PC index as a verifier of the solar wind parameters presented at OMNI website.

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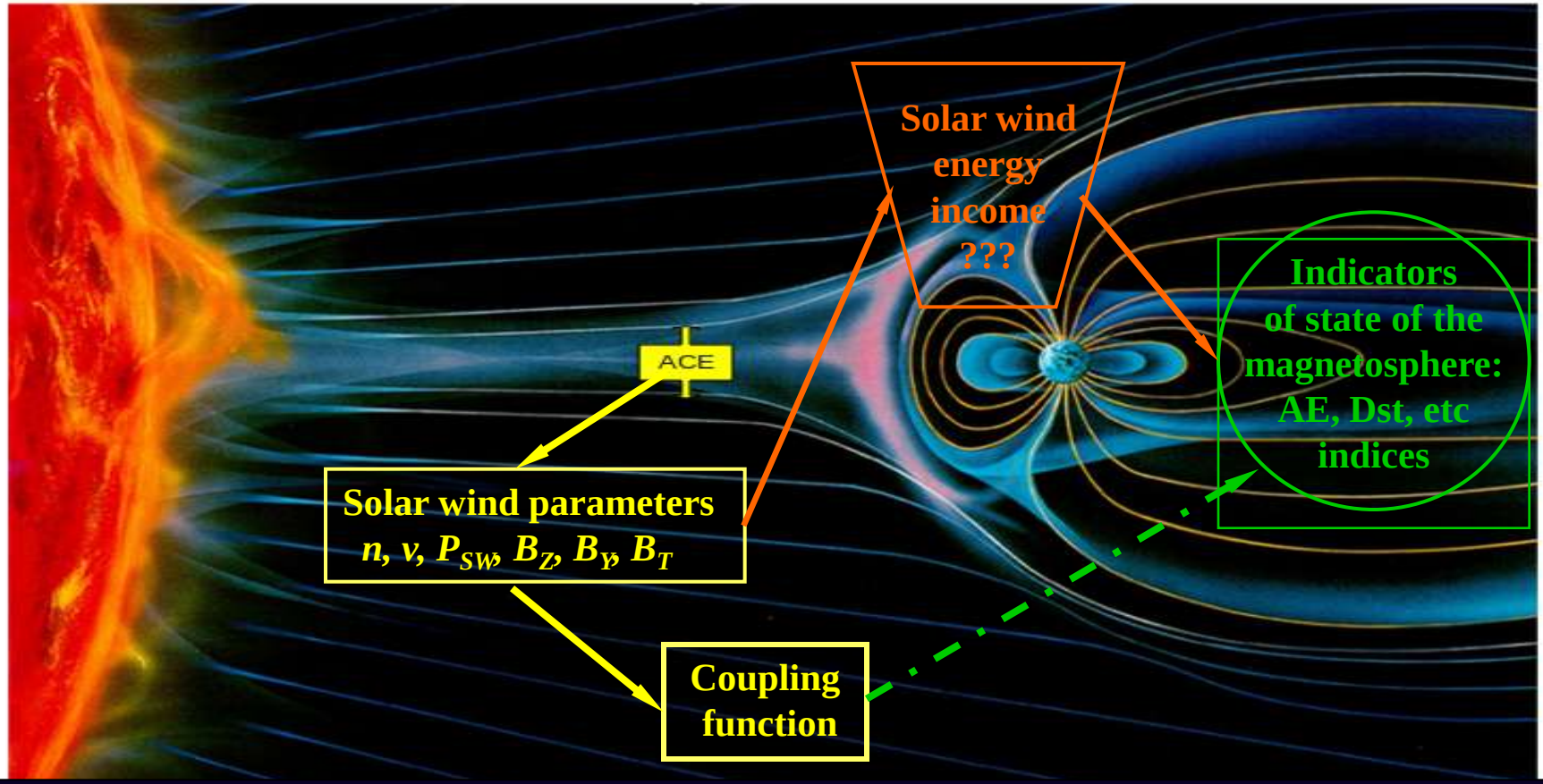
Short-term space weather forecast and monitoring

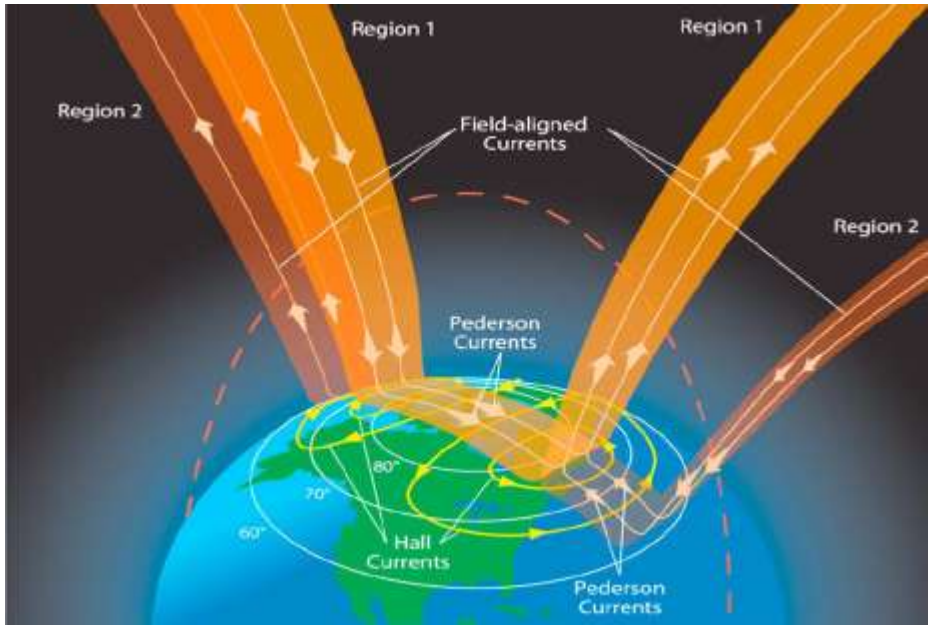


Quantitative space weather forecasting and monitoring is based on measurements of the solar wind parameters in the Lagrange point L1 spaced 1.5 M km apart the Earth

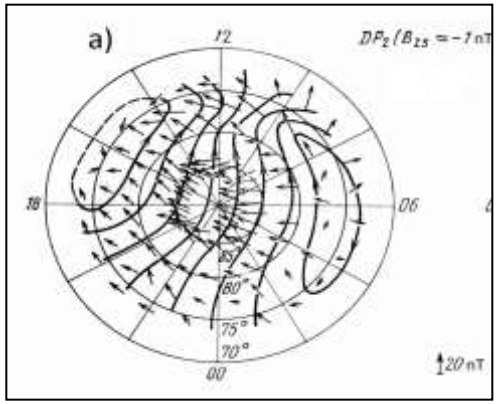
The solar plasma parameter and interplanetary magnetic field detected in point L1 are used to derive a hypothetic "coupling function" which is designed to monitor the solar wind geoefficiency and forecast the magnetosphere state (i.e. space weather).

The magnetosphere state is usually evaluated by such indicators as the magnetic AE and Dst indices.

PC index as an indicator of the polar cap magnetic activity



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).

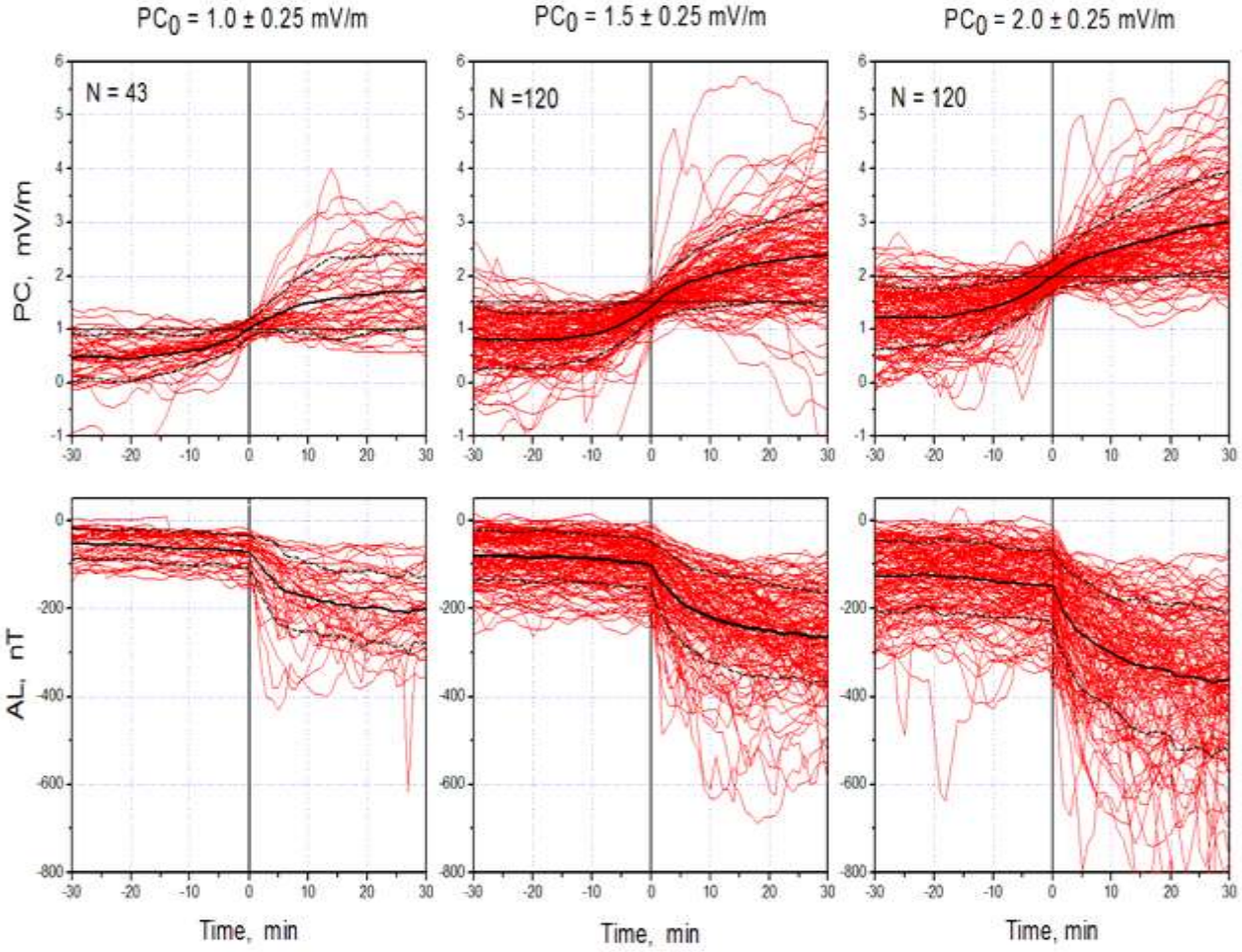


The field-aligned currents generate the potential difference across the polar caps and the appropriate polar cap DP2 magnetic disturbances (Troshichev and Tsyganenko, 1979; Troshichev et al., 1979).

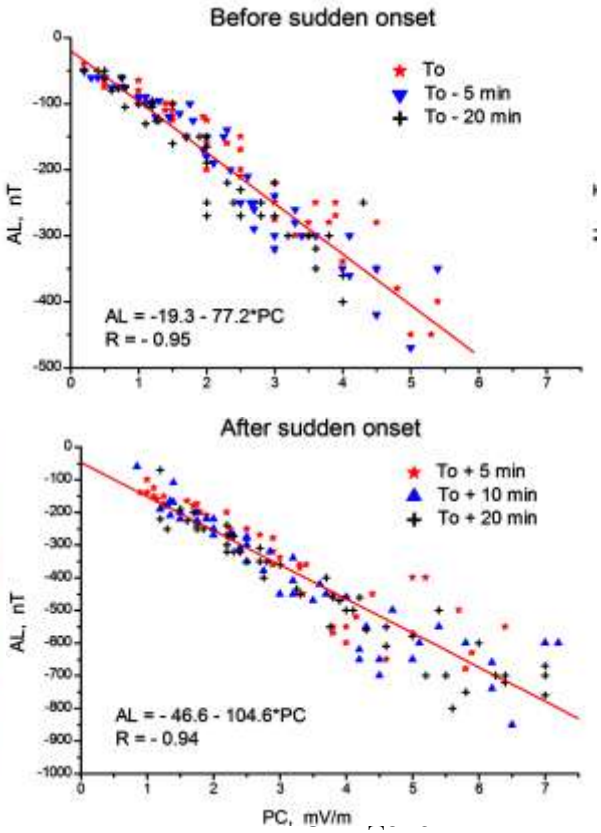
***PC* index has been introduced [*Troshichev et al.*, 1988] to characterize the polar cap magnetic activity produced by the interplanetary electric field E_{KL} [Kan and Lee, 1979] $E_{KL}=V_{SW}B_T^2\sin^2(\theta/2)$**

Time evolution of the PC index in course of substorm development is well consistent with discrete measurements of the R1 field-aligned current intensity on board SWARM spacecrafts in the morning (R=0.66) and evening (R=-0.62) sectors of the auroral zone [*Troshichev O.A., D.A.Sormakov, and R.Behlke (2018) J Atmos Solar-Terr Phys.*, 80, 37-47. DOI 10.1016/j.jastp.201710.012.001]

PC index: relation to magnetospheric substorms



Relationship between PC and AL indices before and after the substorm onset



Development of magnetospheric substorms is always preceded by growth of the *PC* index.

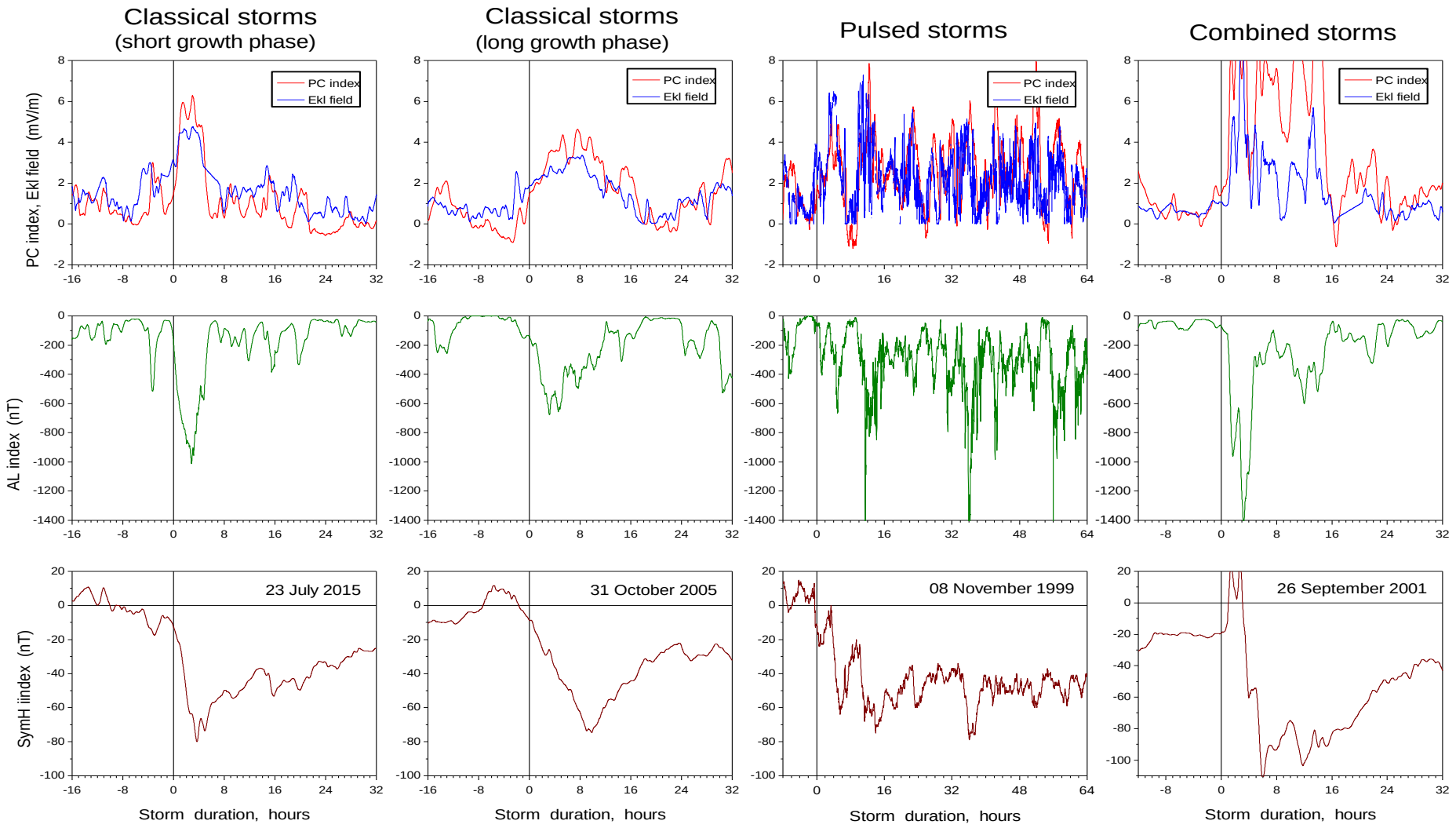
The magnetospheric substorms start when the *PC* index reaches the threshold level (1.5±0.5 mV/m) and last as long as *PC* continues to be higher than this level.

The substorm sudden onsets (SO) are related to sharp increases in the *PC* growth rate.

The linear dependency of the *AL* value on the *PC* index being typical of periods before and after SO, irrespective of the substorm type and intensity.

Time evolution and intensity of magnetic substorms is controlled by the *PC* value and dynamics

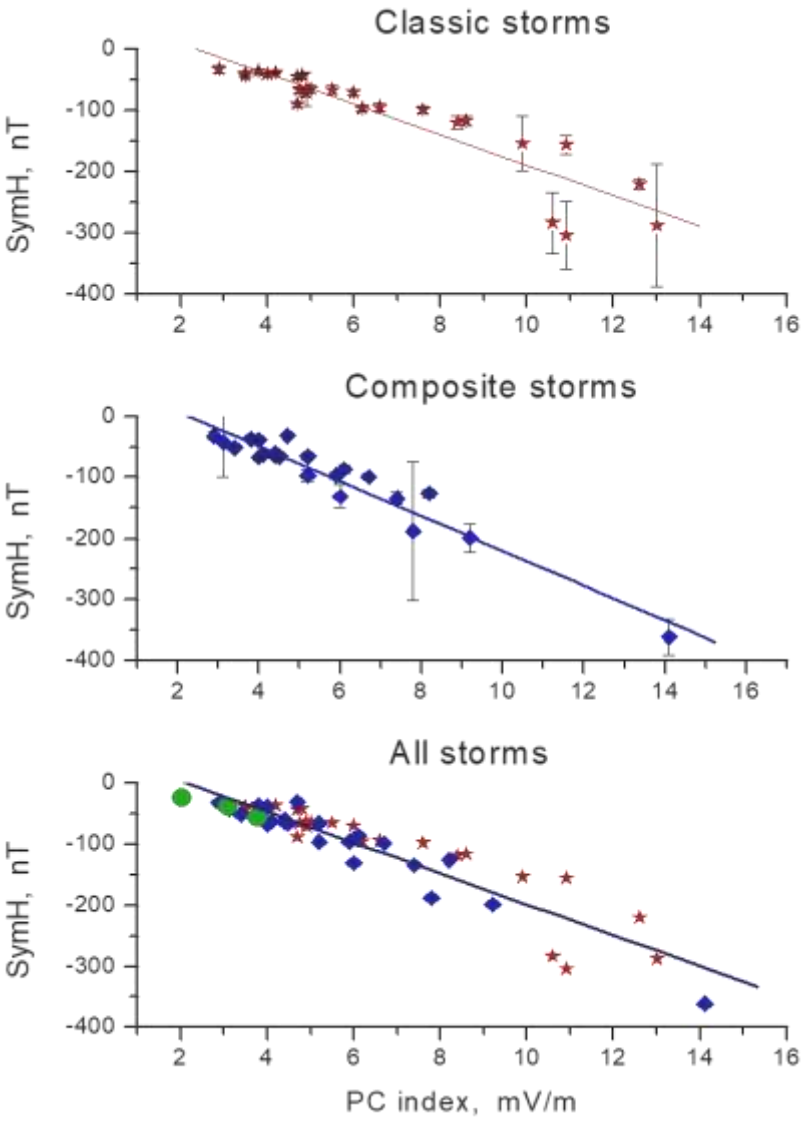
Development of magnetic storms: relation to the PC index



Three basic types of magnetic storms have been determined taking peculiarities of PC index evolution :

- "**classic 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%**).

Development of magnetic storms: relation to the PC index



Development of magnetic storms is determined by time evolution of the *PC* index: the geomagnetic field depression starts to develop if the *PC* index steadily (in lapse > 1 hour) exceeds the threshold level of 1.5 mV/m; the storm is in progression as long as *PC* exceeds this level, comes to maximum following the *PC* maximum and starts to decay as soon as *PC* displays a decline.

The maximal depression of magnetic field (storm intensity) follows to maximum value of the smoothed *PC* index. **Intensity of storm (Dst_{MIN}) is linearly related to preceding maximal PC value (PC_{MAX}): the higher the *PCmax* value, the larger is magnetic storm intensity (Dstmin).**

Delay times ΔT in response of *SymHMIN* to the *PCMAX* occurrence lie in the range from 30 to 180 minutes. Value of time ΔT seems to be slightly dependent on the storm growth phase duration.

Conclusion: **Time evolution and intensity of magnetic storms is determined by the *PC* value and dynamics**

Results of studies fulfilled in AARI showed that the PC index should be regarded as an the ground-based proxy of the solar wind energy that entered into the magnetosphere.

Resolution 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.

Therein lies the 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 substorm and magnetic storms).

Relationship between PC index and interplanetary electric field E_{KL}

The interplanetary electric field E_{KL} is estimated by such solar wind parameters, as the solar wind velocity **Vsw** and interplanetary magnetic field (IMF): $E_{KL}=V_{SW}\,B_T^2 \sin^2(\theta/2)$

These parameters, available at the OMNI database (https://omniweb.gsfc.nasa.gov/), are fixed at around of Lagrange point L1, far upstream of the magnetosphere (at distance of ~ 1.5 millions km from the Earth). Thereupon they are reduced to the Earth's magnetopause, **under the silent presumptions that solar wind observed in the Lagrange point always encounters the magnetosphere, and the Vsw and IMF parameters are not altered on the way from the L1 point to the magnetopause.**

The *PC* index responds to changes of the interplanetary electric field E_{KL} with time delays ΔT, values of ΔT being dependent on the E_{KL} growth rate (dE_{KL}/dt) [*Troshichev and Sormakov,* 2015];

Results of analysis of Vochmyanin et al. [2019]

***Vochmyanin et al*. [2019]** compared the OMNI data and Geotail measurements in limits of 2-hr intervals, when the spacecraft occurred to be in vicinity of the magnetosphere bow shock.

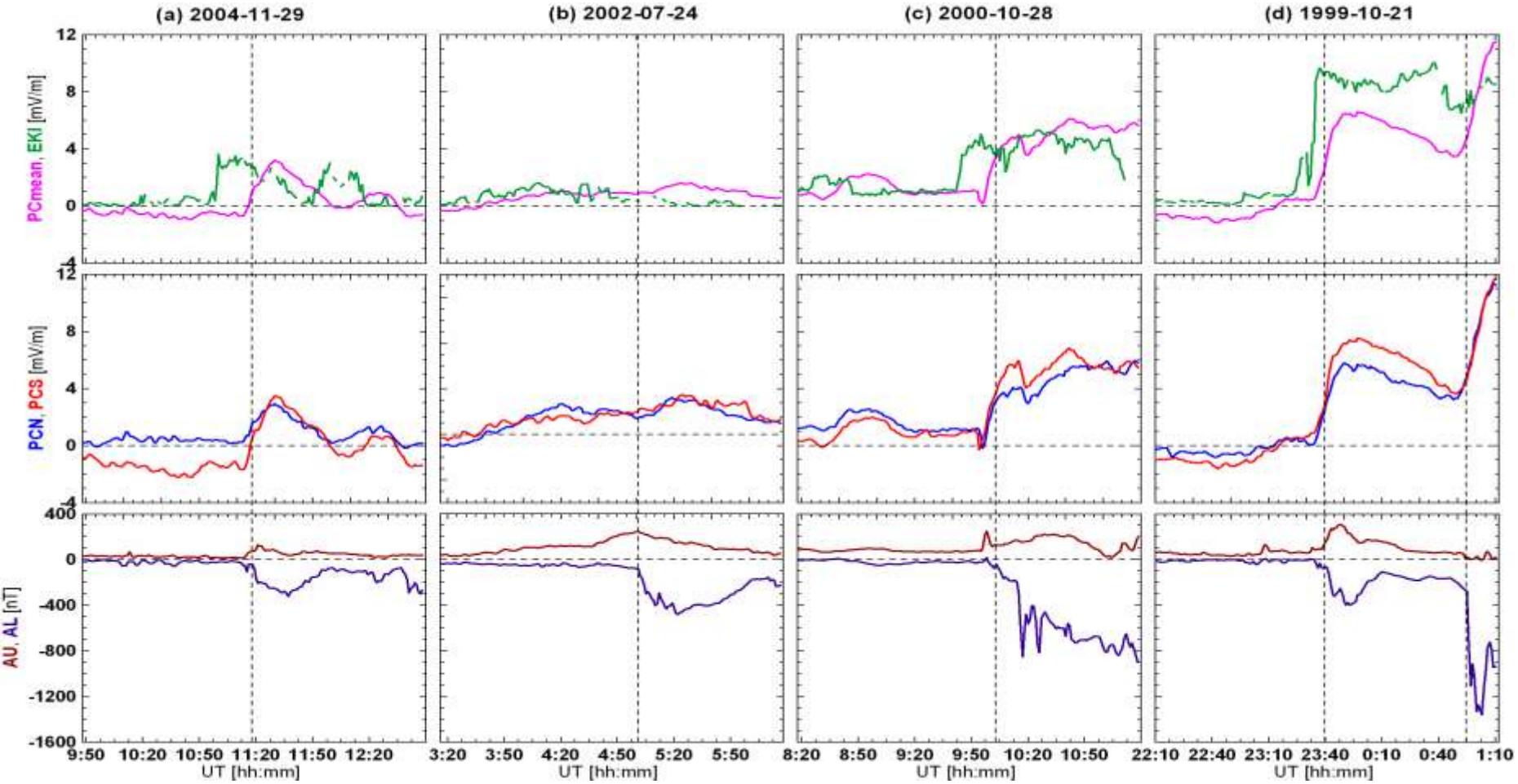
Results of the analysis, obtained for 10 409 intervals available in both datasets over the period from 1997 to 2016, have demonstrated that **relevant solar wind parameters fixed in the Lagrange point and in vicinity of magnetosphere were distinct in ~ 25% of data under analysis.** Authors met with stubborn problems of separation of useful signals against the noise background, when IMF variance became lower than 1.0-1.5 nT

Unfortunately, such direct and reliable method for utility evaluation of measurements performed in the Lagrange point can not be designed for routine inspection, since the Geotail spacecraft appearance in front of magnetosphere is seldom the case and strongly limited in time.

According to *Vochmyanin et al*. [2019], **the *EKL* field values derived from OMNI database and calculated from Geotail measurements were in good agreement, when the *PC* index correlated well with *EKL* field**.

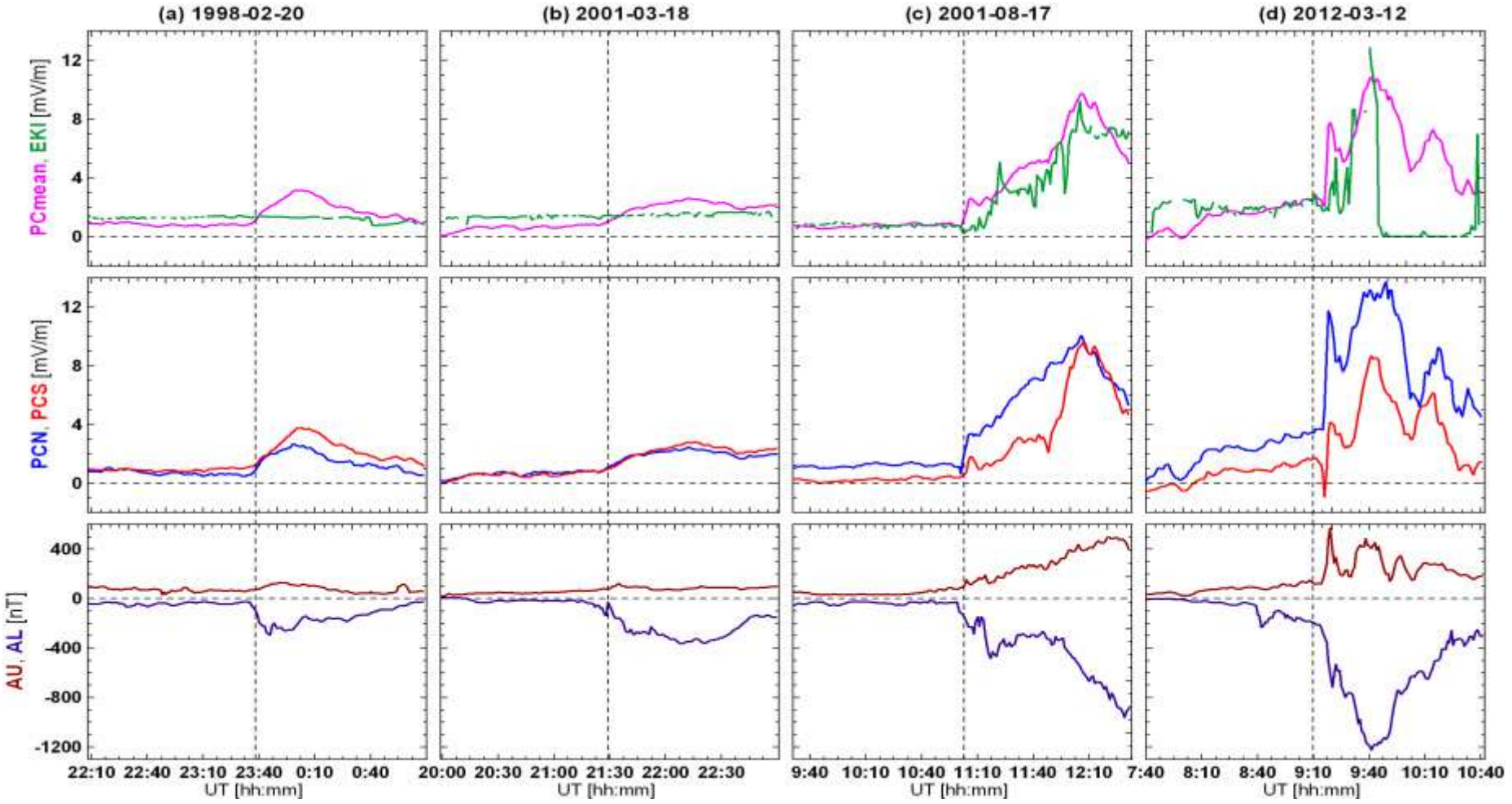
The aim of the study was to demonstrate the efficiency of *PC* index for evaluation of utility of SW measurements made in the Lagrange point **under conditions of extreme space weather, which are identified with magnetospheric disturbances**.

Examples of relationships between "estimated" E_{KL} field and PC index in course of extreme space weather events: PC index follows E_{KL} changes



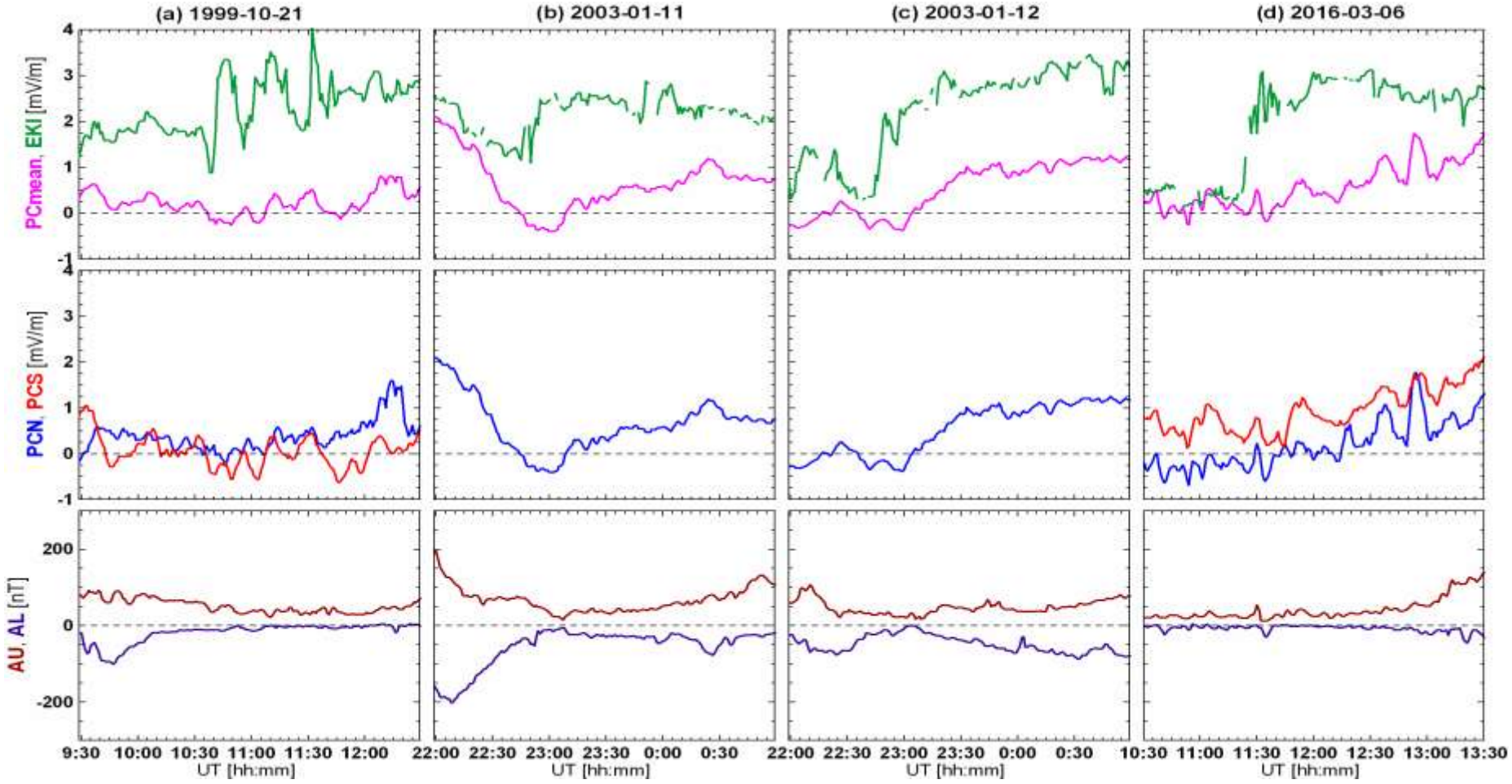
(a) **29 November 2004,** the substorm progression correlated with *PCN* better than with *PCS.*
(b) **24 July 2002,** the substorm progression correlated with *PCS* better than with *PCN*.
(c) **28 October 2002** and (d) **21 October 1999,** similarity in behavior of *PCN* and *PCS* indices is seen, the latter substorm displayed two successive sudden onsets (in 23:40UT and in 00:55UT on October 22), associated with the corresponding jumps in the *PC* growth rate.

Examples of relationships between "estimated" E_{KL} field and PC index in course of extreme space weather events: <u>disagreement</u>



Substorm on **20 February 1998** (a) and **18 March 2001** (b) are associated with the *PC* jump occurring against the background of invariable E_{KL} field (estimated by OMNI data). The actual E_{KL} field, providing the *PC* growth, was evidently distinct from the "estimated" E_{KL} field derived from measurements in the L1 point. In case of substorms on **17 August 2001** (c) and **12 March 2012** (d) the *PC* jump was observed ahead of the estimated time of E_{KL} jump (derived from OMNI data), evidently, as a result of acceleration of real solar wind.

Examples of relationships between "estimated" E_{KL} field and PC index in course of extreme space weather events: <u>disagreement in value</u>



The events are shown, when the E_{KL} field (derived from OMNI data) exceeded the level 2 mV/m during some hours: the E_{KL} field oscillated in case of **21 October 1999** (a), rose on **11 October 2003** (b) and sharply jumped up by ~ 2 mV/m on **12 January 2003** (c) and **06 March 2016** (d). These leaps of E_{KL} field were not followed by the appropriate *PC* index growth and the substorm development. Such inconsistency evidently testifies that actual E_{KL} field, coupling with the magnetosphere, was other than estimated E_{KL} field.

Data and Method of the analysis

The following restrictions were imposed upon the magnetic disturbances included in the analysis:

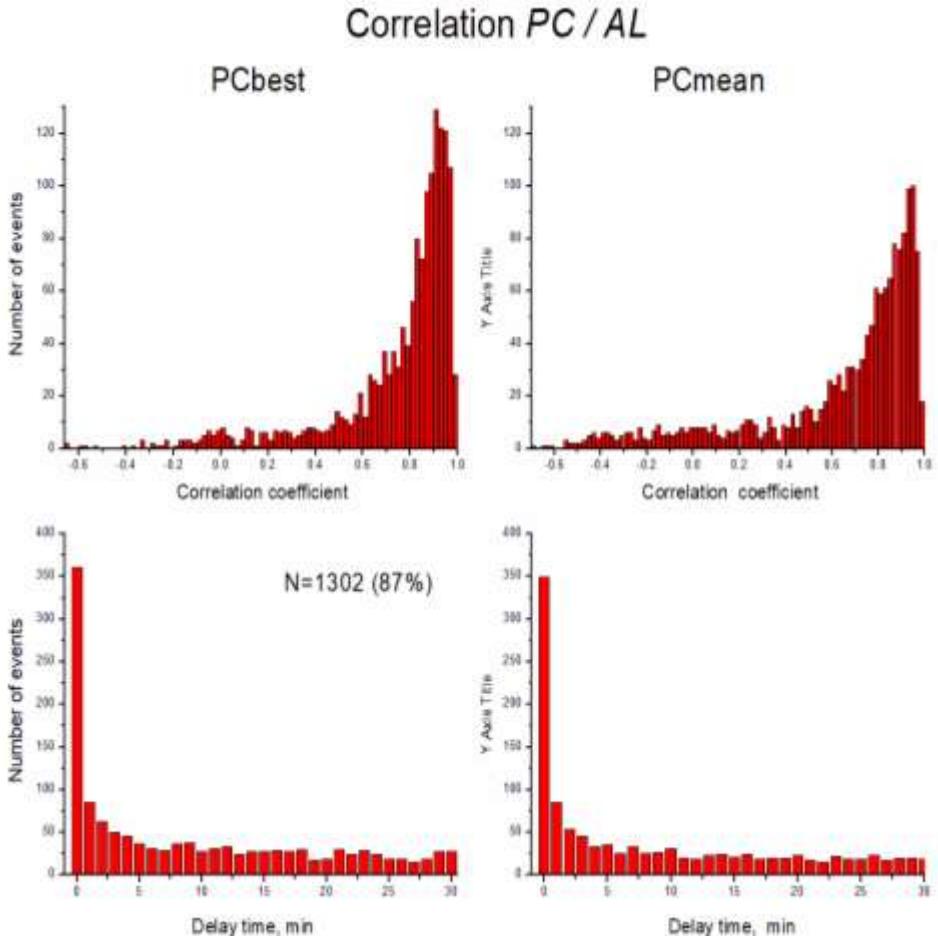
- the magnetic disturbances with SO occurring against the background of the quiet geomagnetic field, are examined
- the substorm sudden onset (SO) is identified as a moment when *AL* value drops by 20nT in the first minute and by no less than 50nT in the subsequent 5 minutes.

All magnetic substorms occurring in period from January 1998 to June 2017 and satisfying to the above criteria were selected for analysis (N=1470).

Correlation between the appropriate *PC* and *AL* indices was estimated for each substorm event at the time interval from T_0-30min to T_0+15 min, where T_0 is SO moment.

The magnetic substorms were regarded as independent proxy of the solar wind impact on the magnetosphere. Disagreement between the E_{KL} behavior, on the one side, and growth of *PC* index and magnetic disturbances, on other side, is treated as evidence that solar wind fixed in point L1 did not encounter the magnetosphere

Correlation between the PC growth and substorm development



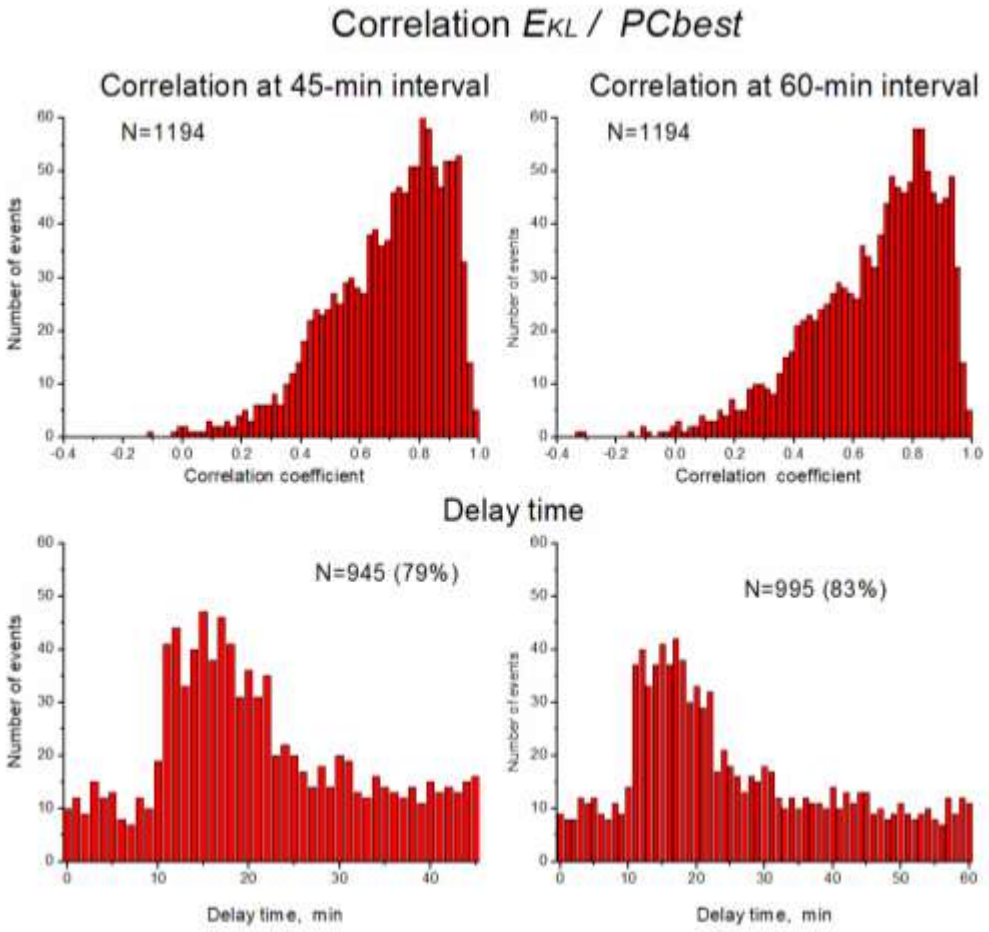
The substorm onset is related to jump in the *PC* growth rate, displayed by both *PCN* and *PCS* indices, or by one of them. Correlation was calculated independently for *PCN* and *PCS* indices and for their mean value, *PCmean*=(*PCN*+*PCS*)/2.

The index (either *PCN* or *PCS*) supplied the higher correlation with substorm development, was identified as "*PCbest*" index for each substorm.

Delay times ΔT for *PCbest* and *PCmean*, providing the best correlationlie in range from 0 to 10 min with maximum at ΔT=0-1min.

Distribution of substorms number over the correlation coefficients R (upper panel) and over the delay times ΔT (lower panel) is shown for two *PC* index options: *PCbest* and *PCmean*.
In case of *PCbest* the well correlation R>0.5 was observed in 1302 cases (89%) of 1470 examined substorms, in case of *PCmean* the well correlation was observed in ~78% of events .
The poor correlation (R<0.5) between *PC* and *AL* indices was observed in case of substorms started under conditions of strongly undulating *PC* index, these events were excluded from examination.

Correlation between "estimated" E_{KL} field and PC index



Only substorm events showing well correlation (R>0.5) between *PC* and *AL* indices were included in the analysis (N=1302).

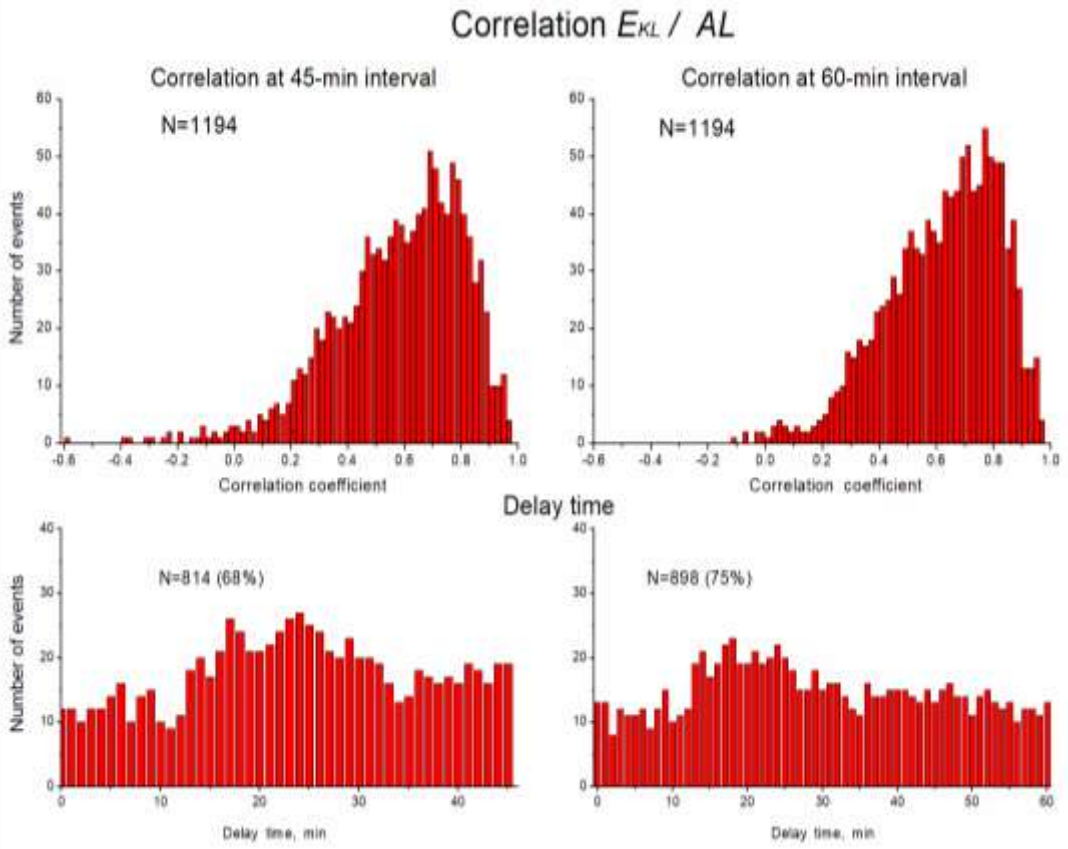
Statistical relationships between E_{KL} and *PC* were examined in the the 45-min and 60-min intervals preceding the SO moment.

The events with gaps in E_{KL} data (i.e. gaps in the solar wind parameters in the OMNI dataset) were excluded from the analysis, if the gaps were in excess of 40% of the event data series; otherwise the data with gaps were extrapolated.

The results of the analysis are indicative of loss of correlation between the "estimated" E_{KL} field and *PC* index in about 20% of substorm events, in spite of fact that development of these substorms was obviously preceded by *PC* growth.

In few cases, the correlation between E_{KL} and *PC* changes was perfect, but moments of the *PC* jump and substorm onset were observed ahead of the E_{KL} changes

Correlation between "estimated" E_{KL} field and substorm development



Correlation R>0.5 between *EKL* and *AL* was observed only in 68% of events for 45 min interval (Rmean=0.70) and in 75% of events for 60 min interval (Rmean=0.71).

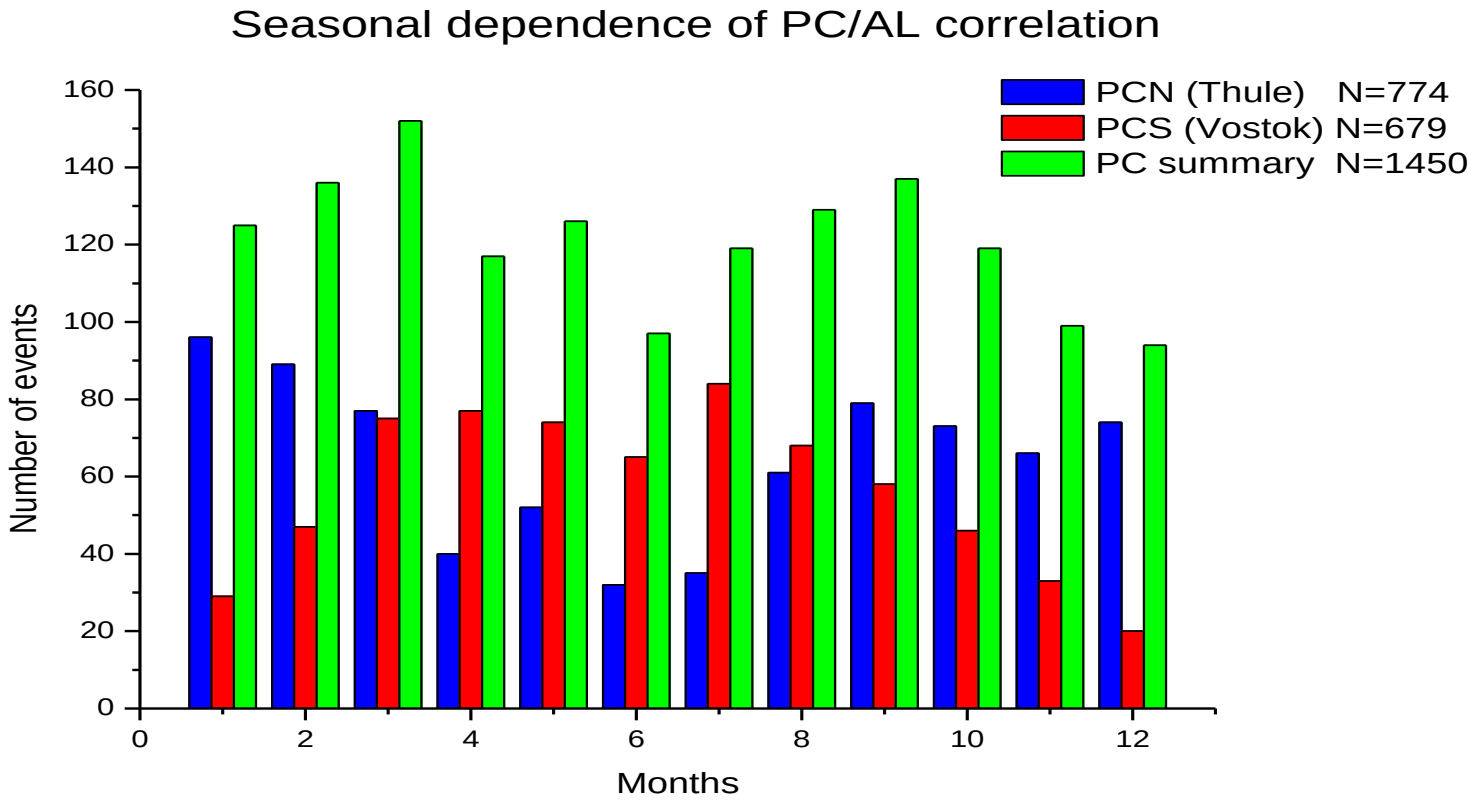
The delay time of *AL* response to *EKL* variations is slightly expressed at $\Delta T = 13 \div 32$ minutes, the regularity being more distinct for 60-min interval.

These delay time values appear to be in perfect agreement with above shown delay times in the *PC* response to *EKL* changes ($\Delta T = 10 \div 26$ min) and delay times in the *AL* response to *PC* changes ($\Delta T = 0 \div 10$ min).

Thus, the correlation between *EKL* field variations and substorms development turned out to be worse than correlation between *EKL* field and *PC* index, in spite of high correlation between *PC* and *AL* indices. Such regularity seems to be quite reasonable, because the *PC* index, as a proxy of the solar wind energy input into magnetosphere, responds to solar wind affecting the magnetosphere in actuality, whereas E_{KL} field is estimated by the solar wind parameters fixed far upstream of the magnetosphere and these parameters and, therefore, real E_{KL} field can be modified on way from the Lagrange point to the Earth.

Seasonal dependence of PCbest index

Occurrence of the *PCNbest* and *PCSbest* indices demonstrates a distinct seasonal variation.
Graph shows the number of the *PCNbest* and *PCSbest* occurrences over year, and their total number .

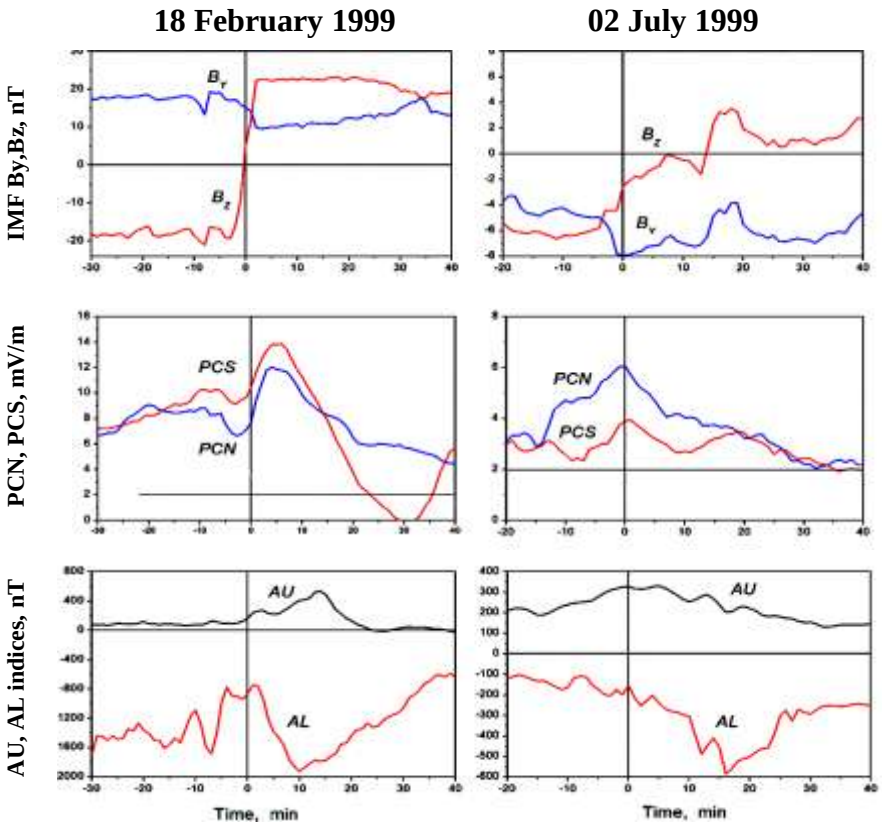


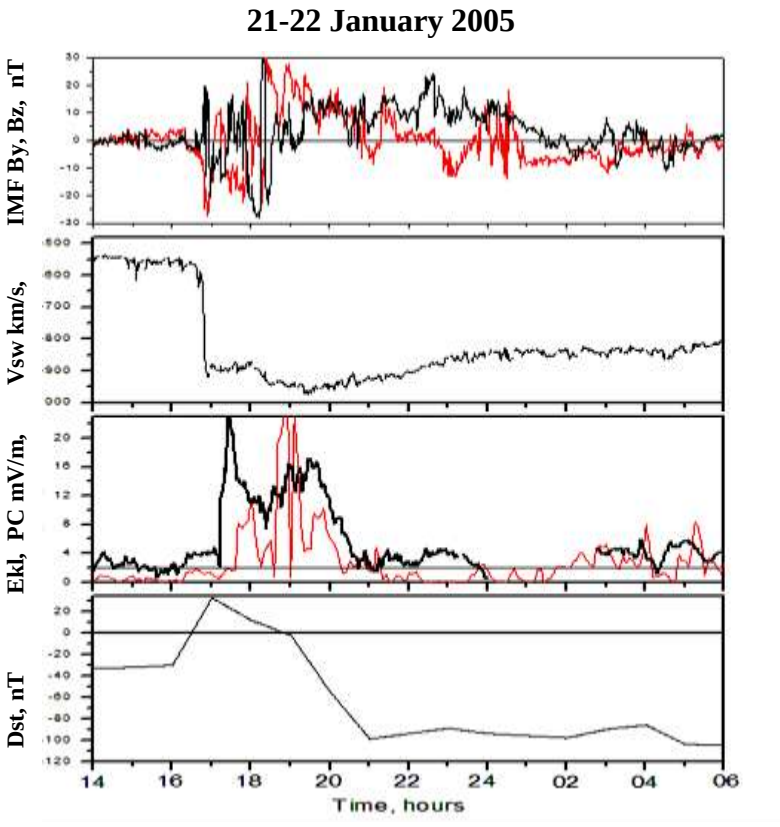
Input of the *PCNbest* index is about twice as much as the *PCSbest* index during November-February, whereas input of the *PCSbest* index is about twice as much as the *PCNbest* index during April-July, the input of both indices being nearly equal in equinox.

This result makes it possible to conclude that magnetic activity in the winter polar cap ensures generally the more correct result than that in the summer polar cap.

The "extraordinary magnetic disturbances" and PC index

The term "extraordinary magnetic disturbances" was referred to magnetic substorms [*Wu et al.*, 2002; *Kullen and Karlson*, 2004; *Miyashita et al.*, 2006; *Lee et al.*, 2007, 2010] and magnetic storms [*Du et al*., 2008] observed under conditions of ineffective northward IMF.





Results of *Troshichev et al.* [2011] demonstrated that "extraordinary disturbances" described by *Du et al.* [2008] and *Lee et al*. [2010] happened, when *PC* index was above the required threshold level ~1.5 mV/m. **It implies that the northward IMF fixed in the Lagrange point in period of "extraordinary magnetic disturbances" did not contact with the Earth's magnetosphere in reality; so the "extraordinary disturbances" turn into category of ordinary events, as soon as the *PC* index is taken for estimation of the space weather conditions.**

Conclusions

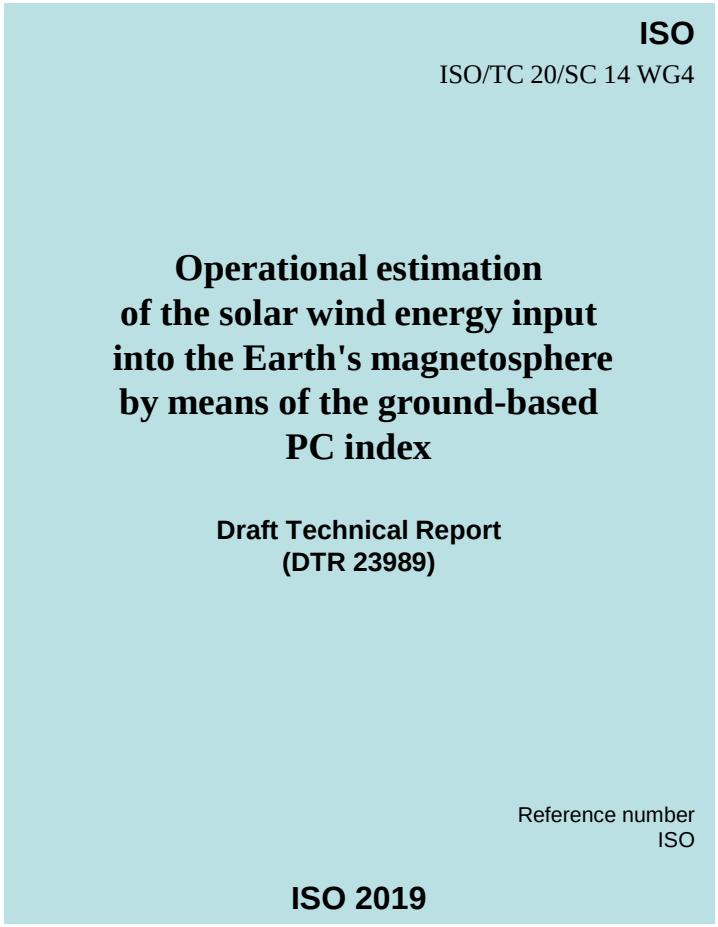
Statistical relationships between *PC* and E_{KL} demonstrate that time evolution of the *PC* index is generally controlled by the E_{KL} variations, the E_{KL} increase being followed by the *PC* growth with delay time $\Delta T \sim 12\text{-}20$ min.

Correlation between the "estimated" E_{KL} field and *PC* index breaks down in about 20% of substorm events, in spite of fact that the *PC* growth was accompanied by substorm development. It implies that the "estimated" E_{KL} field in these cases did not impact on the Earth's magnetosphere and, therefore, the solar wind fixed far upstream of the Earth (in the Lagrange point) was not consistent with real solar wind contacting with the magnetosphere.

Index of magnetic activity in the winter polar cap *PCwinter* ensures in general the better correlation with E_{KL} field than the *PCsummer* index, which is to say that the problem of random discordances between *PCN* and *PCS* indices is removed.

Thus, the *PC* index makes it possible to validate the actual interplanetary electric field E_{KL} coupling with the magnetosphere, and verify, in such manner, whether or not the solar wind, whose parameters are given in OMNI dataset, encountered the magnetosphere.

PC index as International Standard of the solar wind energy input into the Earth's magnetosphere



The International Organization for Standardization (ISO) suggested to prepare "Project" concerning the PC index usage as a standard of the solar wind energy input into the Earth's magnetosphere.

The "Project" was prepared and presented in November 2018 at Meeting of the Working Group WG4 of the ISO Technical Committee "Space systems and operations" (**I O TC 20/SC 14).**

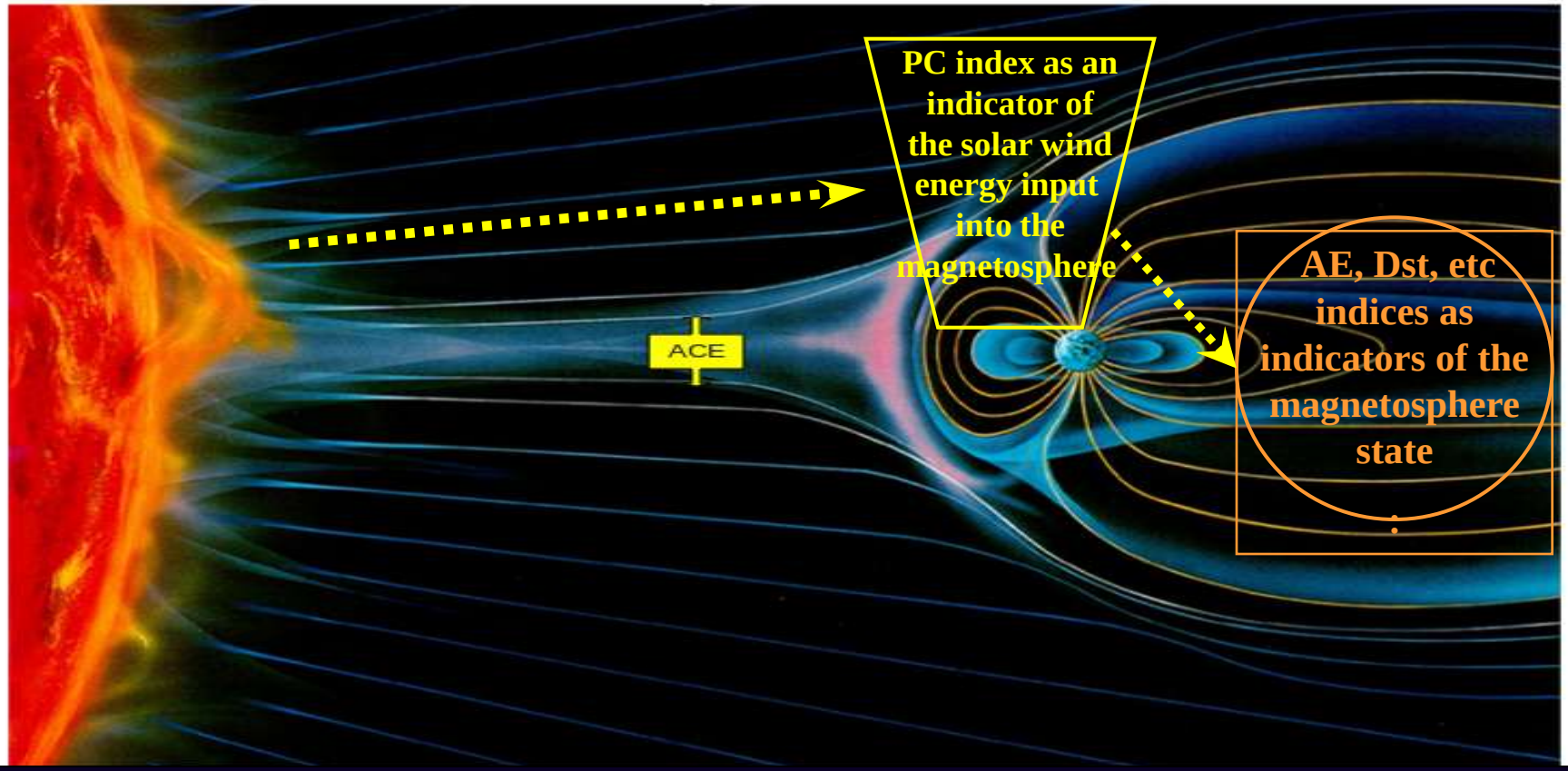
The ":Project" was approved by experts of WG4 and was sent to national representatives of ISO TC 20/SC 14 who also approved the Project with some comments.

At present I have prepared the Draft Technical Report, with answers to the experts' remarks.

After examination and approval of my answers

the formal documents satisfying the ISO rules will be prepared

Many thanks for attention!



The experimental facts are indicative of the *PC* index as the ground-based standard of the solar wind energy input into the magnetosphere.

The *PC* index might be useful as a means for monitoring the space weather, nowcasting the magnetosphere state, fitting the solar wind-magnetosphere coupling function, calibrating the different phenomena and processes in the disturbed magnetosphere, and serve as a filter of good OMNI data.

The sets of data on PC index for 1997-2017 and the current *PCN* and *PCS* indices calculated on-line by magnetic data from stations Thule and Vostok are presented at web site:

http://pcindex.org