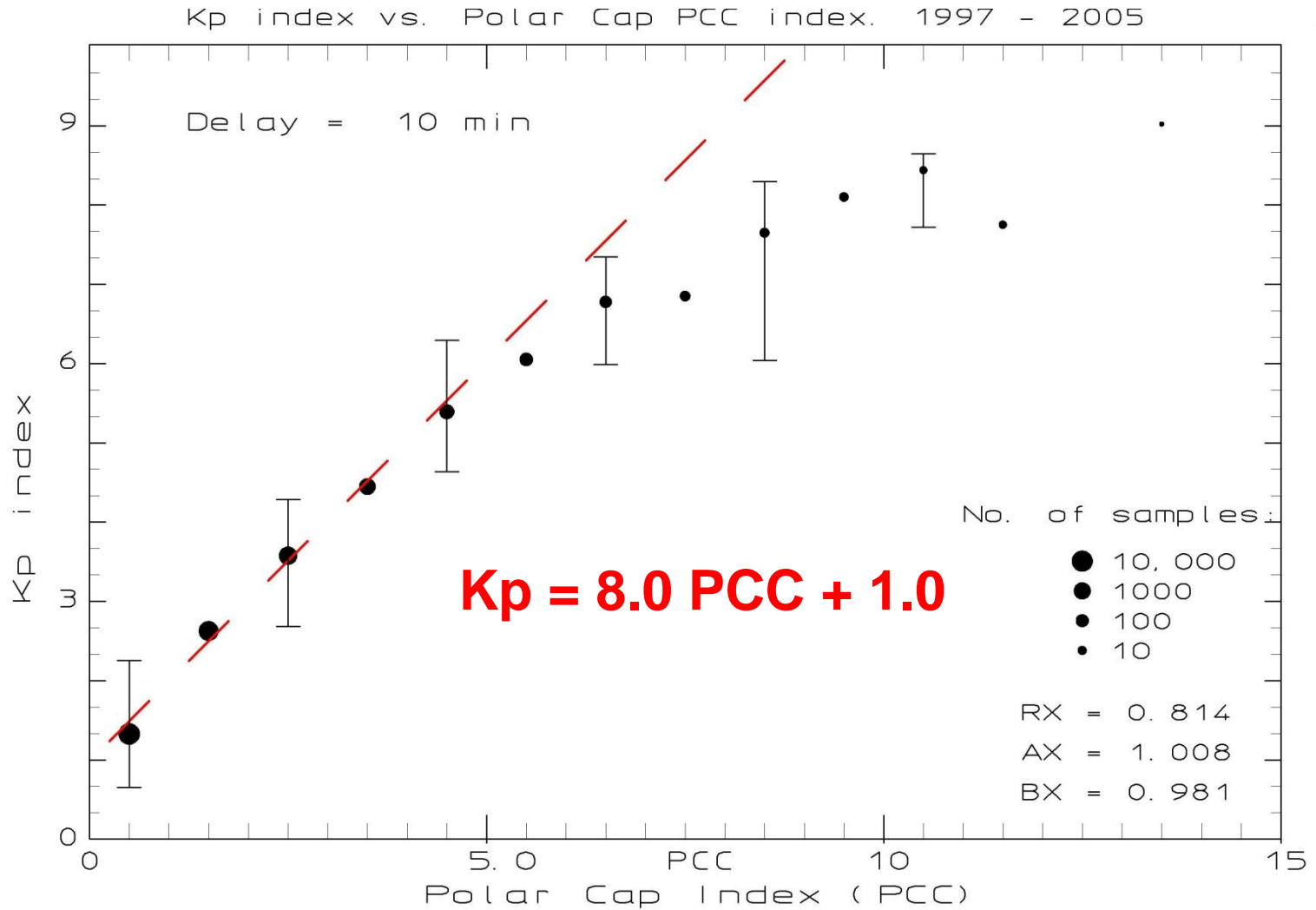
The PC index has been averaged over the 3-hr Kp interval with a small shift

Relations between PCC and Ring Current ASY-H Indices

Note the linear relation up to high PCC values

SSWT Plenary Brussels 2012 PSt/DMI

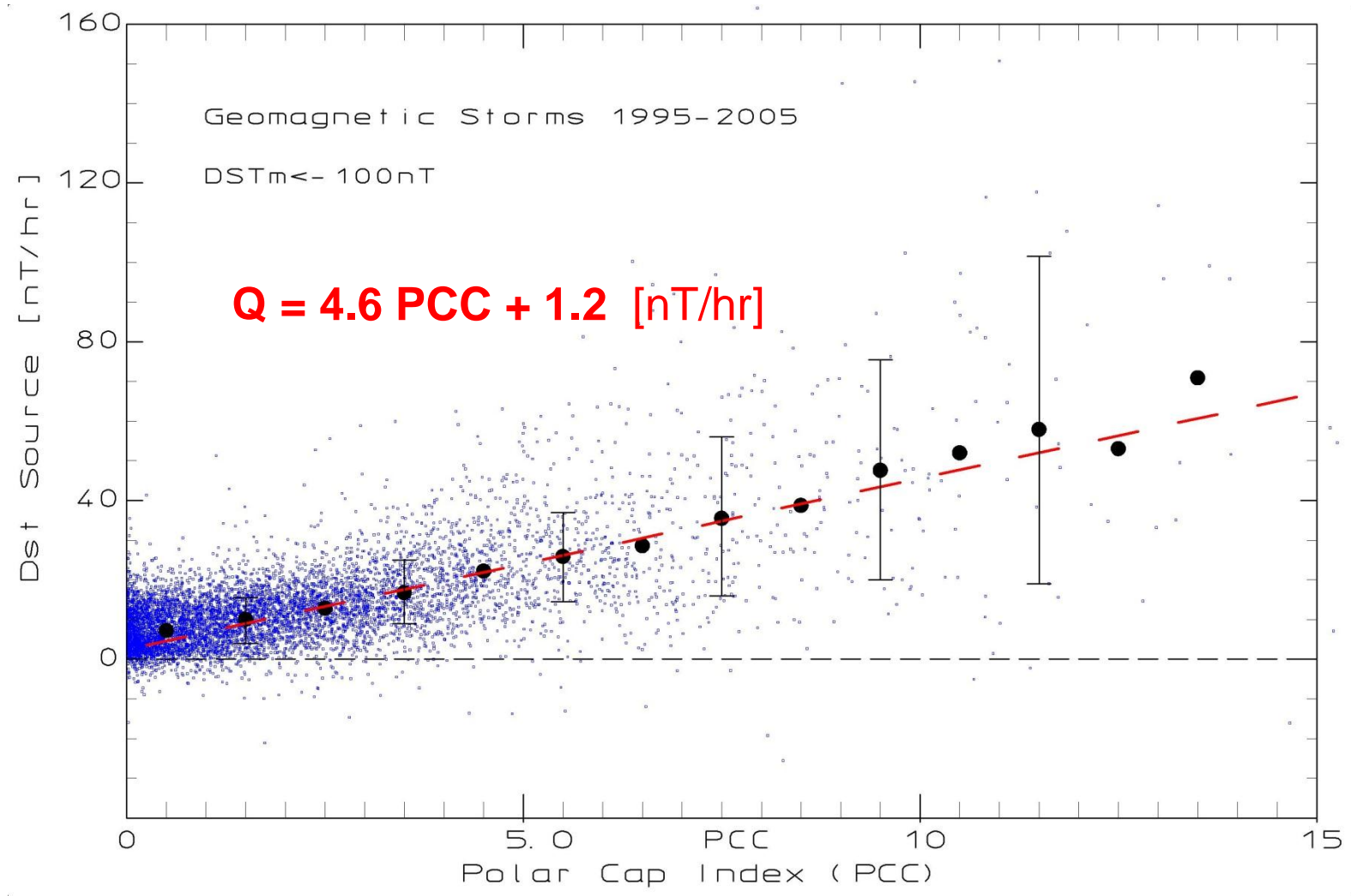## Relations between PCC and Ring Current Dst Source Function

The merging electric field, EM, or, equivalently, the polar cap PC indices should be considered to represent a source function for the Dst index rather than being related to its current value. Following Burton et al. (1975) the change in the Dst index with time could be written:

$$dDst*/dt = Q - Dst* /\tau \quad [nT/hr]$$

Q is the source term while the last term is the ring current loss function controlled by the decay time constant τ here measured in hours. For the small actual MPC corrections, the Dst dependent statistical values provided in Joergensen et al. (2004) are used while the decay function given in Feldstein et al., (1984) is used for the loss term.
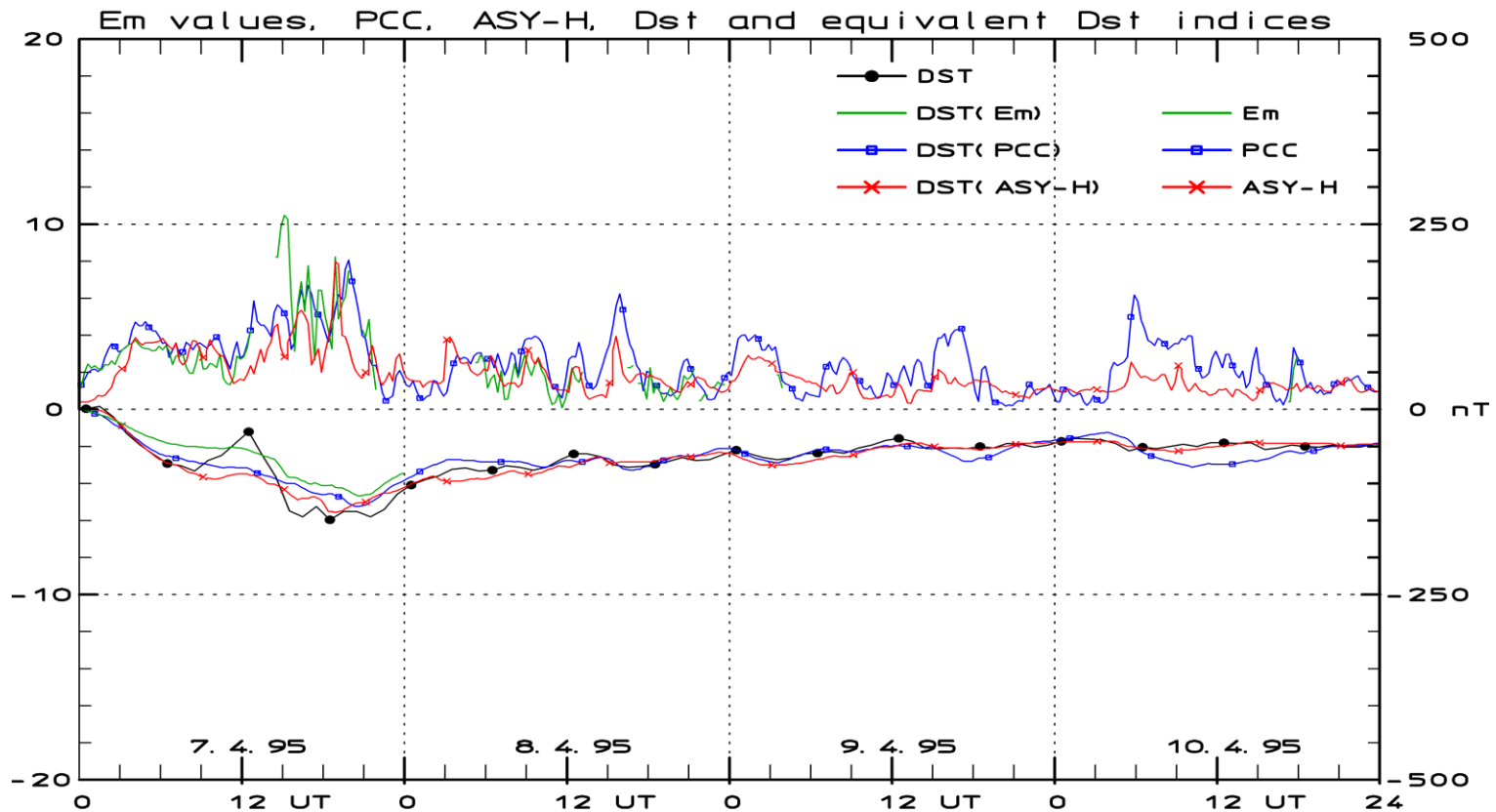
Relations between PCC and Ring Current Source Function

Geomagnetic Storms 1995-2005

DSTm<-100nT

Q = 4.6 PCC + 1.2 [nT/hr]

Dst Source [nT/hr]

Polar Cap Index (PCC)

Note the linear relation up to high PCC values

Example of Dst Index values calculated from E_M, PCC, and ASY-H

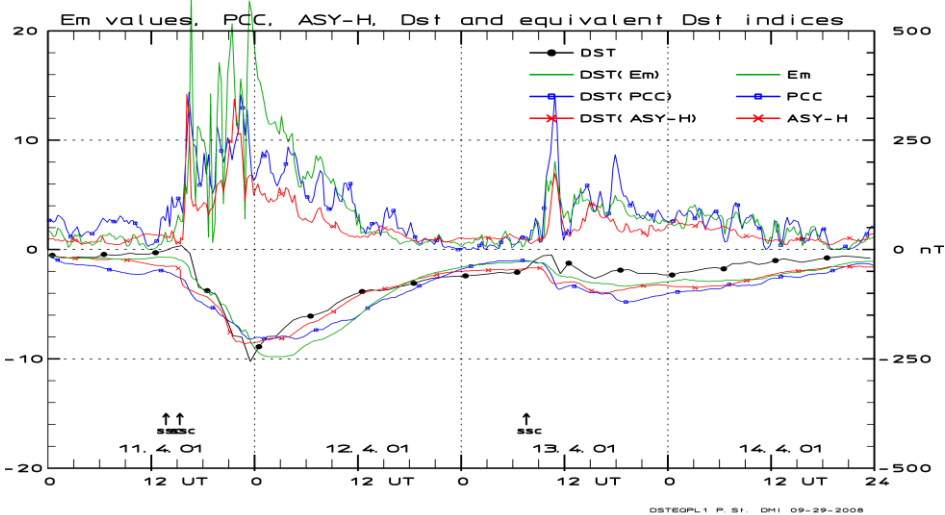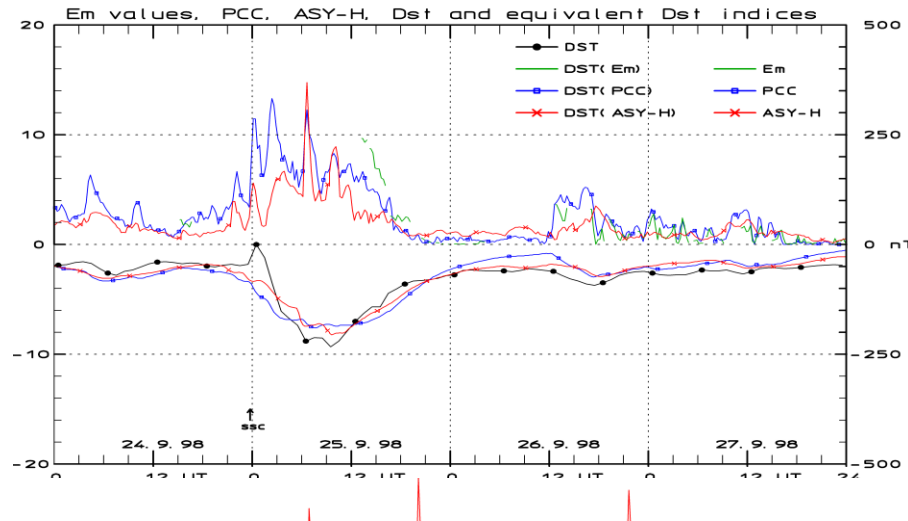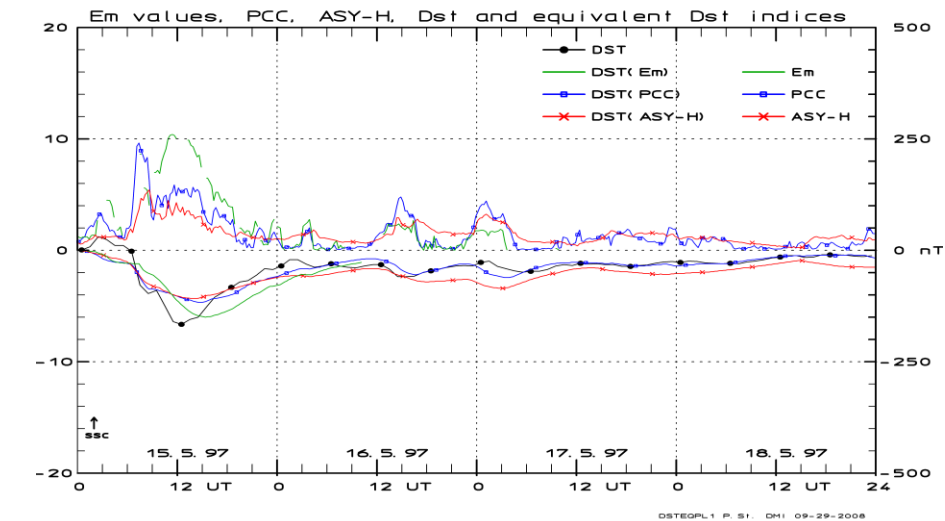The Dst(source) index has been constructed by integration of the source function through 4 days using the real Dst as start value

Relations between PCC and Ring Current Index Dst

A few further examples
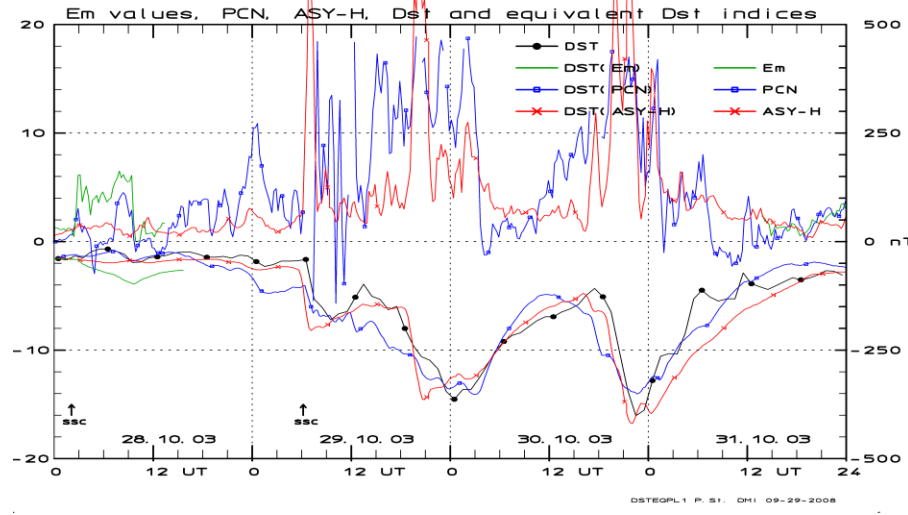
Comparison of different Ring Current Source Functions

Source: Parameter	E_M field	PCC index	PCN index	AL index	ASY-H index
No. hourly samples	3992	7776	8640	7968	8640
Avr. deviation	-7.6	1.8	2.7	11.5	- 4.9 nT
Std. deviation	27.6	30.6	31.4	34.2	24.7 nT

The statistics have been built on all major magnetic storms during cycle 23 from 1995 to 2006.

Summary and Conclusions

- **The Polar Cap (PC) indices are derived from polar magnetic variations scaled to equal the merging electric field (in mV/m) in the solar wind. They 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.**

- **The PC indices are the best ground-based indices for early warning of strong substorm-related GIC events that may threaten High Voltage supply systems.**

- **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 shifts 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.**

References

- Stauning, P., Troshichev, O. A. & Janzhura, A. (2006). Polar Cap (PC) index. Unified PC-N (North) index procedures and quality. *DMI Scientific Report, SR-06-04.* (available at www.dmi.dk/publications/sr06-04.pdf).

- Stauning, P., (2007). A new index for the interplanetary merging electric field and geomagnetic activity: Application of the unified polar cap indices, *Space Weather*, *5*, S09001, doi:10.1029/2007SW000311.

- Stauning, P. & Troshichev, O. A. (2008). Polar cap convection and PC index during sudden changes in solar wind dynamic pressure, *J. Geophys. Res.*, 113, doi:10.1029/2007JA012783.

- Stauning, P., Troshichev, O. A. & Janzhura, A. (2008). The Polar Cap (PC) index:. Relations to solar wind parameters and global activity level, *J. Atmos. Solar-Terr. Phys.*, doi:10.1016/j.jastp.2008.09.028.

- Stauning, P. (2011), Determination of the quiet daily geomagnetic variations for polar regions, *J. Atmos. Solar-Terr. Phys.*, doi:10.1016/j.jastp.2011.07.004.

- Stauning, P. (2012), "The polar cap PC indices: Relations to solar wind and global disturbances", pp. 357-397, in: "Exploring the Solar Wind", ISBN 978-953-51-0339-4, ed by: M. Lazar, InTech Publ. Co., 2012.

- Troshichev, O. A., Janzhura, A. & Stauning, P. (2006). Unified PCN and PCS indices: method of calculation, physical sense and dependence on the IMF azimuthal and northward components, *J. Geophys. Res., 111*, A05208, doi:10.1029/2005JA011402.