Relation of PC index to Solar Wind parameters and to AL and Dst indices in course of Magnetic Storms

O.A.Troshichev *and* D.A.Sormakov

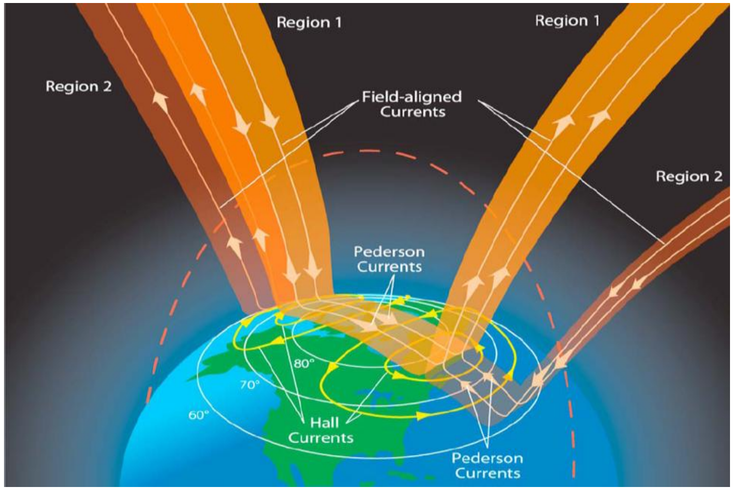
Arctic and Antarcrtic Research Institute, St.Petersburg

olegtro@aari.ru

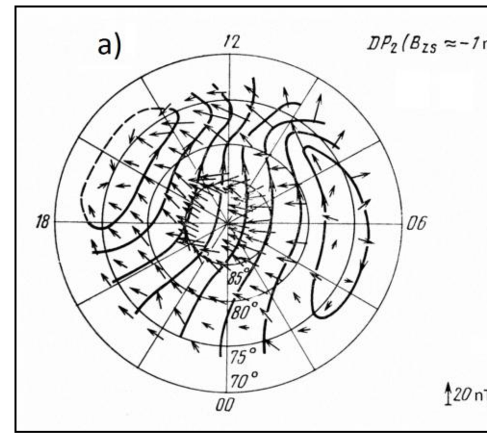
Outline:

1. Introduction
2. Magnetic storms taken for the analysis.
3. Choice of the smoothing window width.
4. Correlation of the *PC* index with interplanetary electric field E_{KL} and with magnetic activity indices *AL* and *Dst.*
5. Three basic types of the magnetic storms development.
6. Solar wind drivers (ICME and SIR) and types of magnetic storms.
7. Relationship between PC index and magnetic storms (statistical results).
8. Summary

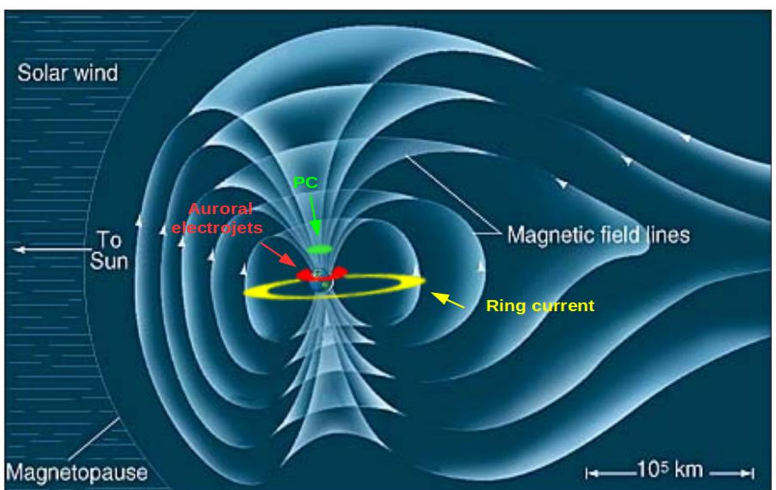
1. Introduction: PC index as indicator of the polar cap magnetic activity generated by the solar wind



Experimental data are evidence that the field-aligned currents permanently presented on the poleward boundary of the auroral oval (Region 1 FAC system) are strongly dependent on southward IMF (Langel, 1975; McDiarmid et al.,1977; Iijima & Potemra, 1982) and interplanetary electric field (Bythrow & Potemra, 1983).



These field-aligned currents generate the potential difference across the polar caps and the appropriate polar cap DP2 magnetic disturbances (Troshichev and Tsyganenko, 1979; Troshichev et al., 1979).



PC index has been introduced [*Troshichev et al.*, 1988] to characterize the polar cap DP2 magnetic disturbances related to the interplanetary electric field E_{KL} [Kan and Lee, 1979]

$$E_{KL}=V_{SW}\,B_T^2\sin^2(\theta/2)$$

As the experimental results (Troshichev et al., JGR, 2014; Troshichev and Sormakov, EPSP, 2015) show, the PC index can be regarded as a proxy of the solar wind energy that entered into the magnetosphere.

*Resolution*s of XXII Scientific Assembly of International Geomagnetism and Aeronomy Association (12th IAGA), Merida, Mexico, August 2013

No. 3: Polar Cap (PC) index

IAGA,

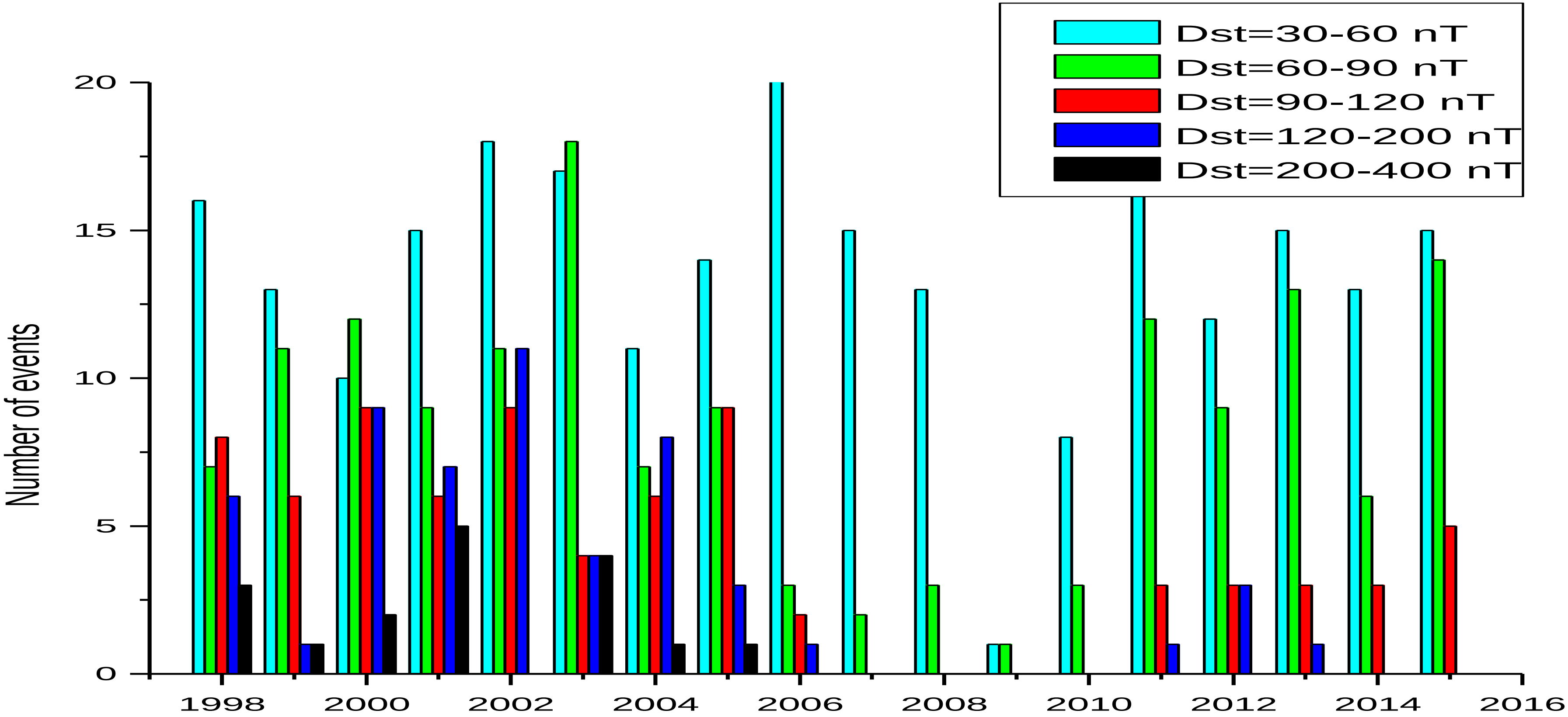
- **noting** that polar cap magnetic activity is not yet described by existing IAGA geomagnetic indices,
- **considering** that the Polar Cap (PC) index constitutes a quantitative estimate of geomagnetic activity at polar latitudes and serves as a proxy for energy that enters into the magnetosphere during solar wind-magnetosphere coupling,
- **emphasising** that the usefulness of such an index is dependent on having a continuous data series,
- **recognising** that the PC index is derived in partnership between the Arctic and Antarctic Research Institute (AARI, Russian Federation) and the National Space Institute, Technical University of Denmark (DTU, Denmark)
- **recommends** use of the PC index by the international scientific community in its near-real time and definitive forms, and
- **urges** that all possible efforts be made to maintain continuous operation of all geomagnetic observatories contributing to the PC index.

The *PC* index serves as a proxy for energy that enters into the magnetosphere. Therein lies a principal distinction of the *PC* index from

- **various coupling functions, which are characteristics of the solar wind arriving to the Lagrange point L1, and**
- **from *AL* and *Dst* indices, which are characteristics of the energy realized in form of magnetospheric substorm and magnetic storms.**

The 1-min *PCN* and *PCS* indices, which calculated on-line by magnetic data from near-pole stations Thule and Vostok, are presented at web site: http://pcindex.org The *PC* index used in our analyses is average of values *PCN* and *PCS*.

2. Magnetic storms taken for the analysis



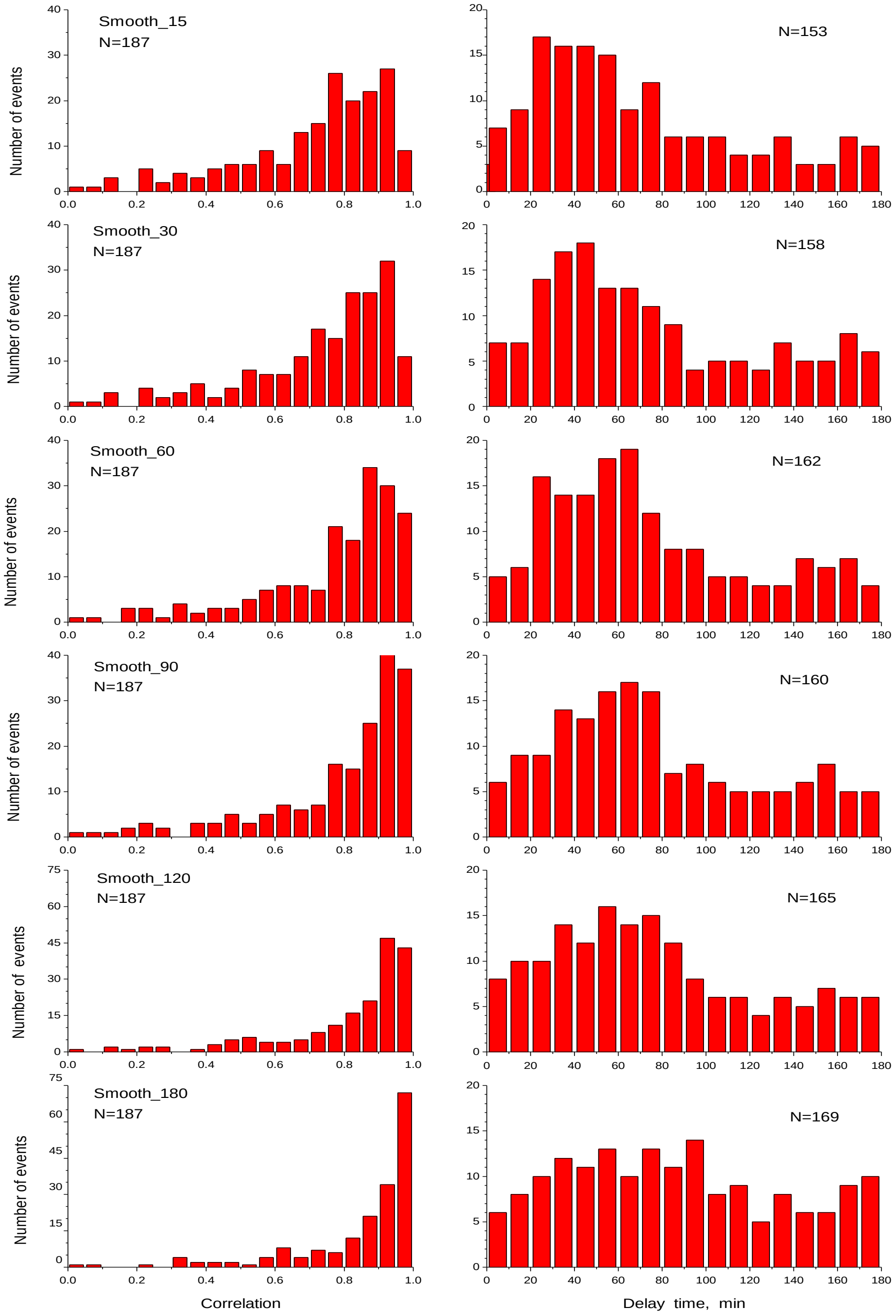
The following parameters were used to characterize magnetic storm:

- **magnetic storm beginning** as a beginning of the geomagnetic field depression (T_0 moment) ,
- **magnetic storm intensity** as a maximum of the geomagnetic field depression (*Dstmin*)
- **storm growth phase** as a time interval between the moments of storm beginning and storm intensity.

For analysis were taken magnetic storms detected in 1998-2015 (**N=568**) answering to the following criteria**:** **intensity higher than = -30nT, duration ΔT longer than 12 hours**.

The **storms were divided by their intensity into 5 categories** : 30-60nT, 60-90nT, 90-120nT, 120-200nT, 200-400nT. Distribution of storms of different intensity over period 1998-2015 is shown in Figure.

3. Choice of the smoothing window width



To reveal conditions of best correlation between the solar wind parameters and magnetic activity indices, all parameters and indices were smoothed using the averaging running window of different width (**from 0 to 180 min**).

Correlation between diverse quantities was calculated with different time shifts between them. **The shift value providing the best correlation was taken as a delay time ΔT between quantities.**

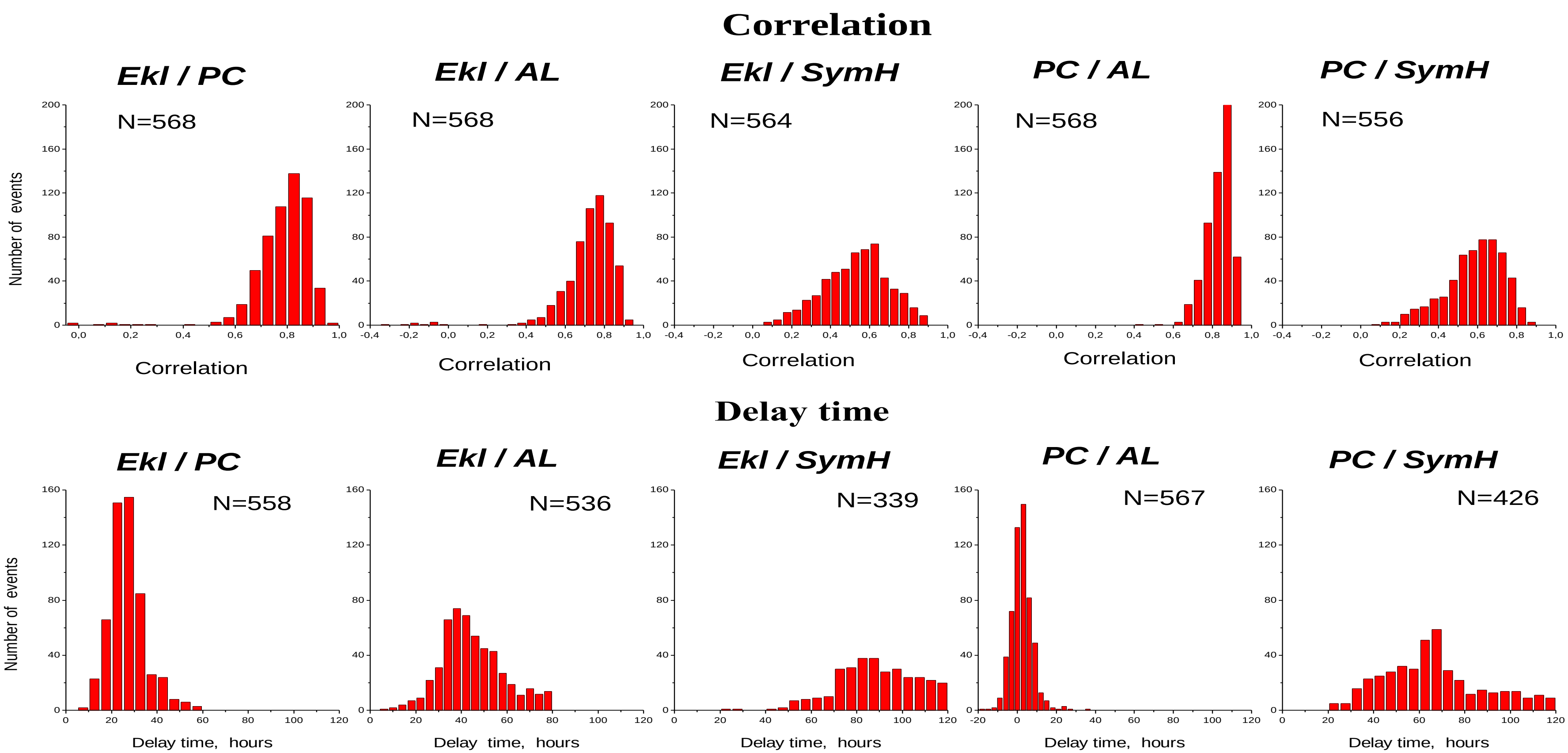
Left column in Figure demonstrates, as a example, **occurrence of events with different correlation** between the smoothed *SymH* and *PC* indices in period of 1998-2001 **under conditions of different smoothing window width** (15, 30, 60, 90, 120 and 180 minutes). **Right column** shows **occurrence of events over delay times ΔT** (when correlation is essential, R>0.5)

Results:

Correlation obviously grows while widening the smoothing interval, but maximum at certain ΔT is also progressively smoothed.

Taking into account these two contrary tendencies, the running window with 30 min width was taken as optimal one.

4. *Correlation of the PC index with interplanetary electric field E_{KL} and with magnetic activity indices AL and Dst in course of magnetic storms*



Correlation between the 30-min smoothed quantities *Ekl*, *PC*, *AL*, *SymH* has been estimated within the intervals (Tmax ± 2 days), where Tmax is moment of maximal storm intensity.

Correlation between $\mathbf{E_{KL}}$ **and PC** index (R > 0.5) is observed for 558 events of 568 (**98%**) with **delay time ~ 20-30 min**.

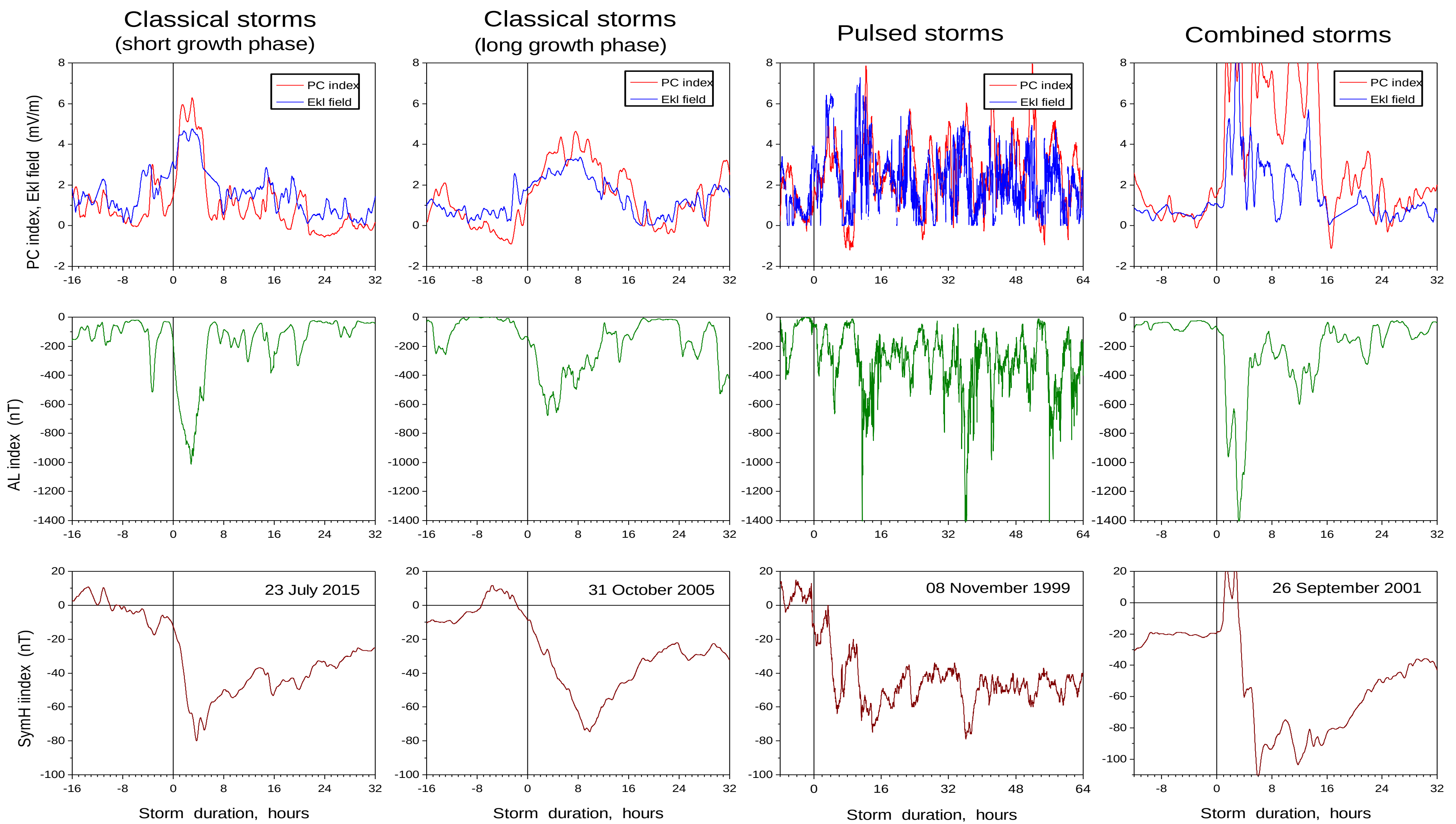
Correlation between $\mathbf{E_{KL}}$ **and AL** index (R > 0.5) is observed for 536 events of 568 (**94%**) with **delay time ~ 30-50 min**.

Correlation between $\mathbf{E_{KL}}$ **and SymH** index (R > 0.5) is observed for 339 events of 564 (**94%**) with **delay time ~ 70-100 min.**

Correlation between **PC and AL** indices (R > 0.5) is observed for 567 events of 568 (**99.8%**) with **delay time ~ 0-10 min**.

Correlation between **PC and SymH** indices (R > 0.5) is observed for 426 events of 566 (**75%**) with **delay time ~ 30-90 min.**

5. Three basic types of the magnetic storm development



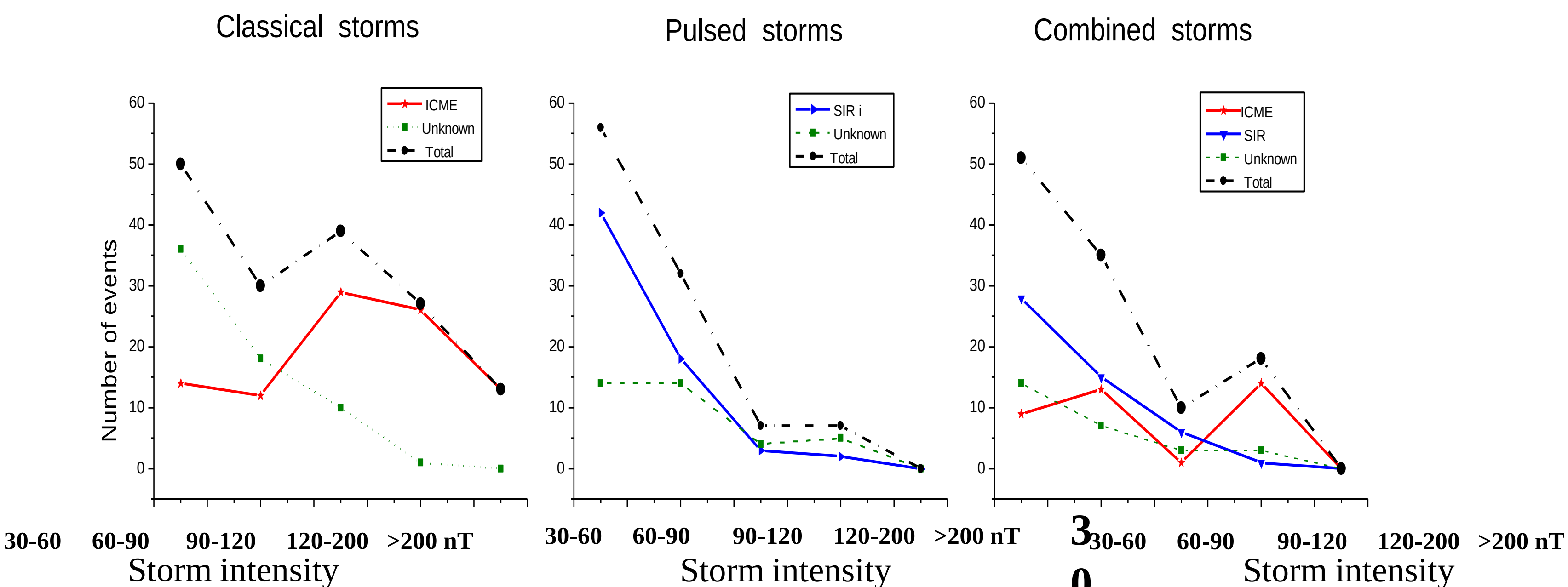
Three basic types of magnetic storms have been determined taking peculiarities of the Dst time evolution as a principle:

- "**classical storms**", which demonstrate the main phase with one clearly expressed maximum of depression (**42%**),
- "**pulsed storms**", which contain a series of periodically repeating depressions, lasting during many hours (**27%**),
- "**combined storms**", which are superposition, with different weight, of classical and pulsed storms (**31%**).

It is significant that the time evolution of Dst index in all cases is predetermined by the PC index behavior.

6. Types of the magnetic storms and the solar wind drivers (ICME and SIR)

Analysis of magnetic storms for 1998-2009 was carried out basing on data presented in **"List of Near-Earth Interplanetary Coronal Mass Ejections (ICME) for 1997-2015"** by *I. Richardson and H.Cane* and **"List of Stream Interaction Regions (SIR) for 1995-2009** by *L. Jian*.



Conclusion:

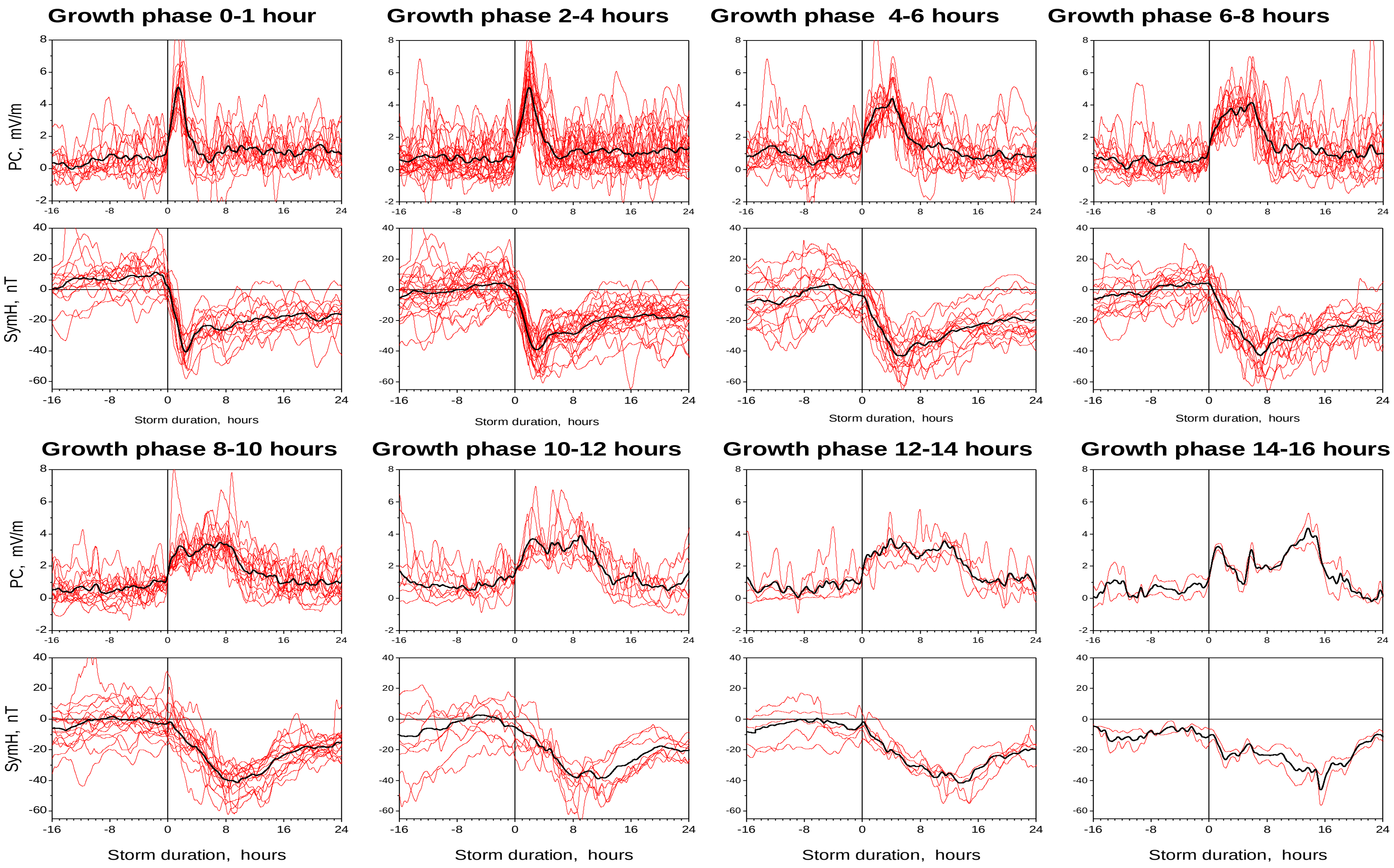
Classical storms are related mainly to Interplanetary Coronal Mass Ejections (59%); the powerful magnetic storms (Dst>120 nT) are generated exclusively by ICME .

Pulsed storms are related (64%) to Stream Interaction Regions (SIRs) or Corotating Interaction Regions (CIRs), it is especially evident in case of weak magnetic storms (Dst<90 nT),

Combined storms are produced by joint action of ICME (32%) and SIR (44%), the weak storms (Dst<60 nT) being mainly related to SIR, the strong storms (Dst>120 nT) being related to ICME.

7. Relationship of the PC index to storm development

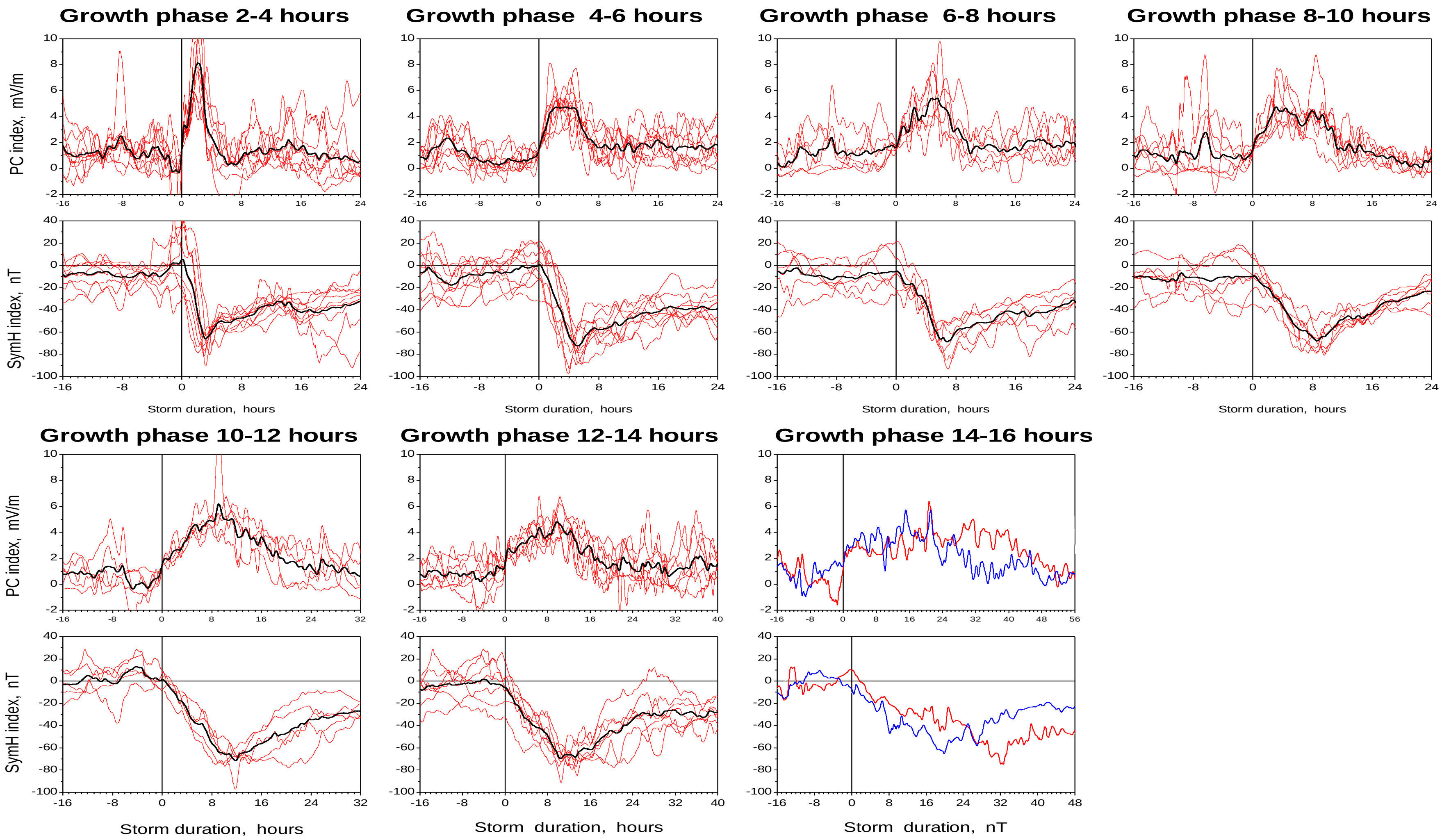
(classical storms with intensity Dst_{max} = 30-60 nT)



Development of classical magnetic storm is determined exclusively by time evolution of the PC index:

- **Magnetic storm starts (T=0) when PC index steadily exceeds the threshold level PC~1.5 mV/m.**
- **Magnetic storm continues till PC index stays higher the threshold level, as a result, the storm growth phase duration is determined by time period with PC>1.5 mV/m.**

Relationship of the PC index to storm development
(classical storms with intensity Dst_{max} = 60-90 nT)

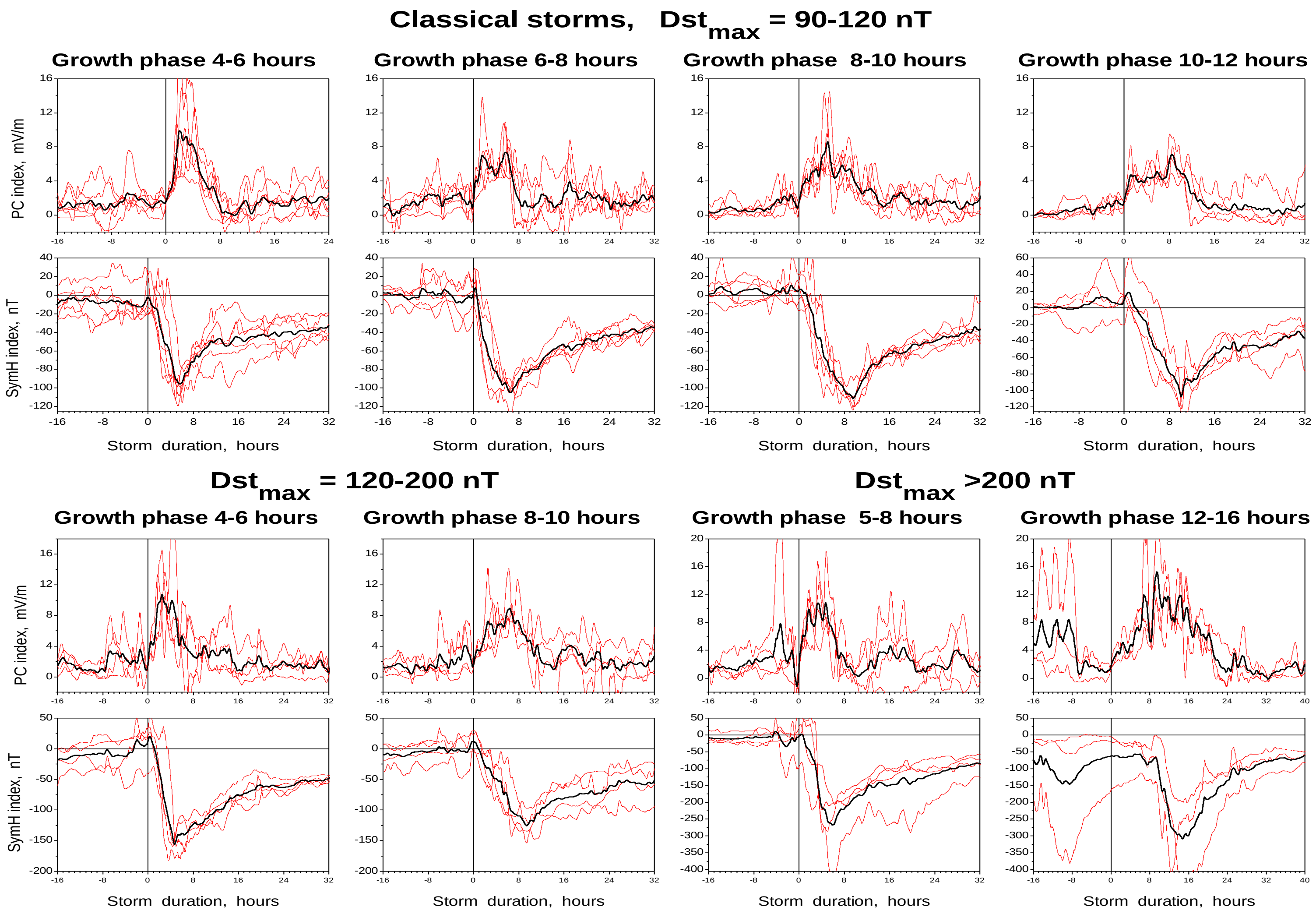


Development of classical magnetic storm is determined by time evolution of the PC index:

- **The maximal depression of magnetic field (storm intensity) follows, with time delay of ~ 1 hour, to maximum of the 30-min smoothed *PC* index, irrespective of storm category and intensity.**
- **The higher the *PCmax* value, the larger is magnetic storm intensity (Dstmin).**

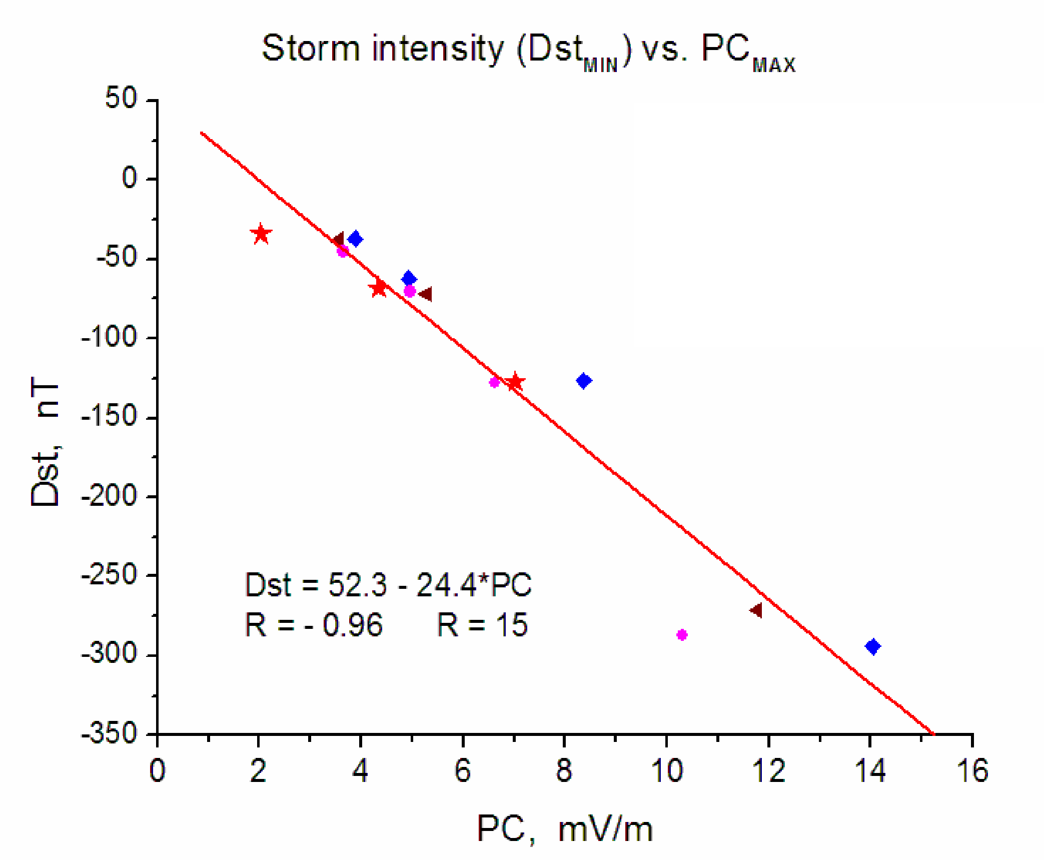
Relationship of the PC index to storm development

(classical storms with intensity Dst_{max} = 90-120, 120-200 and >200 nT)



- **Both, the shorter action of the higher PC value and the longer action of the lower PC value, seem to be followed by magnetic storm of same intensity.**
- **In case of strong magnetic storm the storm beginning moment (T_0) is often delayed owing to strong effect of the solar wind dynamic pressure**

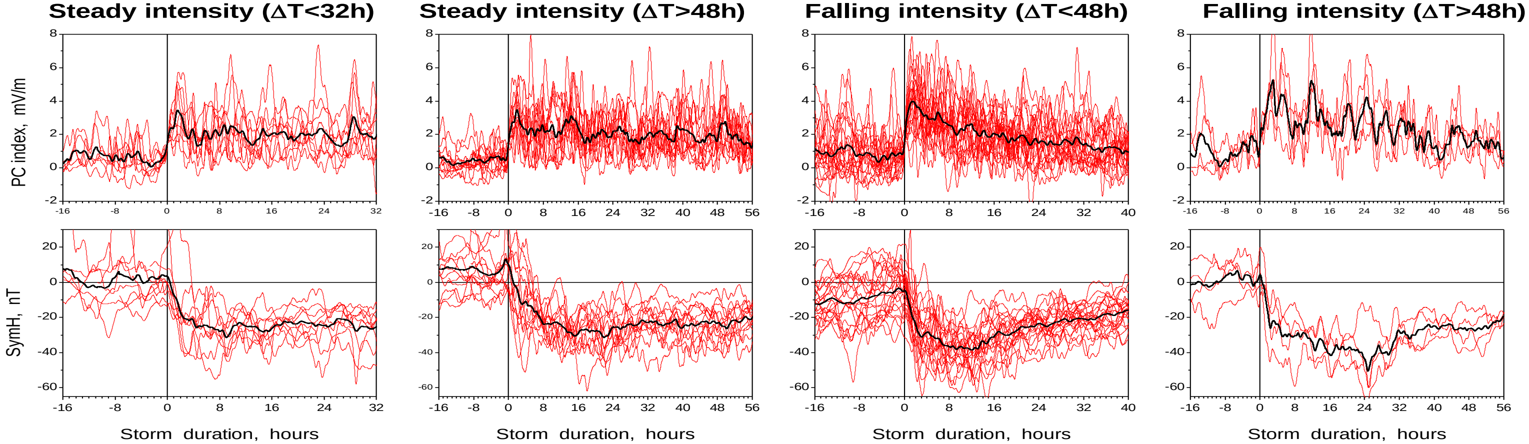
Relationship between the magnetic storm intensity Dst_{MIN} and preceding maximal value PC_{MAX}



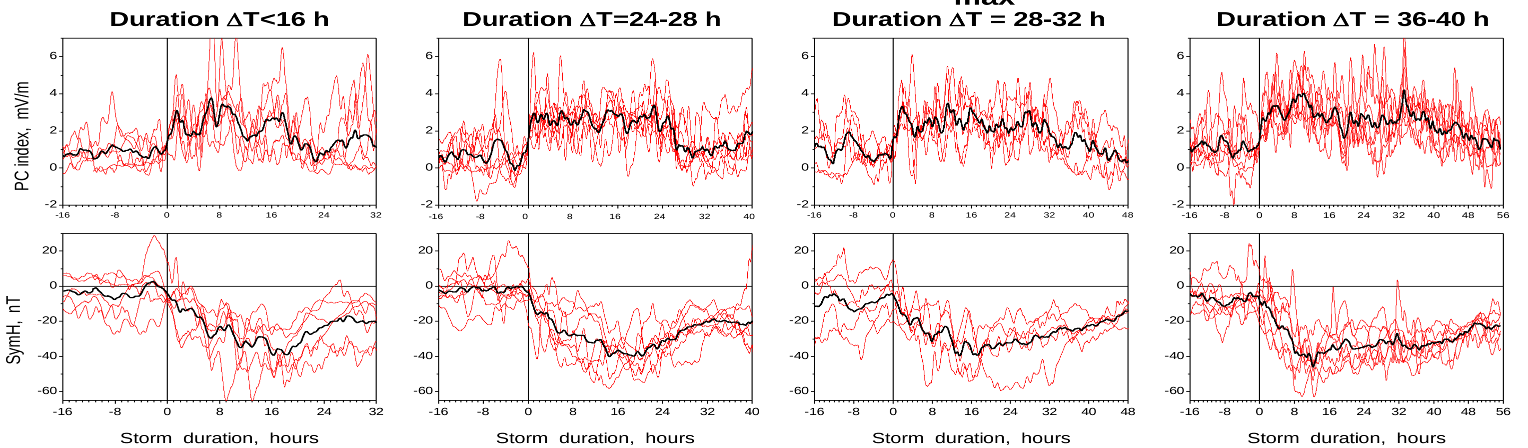
The magnetic storm intensity (Dst_{MIN}) and preceding maximal value PC_{MAX} are connected by linear relationship irrespective of the storm power and length of the storm main phase.

Relationship of the PC index to storm development in case of pulsed and combined storms

Pulsed storms with intensity Dst_{max} = 30-60 nT



Combined storms with intensity Dst_{max} = 30-60 nT



In case of **pulsed magnetic storms** with periodically repeated PC and Dst oscillations, only **relationship between the mean values** (levels) of PC and Dst can be estimated.

In case of **combined storms** the main phase length is evidently controlled by duration of the increased PC value (PC>2 mV/m), but the **relationship between the PCmax and Dstmin can be revealed** only if magnitude of smoothed PC variation (ICME effect) essentially exceeds the oscillation amplitude (SIR effect); otherwise the relationship between the mean PC and Dst values is estimated.

Summary of results

In course of magnetic storms the *PC* index strongly follows the time evolution of interplanetary electric field E_{KL} (correlation **R > 0.5 in 98% of events**) with delay time ΔT **~ 20-30 min**.

AL and *SymH* indices much better correlate with *PC* index than with E_{KL} field **(c**orrelation between ***PC* and *AL*** indices is > 0.5 in **99.8% of events,** with ΔT **~ 0-10 min**, correlation between ***PC* and *SymH*** indices is > 0.5 in **75%** of events, with ΔT **~ 30-90 min).**

The necessary and sufficient condition for the storm beginning (i.e. for development of the geomagnetic field depression) is steady excess of *PC* above the threshold level, like to case of magnetic substorms. Just this moment controls the magnetic storm beginning.

The basic types of magnetic storms are the following: "**classical storms**", related to ICME impact, with clearly expressed maximum of depression, "**pulsed storms**", related to SIR impact, with periodically repeating *PC* and *SymH* oscillations, and "**combined storms**", which seem to be effect of simultaneous ICME and SIR action.

In course of magnetic storms the *SymH* index generally follows the time evolution of the 30-min smoothed *PC* index irrespective of type and intensity of magnetic storms.

In case of classical storms the the maximal depression of geomagnetic field (i.e magnetic storm intensity *Dstmin*), **follows,** with delay ~60 min, the maximal value of smoothed *PC* (*PCmax*)**, the values *PCmax* and *Dstmin* being connected by linear relationship.**

Conclusions:

The *PC* index is an adequate ground-based indicator of the solar wind energy incoming into the magnetosphere. The *PC* index might be useful to monitor the space weather and real state of the magnetosphere and to keep check whether or not the solar wind fixed in Lagrange point L1 actually encounters the magnetosphere.

The historical *PC* indices (sets of data for 1997-2015) and current *PCN* and *PCS* indices calculated on-line by magnetic data from stations Thule and Vostok are presented at web site: http://pcindex.org