

Using PC indices to predict violent GIC events threatening power grids

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Abstract.

Earlier investigations have used the Polar Cap (PC) indices to demonstrate the close relation of GIC-related power grid disturbances to enhanced PC index levels (e.g., *Stauning, 2013*). A remarkable feature of most of the examined cases is the lengthy intervals, ranging up to several hours of PC index values elevated above “alert level” (10 mV/m), preceding GIC-related power grid disruptions.

Agenda:

1. GIC effects. Moderate and violent events.
2. Violent substorms with large dB/dt values
3. The Polar Cap (PC) indices
4. Relations between PC indices and violent substorms
5. Summary and conclusions

1. GIC effects. Moderate and violent events.

Moderate events (many).

Effects :

Gas and Oil pipeline erosion

HV Transformer degradation

Measures:

Pipeline construction

Transformer construction

Power grid structure

Strong events (few).

Power grid effects:

Overvoltage relay tripping

Ground current relay tripping

Transformer heating by unbalanced AC

Measures:

Transformer construction

Power grid structure

Grid management

Forecasts

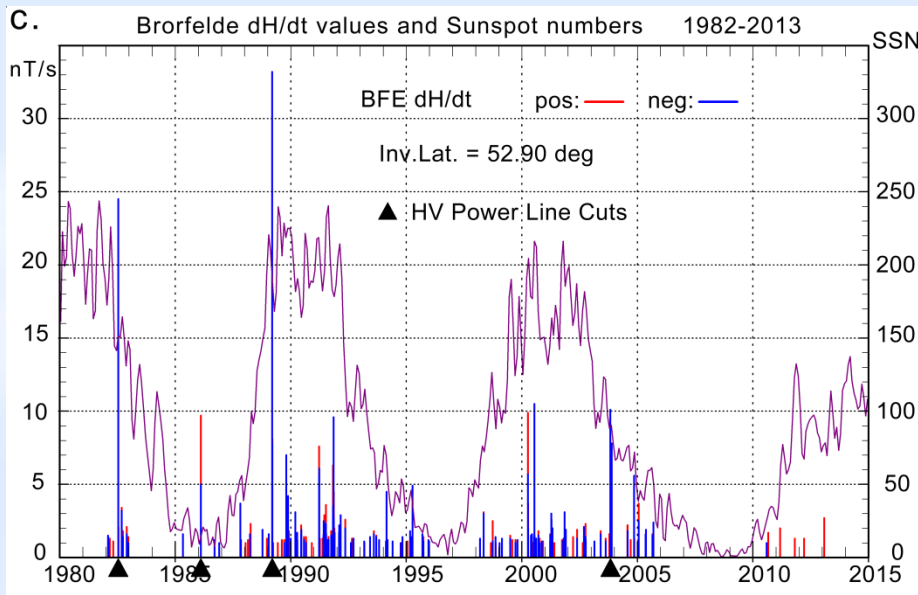
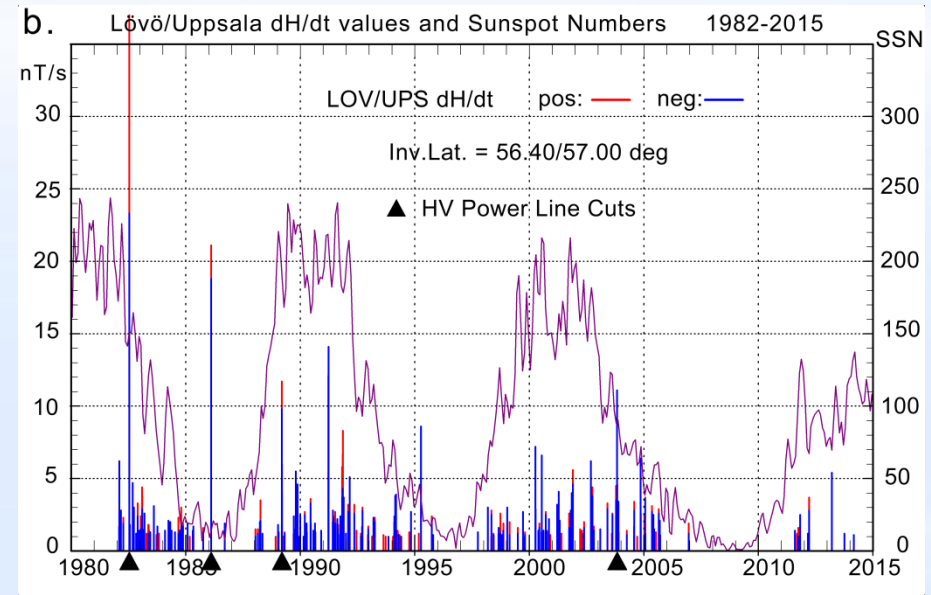
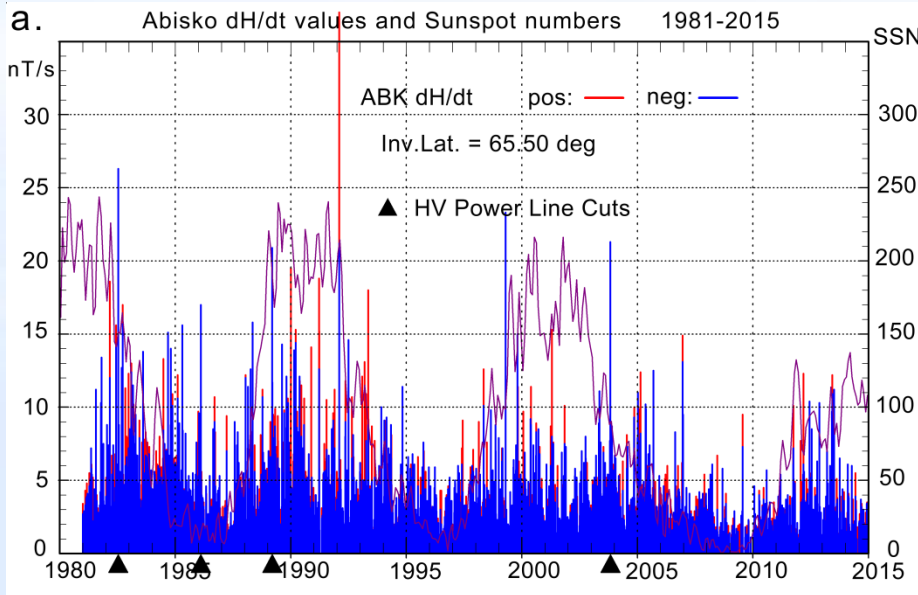
Violent substorms with large dB/dt values

Power grid disturbances related to Geomagnetically Induced Currents (GIC) on High Voltage (HV) power lines have occurred in Sweden (and Canada) during strong magnetic storms.

In Scandinavia the magnetic storm conditions were recorded by a large array of magnetometers including Abisko (Auroral zone), Lovö (Sweden) and Brorfelde (Denmark) (Sub-auroral zone).

Storm period	Max dB	Max dB/dt	Power Line cuts
13-14 July 1982	5353 nT	44.8 nT/s	14 reports
8-9 February 1986	2115 nT	19.0 nT/s	5 reports
13-14 March 1989	2828 nT	11.6 nT/s	9 reports
6-7 April 2000	1324 nT	7.2 nT/s	no reports
15-16 July 2000	1248 nT	6.6 nT/s	no reports
29-30 October 2003	2423 nT	11.1 nT/s	Malmö outage

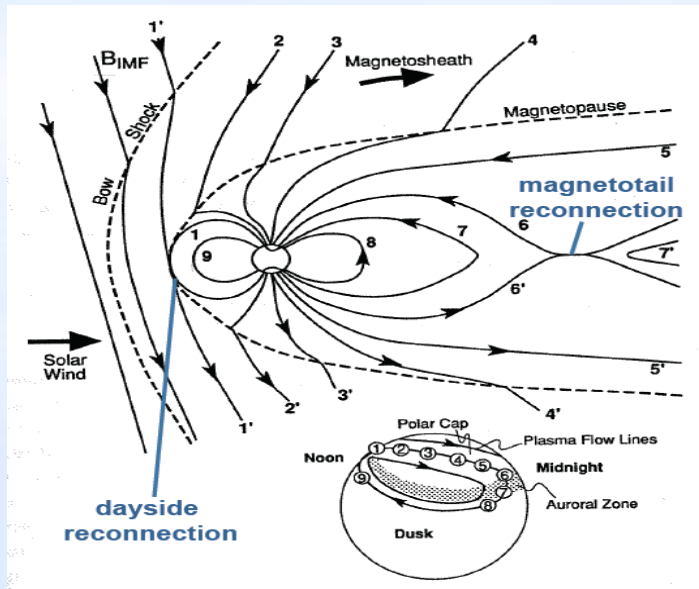
Violent substorms with large dB/dt and HV powerline disruptions in solar cycles.



Power line disruptions are marked by black triangles at the time-line. It is readily seen that the HV power-line disruptions are related to the large dB/dt values.

The relation is particularly clear at the sub-auroral stations (LOV/UPS, BFE) where almost all cases of dB/dt values above 10 nT/sec are accompanied by power line disruptions.

How are violent substorms associated with Polar Cap phenomena ?

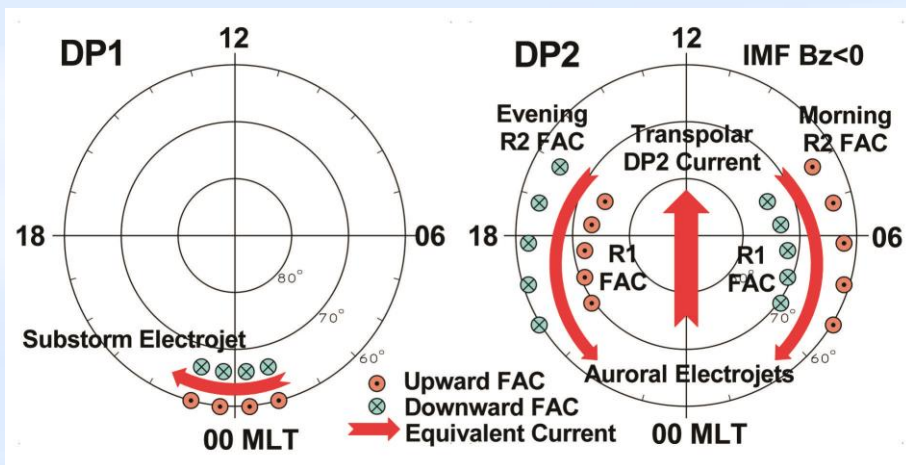


The transpolar part of the DP2 forward convection system transports plasma and magnetic fields from the merging site at the front of the magnetosphere to the tail region. The merging rate and convection intensity are controlled by the solar wind merging electric field,

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

The unloading of the tail is accomplished by recombination processes followed by sunward convection across field lines extending from the auroral oval, at times accompanied by substorms.

Note that the ionospheric Hall currents are in opposite directions of the convection of plasma and embedded magnetic fields.

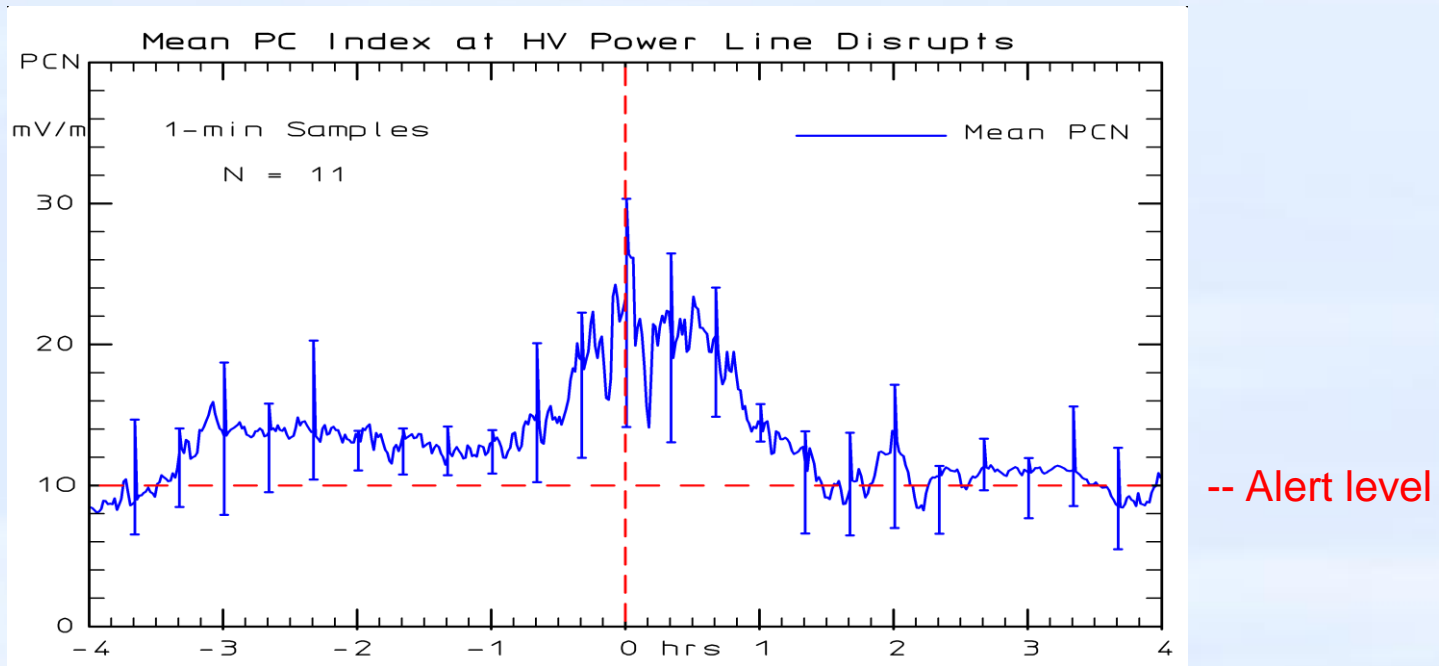


The overhead current systems generate magnetic disturbances at ground level.

The Polar Cap (PC) indices are based on the horizontal magnetic variations in the central polar cap and provide convenient measures of the transpolar convection intensities.

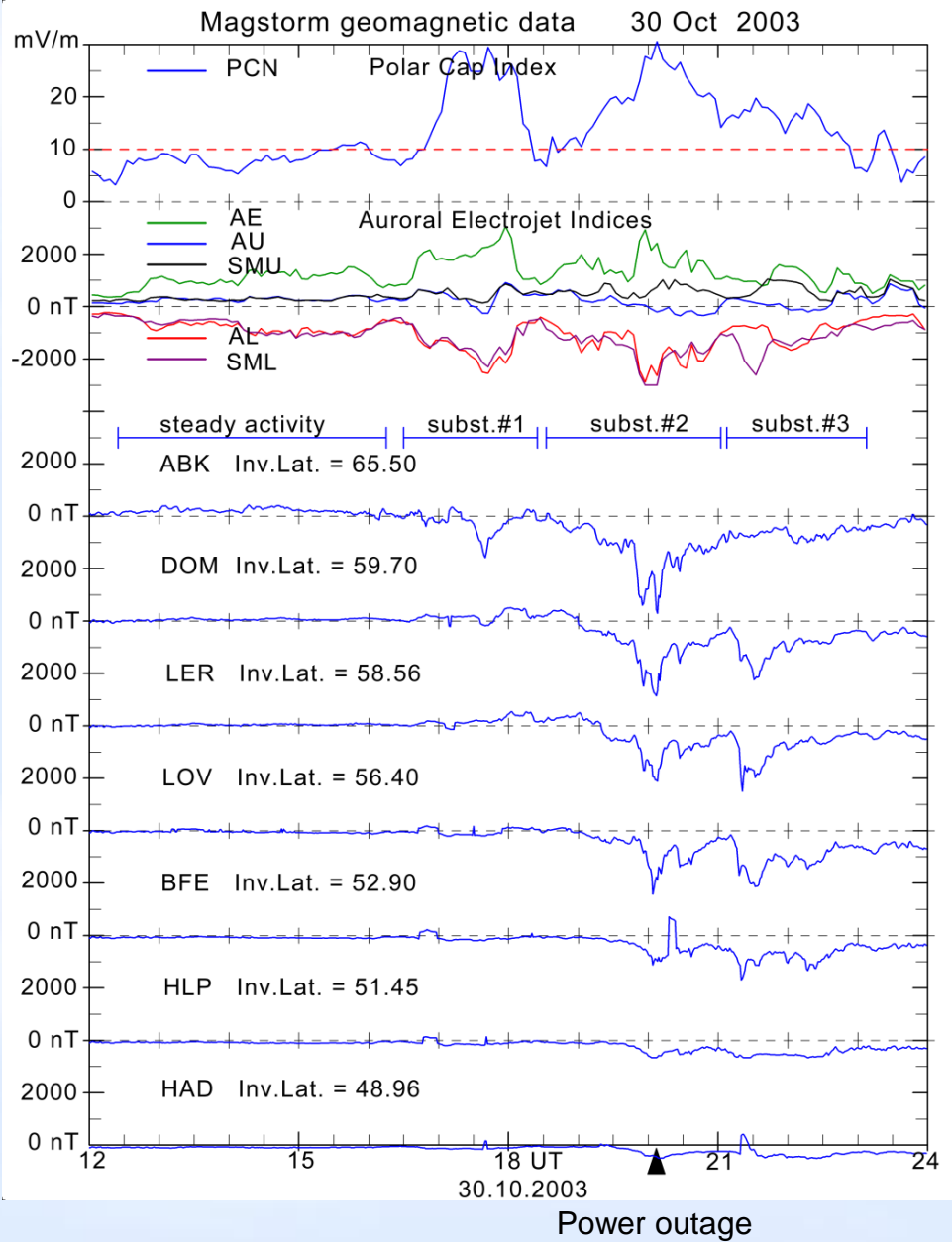
HV Power Line disrupts vs. Polar Cap indices

To make the (northern) active auroral region displaced equatorward to reach locations, where vulnerable power grids reside, requires high transpolar convection intensified (large PC indices) sustained through some time. This is also the prerequisite for building up large amounts of excess energy in the tail configuration to be released during substorms.



From a study of disruptions of high voltage power lines in Sweden related to GIC's (11 cases) it was found that such disturbances were preceded by PCN values exceeding 10 mV/m (alert level) for 2-4 hours. In the strongest cases, the PCN index exceeded 15 mV/m (red alert) during most of the previous hour. (from *Stauning*, 2013).

The Malmö 30 October 2003 power outage event



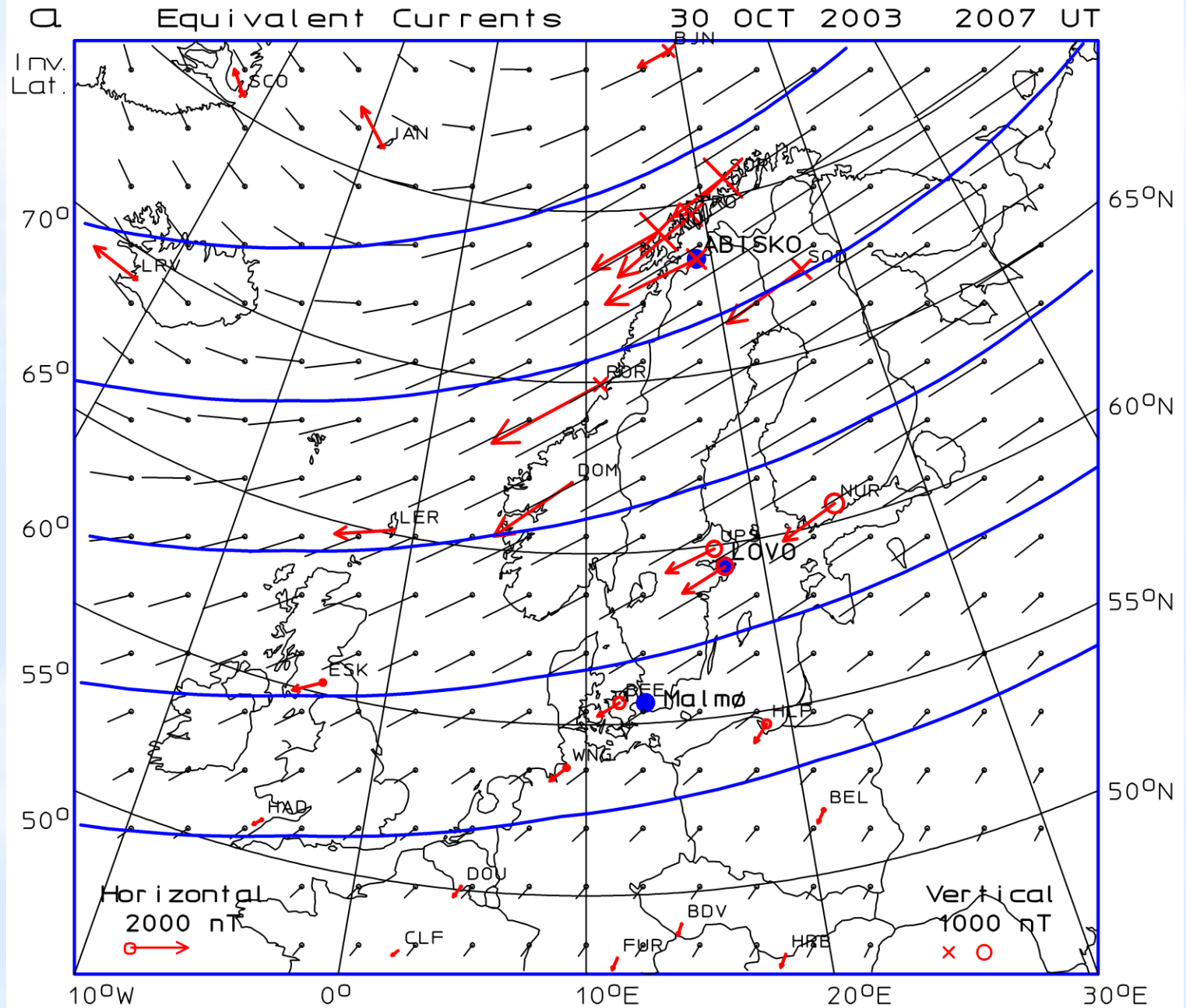
On 30 October 2003 at 2007 UT, the city of Malmö in southern Sweden, was hit by a GIC-related power outage event that lasted for an hour until the power grid was restored.

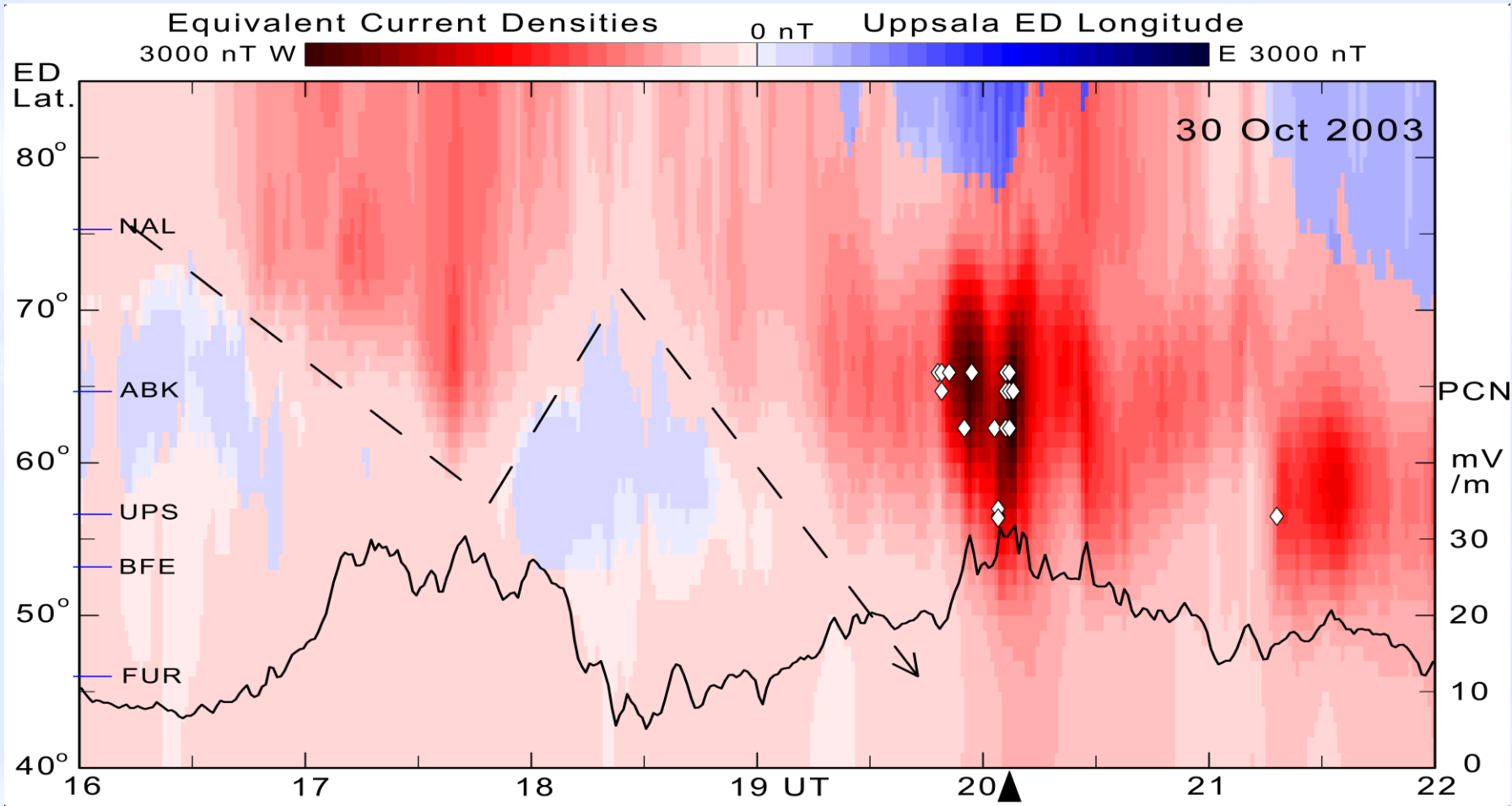
The diagram displays on top the Polar Cap index, PCN, (PCS was nor available at this time). Note the extended duration of PCN>10 mV/m.

The next lower fields display the auroral electrojet indices AE, AU and AL as well as the SuperMag SMU and SML auroral electrojet indices.

The next lower field displays the Dst (1 hour) and Sym-H (1 min) indices.

Then follows a series of recordings of the northward magnetic components for a range of stations ordered according to their latitudes.

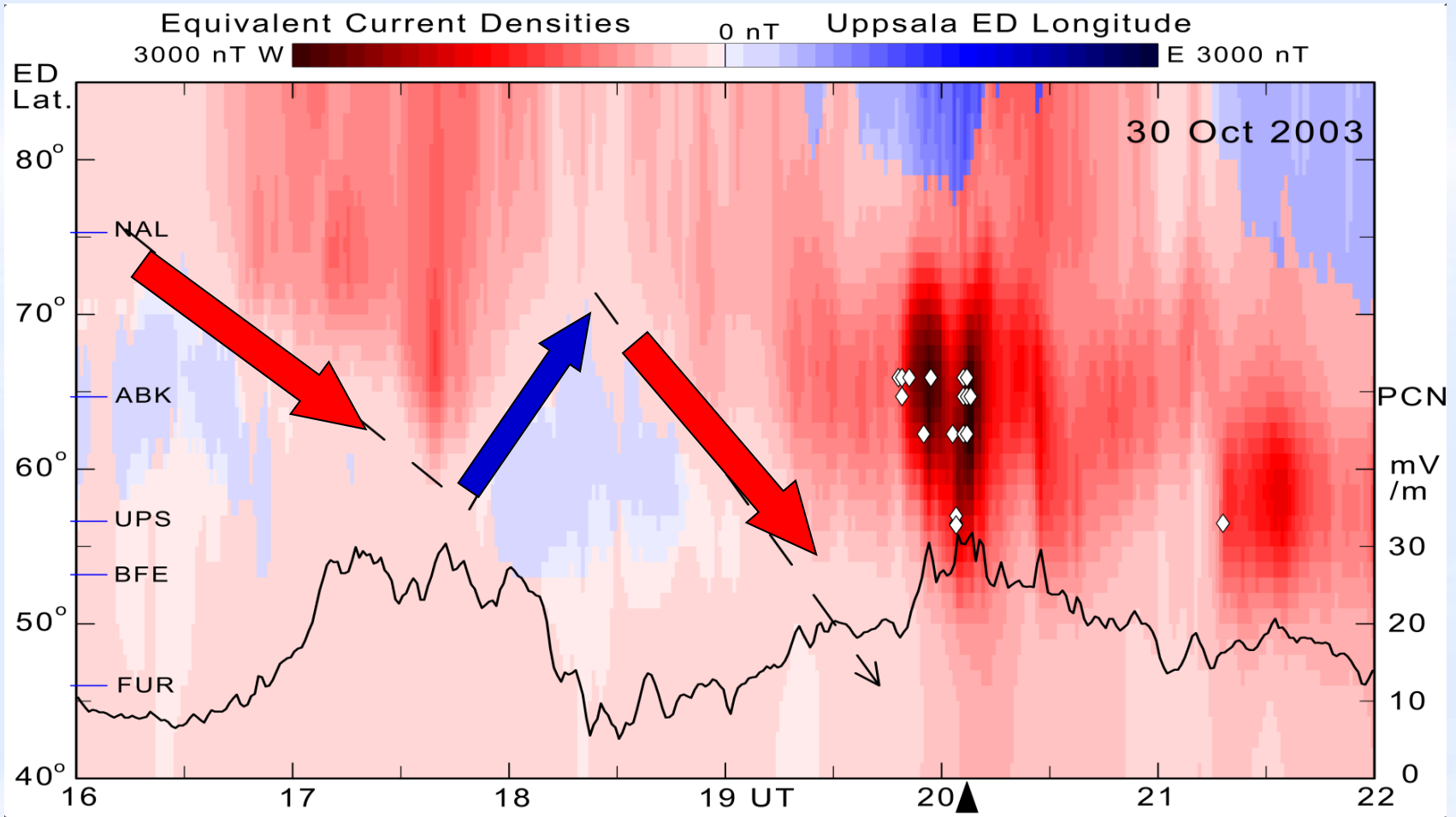




Equivalent current variations 30 Oct. 2003.

Detailed diagram of equivalent current density profiles throughout 16 to 22 UT at the magnetic longitude of Uppsala. The red shades indicate westward currents. Blue shades display eastward currents. Black triangles indicate power line disrupts. The varying PCN index values are displayed in black line.

Note that the region of strong westward currents is displaced equatorward at large PCN values and retreats poleward at substorms.



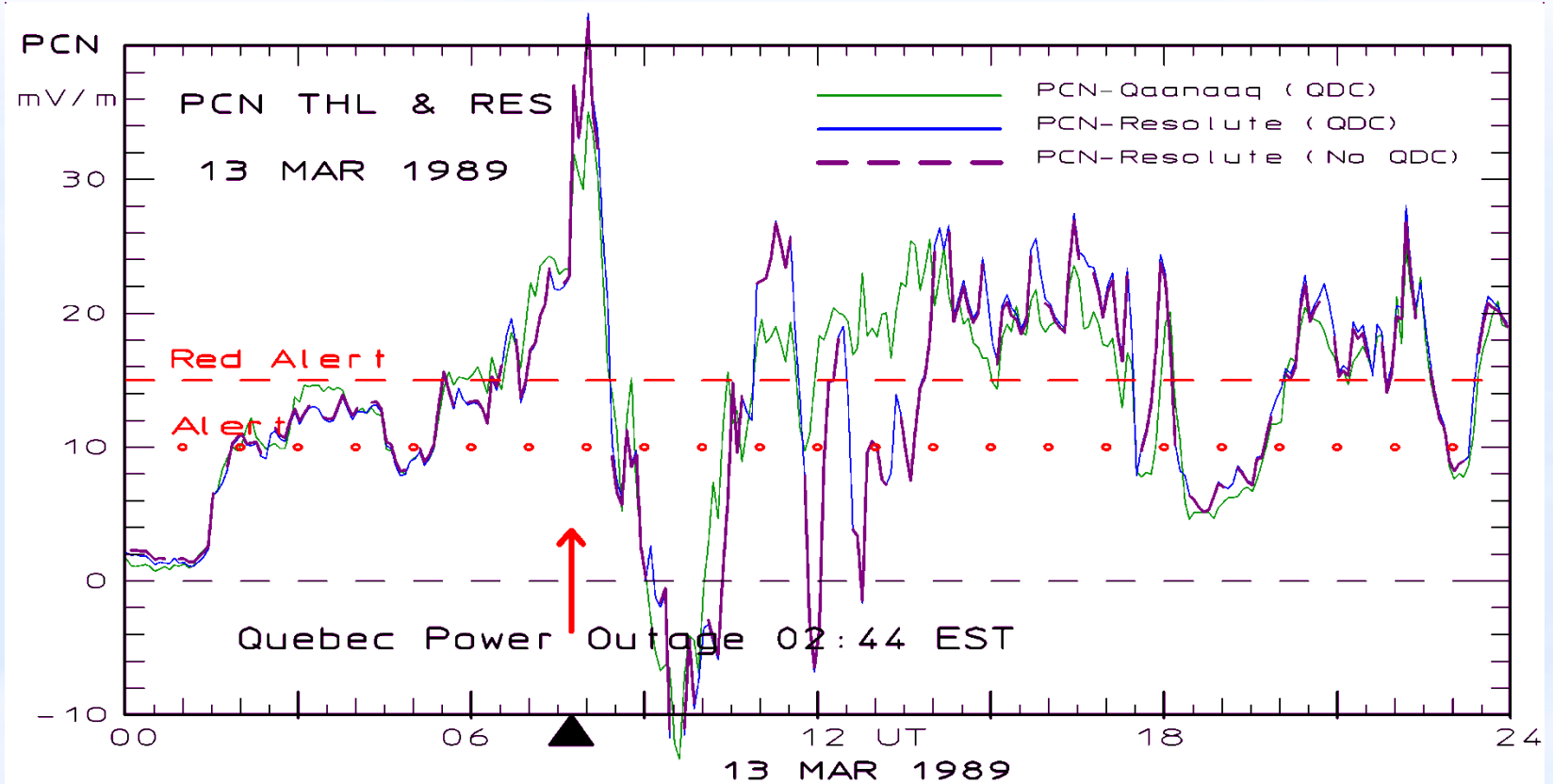
Equivalent current variations 30 Oct. 2003.

The equatorward progression is particularly fast between 19 and 20 UT as the PCN index values reach 20 mV/m. The white diamonds show occurrences of fast variations with $dB/dt > 10$ nT/sec, which may indicate violent substorm onset.

Note that the onset at 20:04 UT close to Uppsala (56.5 invl.) starts a poleward progressing, sharp-onset substorm event, which probably was the cause of the power grid failure in Malmø at 20:07 UT on 30 October 2003.

The Quebec 13 March 1989 substorm-related GIC power outage event

6 hours pre-event warning, 2 hours "red alert"



The figure 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 at 07:44 UT on 13 March 1989. No interplanetary satellite data. From *Stauning, 2018*.

GIC Warnings

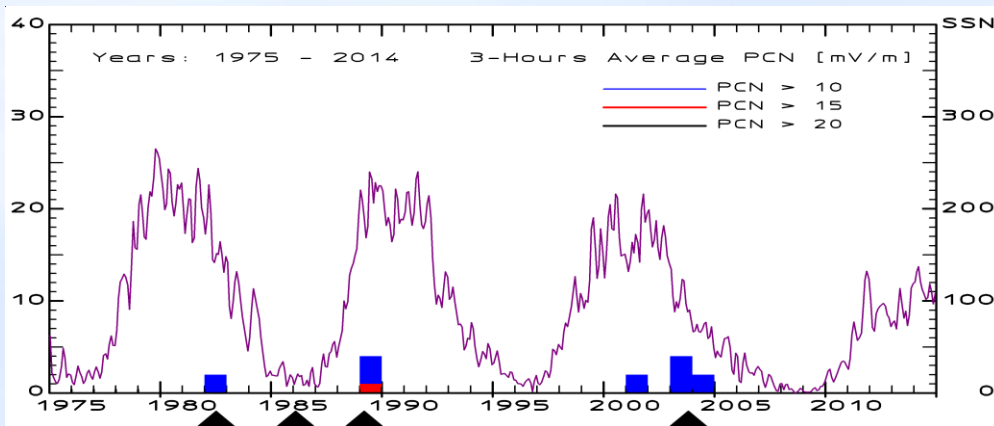
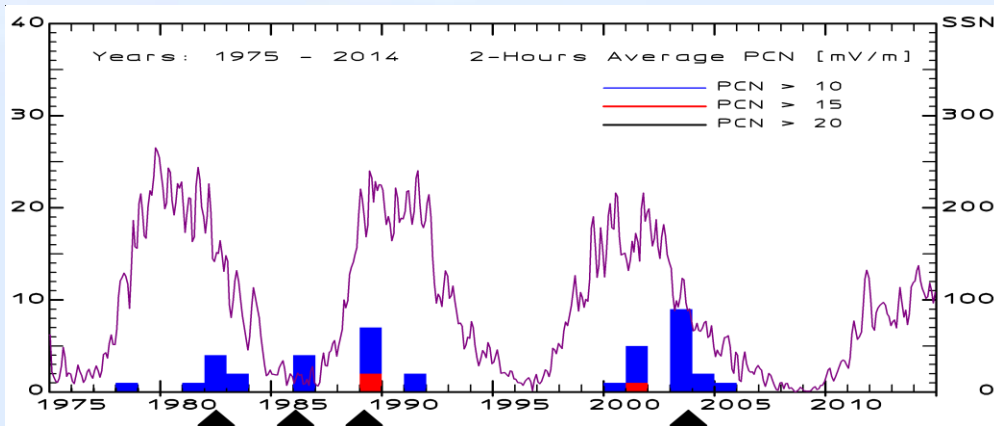
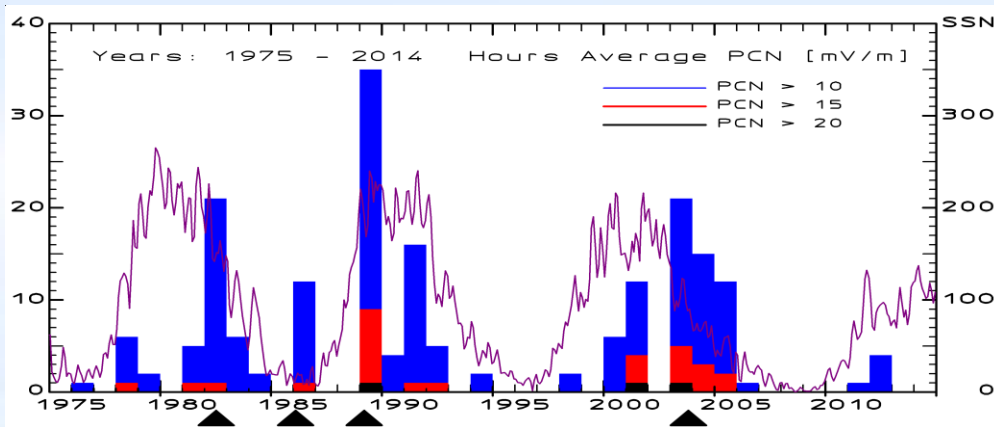
The usefulness of a forecast or warning service also depends on its ability to avoid excessive amounts of false warnings.

The upper diagram displays the number of cases each year where the PCN indices take values consistently above 10, 15, and 20 mV/m throughout one hour. The black triangles indicate cases of HV power line disrupts.

In the middle diagram the interval of PC index values above noted levels is extended to 2 hours. All HV line disrupts are still associated with the condition $PCN > 10$ mV/m.

In the bottom diagram the interval of consistent PCN index values above noted levels is extended to 3 hours. One disrupt is left without marking $PCN > 10$ mV/m (throughout 3 hours).

The sequence suggests that GIC alert should be issued when $PCN > 10$ mV/m for more the 2 hours.



Conclusions

- Real time PC indices could provide prediction of violent substorms that may harm power grids. It appears that PC index values held at or above 10 mV/m throughout an interval of several (2-4) hours is the prerequisite for occurrences of fast magnetic variations $dB/dt > 10$ mV/s at latitudes low enough to harm vital power grids.
- The amount of alert cases (PC > 10 mV/m maintained throughout one or more hours) is fairly small most years (few false alarms). In some years there are none
- The PCN indices could be based on magnetic data from either Qaanaaq (Thule) or Resolute Bay, preferably both for added availability, and eventually supplemented by PCS index values based on Vostok or Dome-C magnetic data for added reliability.
- Reliable real-time programs and sets of calibration indices have been developed for Qaanaaq, Resolute, Vostok and Dome-C magnetic data. The question is the availability of these data in real time (Stauning, 2018)

Thank you for listening !

Please observe the PC index Topical Discussion Meeting

Friday 22 November 15:15 – 16:30

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