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New Regional Geomagnetic Indices for the Russian Sector of the Geomagnetic Observation Network

A. V. Vorobev[1,2], **V. A. Pilipenko**[2,3], **M. N. Dobrovolsky**[2,*], **O. V. Kozyreva**[3], **M. A. Evdokimova**[4], **and D. V. Kudin**[2]

[1]Ufa University of Science and Technology, Ufa, Russia
[2]Geophysical Center of the Russian Academy of Sciences, Moscow, Russia
[3]Schmidt Institute of Physics of the Earth of the Russian Academy of Sciences, Moscow, Russia
[4] Space Research Institute of the Russian Academy of Sciences, Moscow, Russia
* **Correspondence to:** Michael Dobrovolsky, m.dobrovolsky@gcras.ru

Abstract: It was proposed to introduce new regional geomagnetic indices *SME-R* and *VAR* characterizing the values of the geomagnetic field perturbation and its variability (i.e., dB/dt) in the Russian sector at auroral latitudes into space weather studies. The indices are calculated from data of the Russian magnetic stations at geomagnetic latitudes from 40° to 70°. We compared the unofficial and regional indices with the standard planetary indices during some magnetic storms of 2015. In addition to the official IAGA indices *Dst*/ *SYM-H*, *AE*, *PC*, modified and regional indices *SME*, *PC-n*, *ULF*, *EI*, *Wp* (Pi2) were considered. The analysis of these events showed that some auroral activations confidently distinguished by the *SME* index can be missed by the standard *AE* index. The discrepancy between the standard *PC* and the refined *PC-n* indices reaches 1 mV/m to 2 mV/m during strong perturbations. The variability of the magnetic field characterized by the *VAR* index is not uniquely related to the level of geomagnetic perturbation characterized by the *AE* or *SME-R* indices. The events considered show that the use of planetary indices to estimate regional space weather perturbations can lead to false conclusions. The database of standard, modified, and new regional indices for 2015 is freely available at the FTP site ftp://indexguest:indexguest@imagftp.gcras.ru/ for testing.

Keywords: Geomagnetic indices, substorm, geomagnetic variations, geoinduced currents.

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Research Article

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Introduction

The greatest risks associated with the negative impact of space weather on the reliability of Earth technosphere objects – failures of navigation systems and shortwave radio communications, failures of power distribution systems and railroad automation – occur at high latitudes in the area of the auroral oval – a belt of intense luminosity created by the intrusion of electrons into the atmosphere from near-Earth space [*Belakhovsky et al.*, 2018; *Ptitsyna et al.*, 2008; *Sokolova et al.*, 2019]. The global navigation satellite systems (GNSS) GPS and GLONASS also experience problems with accuracy and fault tolerance [*Afraimovich et al.*, 2009; *Kozyreva et al.*, 2016; *Vorobev et al.*, 2022].

It is known that the geoeffectiveness of space weather is most often characterized by the geomagnetic indices. The most widely used are the 1-hour *Dst* index (or its 1-minute analogue *SYM-H*, describing the intensity of the symmetric/asymmetric parts of the magnetospheric ring current); the 3-hour *Kp* index characterizing the geomagnetic perturbation at middle latitudes; and the 1-minute or 1-hour *AE*/*AU*/*AL* indices characterizing the intensity of the auroral ionospheric currents. Additional planetary indices for monitoring specific features of the solar wind impact on the Earth's magnetosphere have been proposed:

the PC index characterizing the intensity of the transpolar current through the polar cap [*Troshichev and Janzhura*, 2012]; the *ULF* index characterizing the level of geomagnetic fluctuations in the frequency range of Ps5 pulsations [*Kozyreva and Kleimenova*, 2008, 2009; *Pilipenko et al.*, 2017].

The work on refining and modifying the geomagnetic indices is constantly under way. It was proposed to refine the standard auroral indices (of the *AE* type) calculated from data of 11 stations by introducing the *SME* index calculated from data of > 100 stations [*Newell and Gjerloev*, 2011a,b]. Work is underway to develop a midlatitude AMC index, an improved version of the Kp index [*Pick and Korte*, 2017]. In addition to planetary indices, regional indices, such as the *EI* for Fennoscandia, are being developed. Based on the calculated indices, substorm onset indicators are constructed [*Forsyth et al.*, 2015; *McPherron and Chu*, 2016]. An index system for describing the elements of substorm development and their impact on near-Earth space was constructed [*Borovsky and Yakymenko*, 2017] using data from a global network of magnetometers and measurements of energetic and relativistic electron fluxes on geostationary satellites. In addition to specific current systems, geomagnetic indices implicitly characterize various aspects of the dynamics of the magnetosphere-ionosphere system.

However, the existing planetary indices are calculated from a selected network of stations, which are distributed over the Earth's surface very unevenly. In addition, many intense geomagnetic phenomena (for example, substorms) develop in a limited longitudinal sector [*Nagai et al.*, 1983]. Therefore, the planetary indices inadequately characterize the geomagnetic situation in the territory of the Russian Federation. In addition, to describe the variability of the geomagnetic field, which is essential for the impact of space weather on terrestrial technological systems, it is necessary to introduce new indices based on the geomagnetic field derivative dB/dt [*Viljanen et al.*, 2006]. Statistical studies of the relationship between geomagnetic field variations and geoinduced currents (GIC) in power transmission lines [*Vorobev et al.*, 2019] have shown that the standard geomagnetic indices (*AE*, RS) characterizing the substorm activity are insufficient to correctly predict the magnitude of GIC in power transmission lines in the northwestern part of the Russian Federation.

Thus, the priority goal of this work is the approbation of the methodology for calculating the regional auroral geomagnetic activity indices from data of the Russian stations and creation of a publicly accessible database of all existing indices for the Russian sector.

As a source of geomagnetic data, we use a network of magnetic stations located on the territory of the Russian Federation, including observatories that conduct regular observations and transmit data to the world aggregators of geomagnetic information SuperMAG (https://supermag.jhuapl.edu/), INTERMAGNET (https://intermagnet.org/), and GC RAS (https://gcras.ru/). In recent years, new stations Saint-Petersburg (SPG) [*Sidorov et al.*, 2017], White Sea (WSE) [*Gvishiani et al.*, 2018], and the IZMIRAN network of stations on Yamal (https://forecast.izmiran.ru/) have been opened. The geographic and geomagnetic coordinates of all Russian stations are given in Table 1, and their positions are shown in Figure 1. Here and further in the text of the article we use the term stations to mean both geomagnetic stations and geomagnetic observatories. To calculate the regional indices for the territory of the Russian Federation, data of all available Russian stations with a time step $\Delta t = 1$ min were used.

The magnetograms of all available stations can be conditionally divided into polar (geomagnetic latitudes $\Phi > 70°$), auroral and mid-latitude ($40° < \Phi < 70°$) and low-latitude ($\Phi < 40°$) stations. The magnetograms of the *X*-component of these stations, divided into 3 panels, for the magnetic storm 2015/09/11 are given in the summary Figure 2.

Indicators of Validity of the Proposed Indices

In the process of researching the new indices, the results obtained were compared with the standard indices, and both 1-hour and 1-min versions of the indices were considered.

Table 1. Russian magnetic stations. Geomagnetic coordinates calculated using the 2015 model for 2015 (https://omniweb.gsfc.nasa.gov/vitmo/cgm.html).

International name	Code	Geographic coordinates (latitude °; longitude °)	Geomagnetic coordinates (latitude °; longitude °)
Heiss Island	HIS	(80.62; 58.05)	(76.1; 143.7)
Vize	VIZ	(79.48; 76.98)	(74.2; 155.7)
Cape Chelyuskin	CCS	(77.72; 104.28)	(72.8; 176.6)
Kotelny	KTN	(75.94; 137.71)	(70.4; 202.0)
Beliy Island	BEY	(73.30; 70.00)	(69.2; 146.9)
Dixon	DIK	(73.55; 80.57)	(68.8; 156.0)
Sabetta	SBT	(71.42; 72.13)	(67.5; 148.2)
Kharasavey	KHS	(71.13; 66.83)	(67.2; 143.3)
Tixie Bay	TIK	(71.58; 129.00)	(66.2; 197.9)
Chokurdakh	CHD	(70.62; 147.89)	(65.7; 214.1)
Pebek	PBK	(70.10; 170.90)	(65.4; 230.2)
Cape Schmidt	CPS	(68.88; 180.55)	(65.4; 239.0)
Amderma	AMD	(69.50; 61.40)	(65.3; 137.7)
Cape Kamenniy	CKA	(68.50; 73.60)	(64.7; 148.8)
Norilsk	NOK	(69.40; 88.40)	(64.6; 162.2)
Lovozero	LOZ	(67.97; 35.08)	(64.1; 114.9)
White See	WSE	(66.55; 33.10)	(63.2; 111.5)
Salekhard	SLH	(66.65; 66.35)	(63.0; 141.5)
Nadym	NAD	(66.54; 72.50)	(62.8; 147.3)
Zhigansk	ZGN	(66.75; 123.26)	(62.0; 195.4)
Zyryanka	ZYK	(65.75; 150.78)	(60.5; 218.7)
Klimovskaya	KLI	(60.86; 39.52)	(57.4; 115.0)
Saint-Petersburg	SPG	(60.54; 29.72)	(57.3; 106.7)
Yakutsk	YAK	(62.02; 129.72)	(54.5; 201.7)
Borok	BOX	(58.03; 38.97)	(54.2; 113.7)
Magadan	MGD	(59.97; 150.86)	(53.9; 219.7)
Arti	ARS	(56.43; 58.57)	(52.5; 131.9)
Kazan	KZN	(55.91; 48.79)	(52.3; 122.6)
Moscow	MOS	(55.48; 37.32)	(51.6; 111.6)
Novosibirsk	NVS	(55.03; 82.90)	(50.9; 155.8)
Kaliningrad	KLD	(54.50; 20.20)	(50.6; 96.1)
Mondy	MND	(51.62; 100.92)	(47.5; 174.9)
Irkutsk	IRT	(52.17; 104.45)	(47.5; 177.6)
Paratunka	PET	(52.94; 158.25)	(46.5; 226.9)
Khabarovsk	KHB	(47.61; 134.69)	(41.3; 207.2)
Popov Island	PPI	(42.98; 131.73)	(36.7; −155.6)

- the mean hourly *Dst* index (https://wdc.kugi.kyoto-u.ac.jp/dstdir/) characterizing the magnitude of the magnetic storm is calculated from data of 4 near-equatorial stations. Its 1-min analog is the *SYM-H* index (https://isgi.unistra.fr/indices_asy.php) characterizing the intensity of the symmetric/asymmetric part of the ring current and is calculated from data of 6 near-equatorial stations.

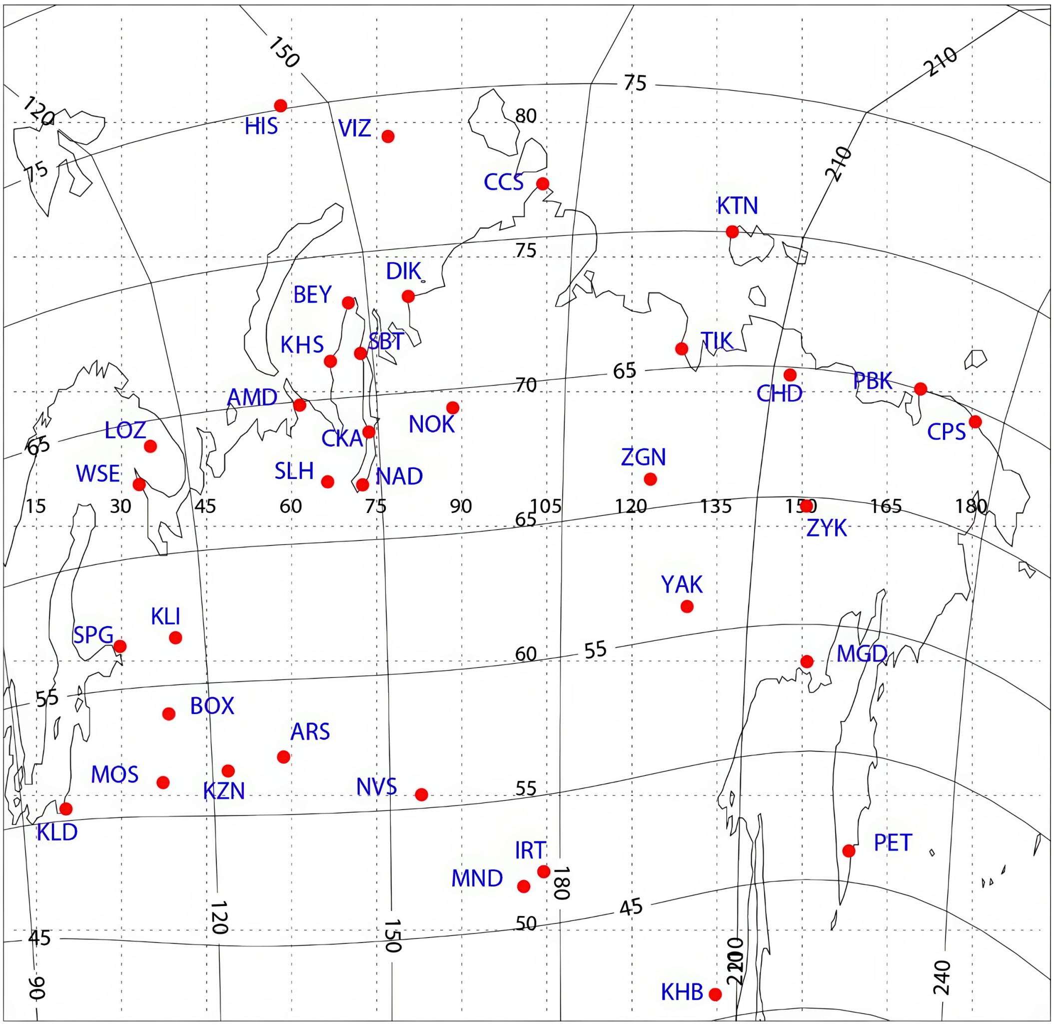


Figure 1. Map with the position of Russian magnetic stations. Solid lines correspond to geomagnetic coordinates, dashed lines - to geographic coordinates.

- auroral 1-min indices *AE*/*AU*/*AL* (https://wdc.kugi.kyoto-u.ac.jp/dstdir/) characterize the intensities of the western and eastern electric jets and are calculated from data of 11 auroral observatories. The *AL* index responds best to the onset of substorm, and the *AE* index characterizes most adequately the substorm magnitude.
- 1-min indices of the northern and southern polar caps *PCN*/*PCS* (https://pcindex.org/), characterizing the intensity of the transpolar current. Presumably, these indices describe the energy transfer from the solar wind to the magnetosphere [*Janzhura et al.*, 2007]. Recently, a number of refinements of the standard index have been proposed [*Stauning*, 2007]. Therefore, the data of the refined *PC-n* index are also included in the analysis.

Standard indices that do not have the status of official IAGA indices were also considered.

- *SME*/*SML*/*SMU* 1-min indices (https://supermag.jhuapl.edu/indices/), which refine the official *AE*/*AL*/*AU* indices [*Gjerloev*, 2012]. To determine these indices, the SuperMAG database uses all magnetic stations located in the range of geomagnetic latitudes 50°–90° (> 150 stations in recent years). The physical meaning of the *SME* index derives from the close correlation ($R \sim 0.9$) with the integral power of precipitating thermal electrons responsible for diffusion auroras, while the standard *AE* index has a lower correlation with $R \sim 0.8$ [*Newell and Gjerloev*, 2011a,b].

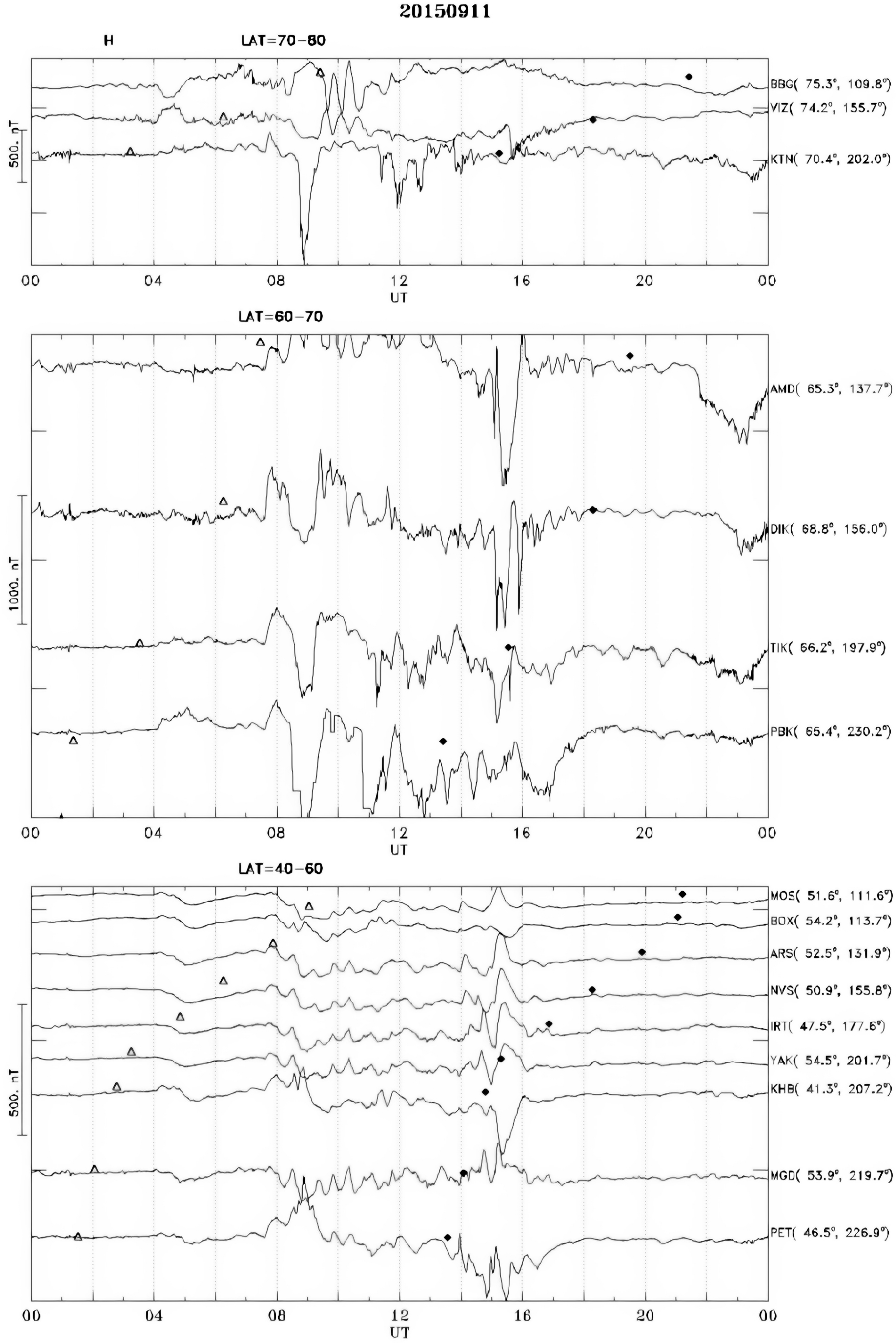


Figure 2. Magnetograms (*X*-component) of three groups of Russian stations for 2015/09/11: (upper panel) high-latitude stations at geomagnetic latitudes $\Phi > 70°$; (middle panel) stations at auroral latitudes $60° < \Phi < 70°$; (lower panel) mid-latitude stations $40° < \Phi < 60°$. The geomagnetic coordinates of the stations are indicated next to their code. Light triangles show local geomagnetic noon and dark rhombuses show local midnight. Magnetograms are arranged in order of increasing geographic longitude.

- *ULF* index *Sgr* (http://ulf.gcras.ru/), which characterizes the integral in the interval of 1 hour spectral power of geomagnetic field pulsations in the northern hemisphere in the frequency range of 1.7 MHz to 7.0 MHz [*Kozyreva and Kleimenova*, 2008, 2009].

- regional *EI* (electrojet indicator) index on the website of the Finnish Meteorological Institute (https://space.fmi.fi/) characterizing the auroral electrojet intensity in Scandinavia, calculated from data of the meridional network of IMAGE stations.

Indicators of Substorm Onset

- Based on the SML index, an algorithm for automatic detection of substorm onset was developed and their catalog was compiled (https://supermag.jhuapl.edu/substorms/).
- the *Wp* (Wave planetary) index, which reflects the intensity of geomagnetic pulsations in the Pi2 range calculated from data of 11 low-latitude stations, was proposed as a wave indicator of the beginning of a substorm. A sharp spike in the *Wp* index can be considered as an indicator of substorm onset [*Nosé et al.*, 2012].
- At midlatitudes, magnetospheric currents create a positive magnetic bay, the beginning of which can be considered as an indicator of the onset of a substorm. Based on these ideas, an index called the midlatitude positive bay (*MBP*) index is proposed, which is calculated as the average power (in nT^2) of the magnetic perturbation from data of 35 nighttime midlatitude stations [*McPherron and Chu*, 2016]. The *MBP* index exceeding a fixed threshold is used as an indicator of substorm onset.

Elements of Formalization of the Proposed Indices

It is proposed to discuss the need to introduce the following new regional indices for the territory of the Russian Federation:

- 1-min *SME-R* (nT) index calculated from data of Russian stations. It differs from the proposed SuperMAG *SME* index [*Newell and Gjerloev*, 2011a,b] by the territorial affiliation of magnetic stations. For its calculation, up to 18 stations located on the territory of Russia in the latitudinal range of geomagnetic latitudes 50°–80° are used (see Figure 1 and Table 1). Following the methodology used in the SuperMAG project [*Gjerloev*, 2012], the daily trend was removed by subtracting the typical values for each day using a 17-day window.
- 15-min *VAR* (nT/min) index, which characterizes the field variability. As such index, the modulus of the derivative $dB_H/dt = \sqrt{(dX/dt)^2 + (dY/dt)^2}$ from the initial 1-min data of the horizontal magnetic components of all Russian stations is calculated. The derivative was calculated using the three-point formula $X'(i) = [X(i+1) - X(i-1)]/2\Delta t$. Two subtypes of the index are proposed:

  (a) *VAR* for 15-min interval averaged over all Russian stations, and
  (b) *VAR*-max – extreme value of the dB_H/dt derivative at any of the stations during the 15-min interval.

- 1-min $\mathbf{J}_\mathrm{W}$ index, which is the total current of the western auroral electrojet [*Evdokimova and Petrukovich*, 2020]. It is calculated from data of the meridional chain of magnetic stations. However, this index can be reliable only in the presence of a substorm (electrojet). The electric jet model is chosen based on the peculiarities of the chain of stations: for chains with a large number of stations, multi-parameter models with a complex current profile can be used; in the case of a small number of stations, only a model with three parameters defining the current and its boundaries is realistic.

Comparison of Different Indices for the 2015 Magnetic Storms

We calculated indices for 2015 (if data for the station were available) for days with strong storms using different algorithms and compared them with each other and with the standard indices. In the graphs, the vertical colored lines correspond to the moments of substorm onset according to the *MBP* index [*McPherron and Chu*, 2016]. The SuperMAG methodology (https://supermag.jhuapl.edu/substorms/) identifies a large number of auroral activations, not all of which correspond to substorm onset, and therefore are not shown here. The graphs below give a sense of how the different indices behave and how they differ.

Consideration is carried out in the order of increasing magnitude of the magnetic storm (extreme value of the *Dst* magnitude).

2015/09/11

The growth phase of this storm extended from 02 UT to 14 UT according to *Dst* index, at the end of which the *Dst* index reached values of -80 nT) (Figure 3a). The hourly average *Dst* index significantly smooths the variations of the *SYM-H* index (e.g., the extreme value of *SYM-H* ~ 95 nT corresponds to *Dst* ~ 80 nT). Against the background of this magnetic storm, 5 activations occur – at ~ 05 UT, ~ 09 UT, ~ 15 UT, and ~ 22 UT, as can be seen from the *AE*, *SME*, and *PCN* indices. The onset of these activations corresponds to the onset of the substorm according to the *MBP* index (shown by the vertical lines) and the Pi2(*Wp*) index spikes. However, the beginning of the substorm at 00:40 UT is weakly manifested in the *AE* index, but is clearly seen in the Pi2(*Wp*) index outburst.

Sometimes, the standard *AE* index can significantly underestimate the magnitude of the auroral disturbance, apparently, when a substorm develops in a sector not covered by standard *AE* observatories. For example, at ~ 09 UT, a perturbation with *SME* ~ 2500 nT manifests itself at *AE* ~ 1300 nT.

The discrepancy between the standard *PCN* index and the modernized *PCN-n* index is small, no more than 1 mV/m. At the same time, the *PCN* almost repeats the *AE* index, no advance growth of *PCN* before substorms is seen.

The regional indices are shown in Figure 3b. The *EI* index responds only to substorms in the Scandinavian region (~ 09 UT, ~ 15 UT, ~ 20 UT). The same activations are also prescribed in *SME-R*. In *SME-R*, the activation at ~ 09 UT is seen even more clearly. The variations of the $\mathbf{J}_W$ index (for the 21:00-24:00 UT interval) match well with the variations of the *EI* index.

During a substorm, the *VAR*-max field variability index can increase from 10 nT/m to ~ 100 nT/m. The time course of *VAR*-mean corresponds well with that of *VAR*-max. The variability of *VAR* is by no means unambiguously consistent with the magnitude of *SME-R*. For example, the maximum values of *VAR* and *VAR*-max are observed not at the most intense substorm at 09 UT, but at a weaker one at 15 UT.

2015/06/23

During this strong storm, the *Dst* index reaches extreme values up to −200 nT, after which a smooth recovery phase begins, against the background of which several activations occur, as seen in the *AE*, *SME*, and *PCN* indices (Figure 4a). These activations are more distinct in the *SME* than in the *AE* index.

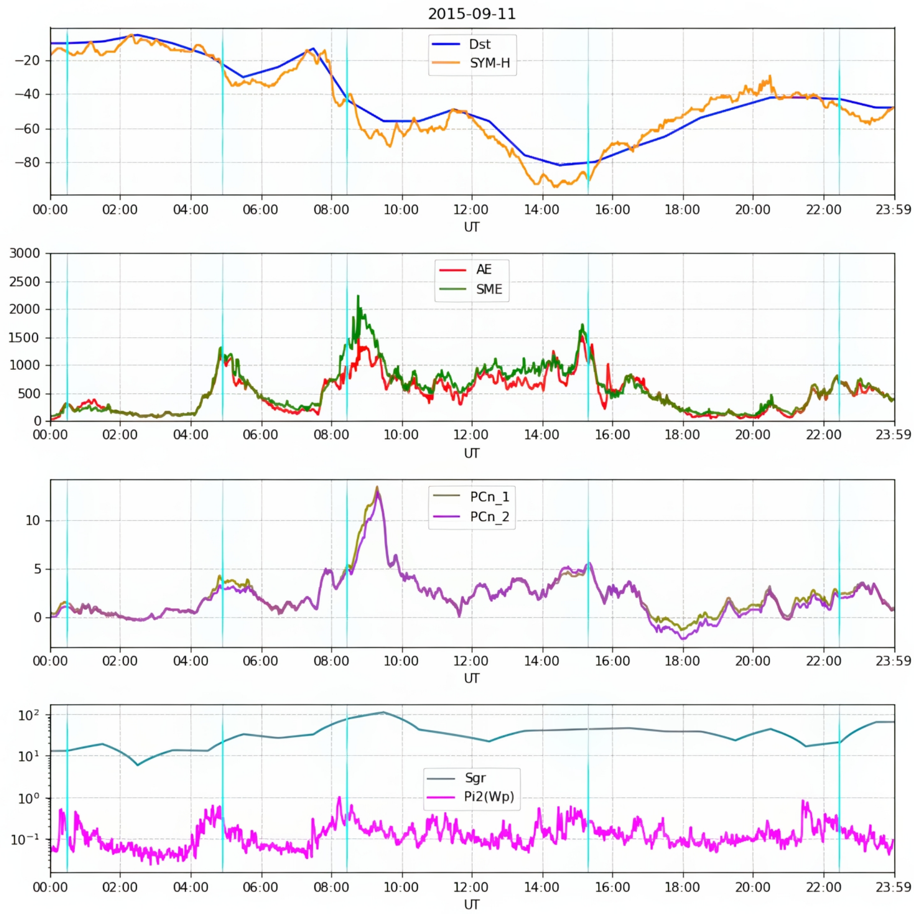
For this complex storm, the results of determining the onset of substorm activation by different methods diverge. For example, the *MBP* index shows substorm activation at ~ 04 UT, while it is not detected in the *AE* and Pi2 indices. At the same time, at ~ 05 UT, the situation is the opposite.

During this event, the discrepancy between the standard and corrected *PCN* indices reaches 2 mV/m to 3 mV/m. The preliminary growth of the *PCN* index before the beginning of the substorm is approximately the same as the growth of the *AE* index.

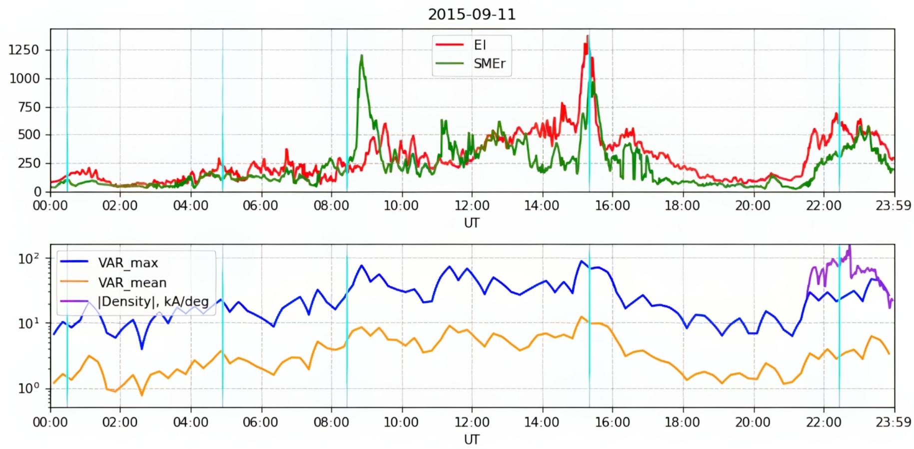
The regional indices are given in Figure 4b. The *SME-R* does not show all the substorms that are evident in the *SME* index. In this event, the variations of the $\mathbf{J}_W$ index (20:00 – 00:00 UT) do not coincide with the variations of the *EI* index. It is worth noting here that the anomaly in the $\mathbf{J}_W$ (21:30 – 22:30 UT) does not look very natural and may be the result of some interference. The time course of *VAR* variability generally corresponds to the *SME-R* course.

2015/03/17 (St. Patrick's Storm)

During this storm, there is a long development phase (*Dst* index reaches −220 nT) starting from ~ 05 UT, against which several activations (~ 07, ~ 09, ~ 14, ~ 21, ~ 23 UT) occur as follows from the *AE*, *SME*, and *PCN* indices (Figure 5a). The onset of activation

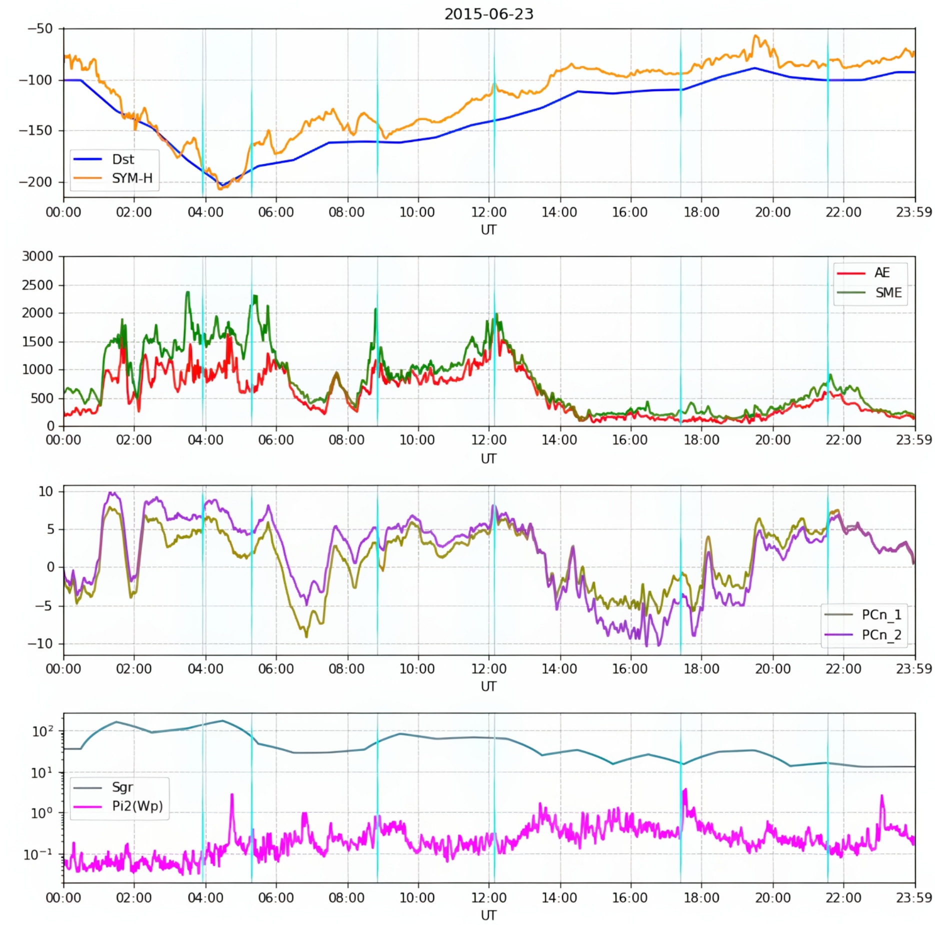


(a)

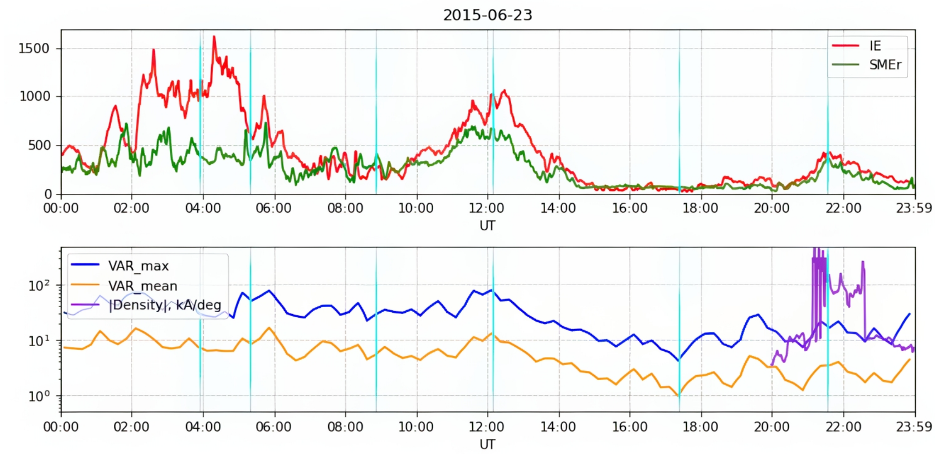


(b)

Figure 3. (a) Planetary geomagnetic indices for the 2015/09/11 magnetic storm: 1-hour *Dst* index and 1-min *SYM-H* index. Vertical cyan lines mark the onset of substorms according to the *MPB* index; 1-min *AE* and *SME* indices; 1-min *PCN* indices: standard (*PCn*_1) and modified (*PCn*_2); 1-h terrestrial VLF activity index *Sgr*, 1-min Pi2 activity index of *Wp* pulsations. (b) Regional geomagnetic indices for the 2015/09/11 magnetic storm: *EI* electrojet intensity index, *SMEr* index; variability of the geomagnetic field in the Russian sector: *VAR*_mean – mean dB_H/dt over 15 min from all RF stations (in blue), and *VAR*_max – maximum dB_H/dt over 15 min from all RF stations (in red). Vertical cyan lines indicate the onset of substorms according to the *MBP* index.



(a)

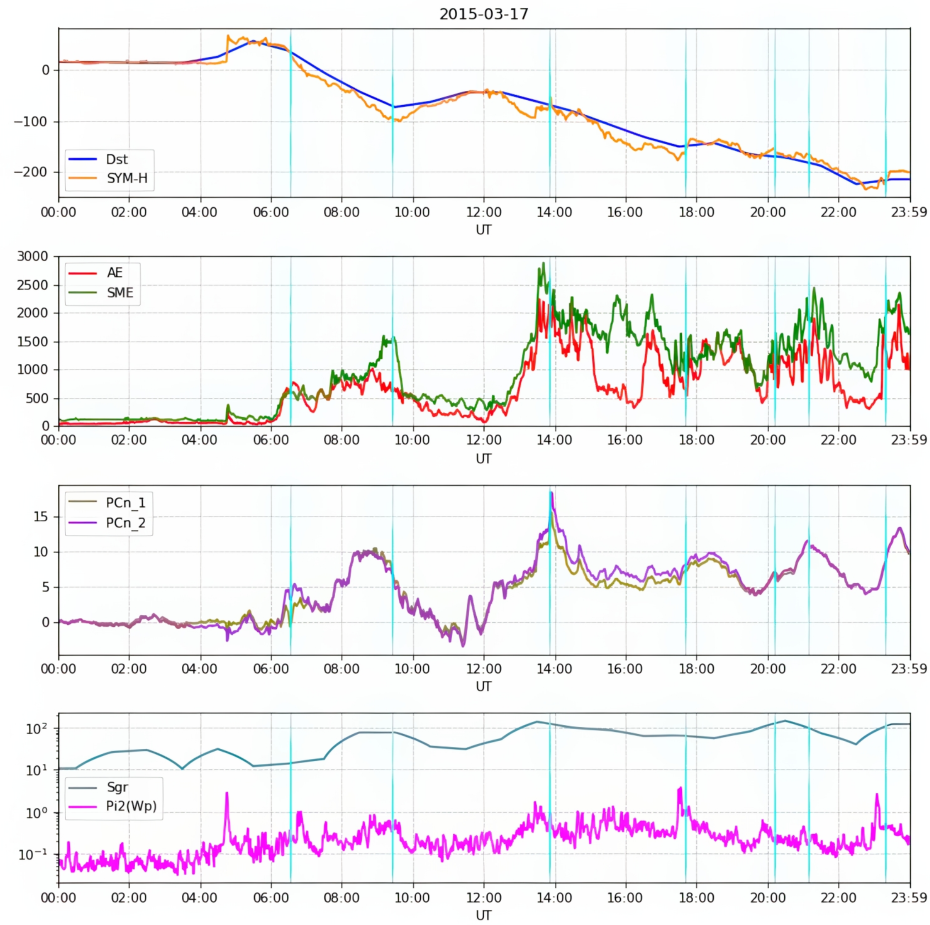


(b)

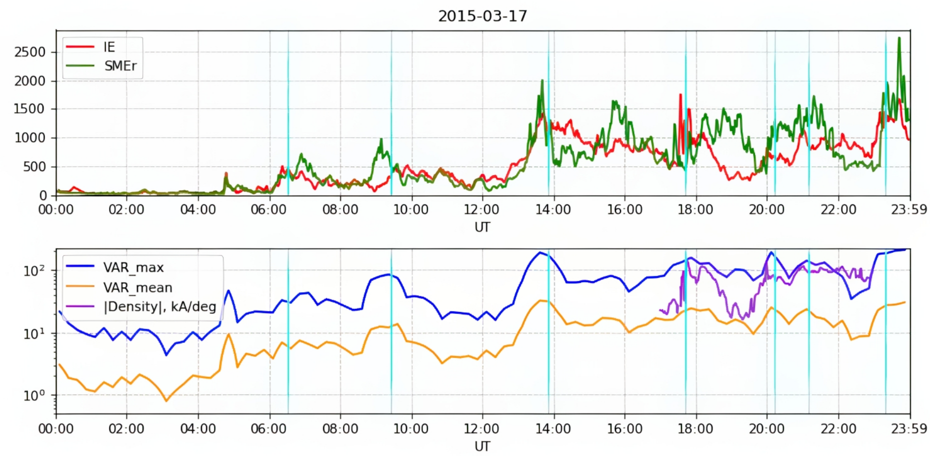
Figure 4. (a) Planetary geomagnetic indices for magnetic storm 2015/06/23. (b) Regional geomagnetic indices for the magnetic storm 2015/06/23. Labels are the same as in Figure 3.

at ∼ 18 UT is clearly evident in the *PCN* and *Pi2*(*Wp*) indices, but not in the *AE* or *SME* indices.

The regional indices are shown in Figure 5b. Compared to the *SME* and *AE* indices, the *SME-R* shows a smaller number of activations because part of the substorms develops in a different sector of local time.



(a)



(b)

Figure 5. (a) Planetary geomagnetic indices for magnetic storm 2015/03/17. (b) Regional geomagnetic indices for the magnetic storm 2015/03/17. Labels are the same as in Figure 3.

As in the events discussed above, the variations of the *VAR*-max index go almost synchronously with the variations of the *VAR*-mean index. Each amplification of *VAR* variability corresponds to an increase in *SME-R*, but no unambiguous relationship between the magnitude of amplifications of both indices is observed. The variations of the $\mathbf{J}_W$ index (for the interval 17:00 – 23:00 UT) coincide well with the variations of the *EI* index.

Information Resources for Testing and Dissemination of the Regional Geomagnetic Index

Existing indices are scattered over Internet resources and are presented in different formats. For free distribution of test versions of new indices and their comparison with standard indices, a specialized FTP site ftp://indexguest:indexguest@imagftp.gcras.ru/ (password indexguest) for downloading data has been created. The database posted on the site is constantly expanding. Submissions include:

- Quick-Look pictures of magnetograms of all Russian stations (X-component). Samples of pictures are given in Figure 5.
- combined Quick-Look pictures of all indices. Samples of the combined picture with all indices are given in Figures 3–5.
- daily files, including both standard indexes and new indexes, in plain text multi-column CSV format.

For the convenience of the researcher, a unified database of geomagnetic indices has been created, including:

1-min indices

- *SYM-H*;
- *AE*, *AU*, *AL*;
- *PCN*, *PCS*, *PCN-n*, *PCS-n*;
- *SME*, *SML*, *SMU*;
- *SME-R*, *SML-R*, *SMU-R*;
- *IU*, *IL*, *IE* (with the original 10-sec data averaged to a unified 1-min time step).

1-hour indices

- *Dst*;
- *AE*, *AU*, *AL*;
- *ULF* index *Sgr*.

15 min indices

- mean(dB_H/dt), max(dB_H/dt).

For a more complete characterization of space weather conditions, in addition to the set of geomagnetic indices described above, one should use the OMNI interplanetary environment database (https://omniweb.gsfc.nasa.gov/) containing 1-min values of solar wind and interplanetary magnetic field parameters.

Discussion of Results

The comparative analysis of the composite plots of the geomagnetic indices allowed us to draw the following preliminary conclusions.

As a rule, the *SME* index responds more clearly to substorms than the *AE* index. Therefore, its use for describing the global auroral activity becomes preferable. The hourly average *Dst* index smoothes the variations of the *SYM-H* index, especially the extreme values. The *AE* index, in comparison with the *SME* index, can underestimate the maximum magnitudes of disturbances at unfavorable positions of WTS and standard observatories. The use of *SME-R* index instead of *AE* allows excluding from consideration the substorms developing outside the Russian sector.

To date, there is no index adequately describing substorm activity. First of all, this is due to the fact that no clear generally accepted definition of a substorm and its onset has been found, and no formalized criterion for distinguishing substorms from pseudo-substorm activations has been found. Since the explosive development of a substorm is a complex process evolving both in time and space, rare networks of stations can incorrectly detect the onset of a substorm. Therefore, the existing algorithms for automatic characterization of substorms by geomagnetic indices give contradictory results: while the SOPHIE algorithm registers ∼ 8 intensifications per day, the *MBP* index – ∼ 10 intensifications, the algorithm [*Borovsky and Yakymenko*, 2017] identifies ∼ 2 substorms per day. The SuperMAG catalog of inferred substorm onset contains a large number of auroral intensifications, not all of which actually correspond to substorm onset. More convincingly, substorm onset can be determined by analyzing several complementary indices – *AL*, *SML*, *MDI*, and *Wp*.

Geomagnetic indices can be very useful in the search for electromagnetic precursors of earthquakes and volcanic eruptions [*Surkov and Pilipenko*, 2016]. The use of the *ULF* index can easily separate local geomagnetic noise anomalies caused by fracture processes in the Earth's crust from planetary disturbances of magnetosphere-ionosphere origin [*Currie and Waters*, 2014]. For example, the *Wp* index was used to show the magnetospheric origin of harmonic geomagnetic signals, which were taken as precursor phenomena before earthquakes [*Kosterin et al.*, 2015].

The calculation of the intensity of the western auroral electrojet from the IMAGE profile data diverges in some events from the regional *EI* index constructed from the same data. The possible reason for the discrepancy, such as the difference in algorithms, remains to be clarified.

An important question – how the *SME-R* index depends on the number of stations – remains unclear. In this version, low-latitude stations ($\Phi < 40°$) are excluded from the calculations. The influence of polar stations ($\Phi > 70°$) on the index values remains to be studied. Also, the stations in Alaska and Finland bordering the territory of the Russian Federation were not taken into account.

It is more correct to connect the study of local geomagnetic and ionospheric perturbations with the regional indices rather than with the planetary indices. For example, to study the possible influence of magnetic storms on the seismicity of the Russian sector of Central Asia, either the world catalog of sudden onset SC storms or planetary geomagnetic indices were used [*Sobolev et al.*, 2001]. It is more correct to use the regional Russian indices described above for these tasks.

Although the variability of the geomagnetic field characterized by the *VAR* and *VAR*-max indices increases during the periods of substorm activity, but the magnitude of the increase is not directly related to the value of the auroral indices *AE* or *SME*. Therefore, the use of existing standard indices is not sufficient for building adequate models of GIC in the Russian power systems, but it is necessary to develop indices such as *SME-R* and *VAR*. Of course, to control magnetic variations near a particular transmission line, it is preferable to use data from a nearby magnetometer. However, it is unrealistic to place a magnetometer at each technological system, so the use of regional geomagnetic indices is a more realistic approach. Approbation of new indices for the construction of statistical models (regression, neural network, etc.) to estimate the possible magnitude of GIT in power lines in the northeast of the Russian Federation will be carried out in the subsequent work.

Conclusion

In modern society, the problem of modernization of methods for processing and effective interpretation of global and regional geomagnetic data in decision support systems is quite acute, which is confirmed by item 19 "Technologies for monitoring and forecasting of environmental conditions, prevention and elimination of its pollution" of the List of Critical Technologies of the Russian Federation.

For example, with all the variety of geomagnetic activity indices, to date there is no indicator adequately describing substorm activity, which is explained by the lack of a clear generally accepted definition of substorms and criteria capable of determining substorms against the background of pseudo-substorm activations. In addition, since the explosive development of substorms is a complex process developing both in time and space, rare networks of stations can incorrectly detect the onset of substorms.

There are also known problems with access to geomagnetic data, such as *AE*, *AU*, *AL* indexes, which greatly complicates, and in some cases excludes the possibility of working with this kind of information.

Thus, in the course of the present studies, the authors proposed a set of new geomagnetic indices, which are mainly regional modifications of the existing and well-proven indicators.

For example, it is shown that during the substorm of September 11, 2015, the *VAR*-max field variability index proposed in this paper can vary from 10 nT/m to ~ 100 nT/m. While the time course of *VAR*-mean corresponds well to that of *VAR*-max, the variability of *VAR* does not at all uniquely correspond to the magnitude of the *SME-R* index. For example, the maximum values of *VAR* and *VAR*-max are observed not at the most intense substorm at 09 UT, but at the weaker substorm at 15 UT.

It should also be noted that although the variability of the geomagnetic field characterized by the proposed *VAR* and *VAR*-max indices increases during the periods of substorm activity, but the magnitude of the increase is not directly connected with the magnitude of the auroral indices *AE* or *SME*. In this connection, we conclude that the use of existing standard indices is insufficient for building adequate models of GIC for the RF power systems, and their rethinking in the context of the *SME-R* and *VAR* indices proposed here is necessary

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