Доклади на Българската академия на науките
Comptes rendus de l'Académie bulgare des Sciences
Tome 76, No 2, 2023

SPACE SCIENCES
Space physics

INVESTIGATION OF DST VARIATIONS IN X COMPONENT AT MIDLATITUDES DURING GEOMAGNETIC STORM ON FEBRUARY 3, 2022

Rumiana Bojilova, Plamen Mukhtarov

Received on November 26, 2022
Presented by P. Velinov, Corresponding Member of BAS, on January 31, 2023

Abstract

The main idea of this study is to investigate the Dst variations in the X component of the Earth's magnetic field and their latitudinal distribution in the conditions of geomagnetic disturbance on February 3, 2022. For this purpose, data from the world database of geomagnetic observatories INTERMAGNET were used. Three sectors of geomagnetic observatories were selected: (i) Eastern Europe, (ii) Western Europe, (iii) Eastern Asia. The considered stations are located at different latitudes (GLAT) but are close to each other in longitudes (GLON). For each sector, changes in the X component were considered and Sq variations were previously removed, based on data for five quiet days determined by the Helmholtz Centre Potsdam, GFZ German Research Centre for Geosciences. The results allow proposing a methodology for filtering the variations in the X component for the considered geomagnetic observatories resulting from the geomagnetic disturbance. In the concluding part of this work, an analysis of the relationship between variations in the X component and the equatorial ring current represented by Dst is proposed. The obtained linear regression coefficients for each of the sectors show the well-known dependency, expressed in the reduction of the influence of Dst on the changes in the X component as it moves from the equator to higher northern latitudes.

Key words: Dst index, Earth magnetic field, equatorial ring current

This work was partially supported by the Bulgarian Ministry of Education and Science under the National Research Programme "Young scientists and postdoctoral students-2" approved by DCM No. 206/07.04.2022.

DOI:10.7546/CRABS.2023.02.11

Introduction. In the field of solar-terrestrial physics, one of the most current tasks is the study of the reaction of some geophysical quantities, one of which is the elements of the Earth's magnetic field on magnetic storm conditions. The definition of the concept of geomagnetic storm is a temporary disturbance of the Earth's magnetosphere caused by a solar wind shock wave and/or cloud of magnetic field that interacts with the Earth's magnetic field [1, 2]. It is well known that the influence of the ring current on the X component of the Earth's magnetic field is stronger at the equator and decreases to the pole [3–7].

A geomagnetic storm is defined by changes in the disturbance storm time index (Dst index). The Dst index estimates the globally averaged change of the horizontal component of the Earth's magnetic field at the magnetic equator based on measurements from a few magnetometer stations. During quiet periods, Dst is between +20 nT and −20 nT. A geomagnetic storm has three phases: initial, main and recovery. The initial phase is characterized by Dst increasing by 20 to 50 nT in tens of minutes. The main phase of a geomagnetic storm is defined by Dst decreasing to less than −50 nT. The duration of the main phase is typically 2–8 h. The recovery phase is when Dst changes from its minimum value to its quiet time value. The recovery phase may last as short as 8 h or as long as about 7 days. The size of a geomagnetic storm is classified based on the Dst values, namely: moderate: $-50 > \text{Dst} > -100$ nT, strong: $-100 > \text{Dst} > -200$ nT, severe: $-200 > \text{Dst} > -350$ nT, great: $\text{Dst} \geq -350$ nT [8, 9].

Another geophysical parameter that is used to characterize the magnitude of geomagnetic storms is Kp index. The planetary Kp index is 3 hourly and is determined by 13 geomagnetic observatories located between 44° and 6° in both hemispheres of the Earth. The Kp value, which is an estimate of changes in the horizontal component of the Earth's magnetic field, is denoted by an integer value in the range from 0 to 9. The following scale was adopted to evaluate the strength of the geomagnetic storm according to the Kp index: i) Kp about 5 – Minor (G1); ii) Kp about 6 – Moderate storm (G2); iii) Kp about 7 – Strong storm (G3); iv) Kp about 8 – Severe storm (G4); v) Kp about 9 – Extreme storm (G5) [10–12].

Another type of disturbance in the Earth's magnetic field besides geomagnetic storms are substorms. There are several main differences between the two events: i) geomagnetic storms can last up to several days, while substorms last up to several hours; ii) unlike geomagnetic storms, which can be observed from anywhere on Earth, substorms are concentrated primarily in the polar regions; iii) geomagnetic storms inject a large number of ions into the outer radiation belt, while substorms do not inject many particles into the radiation belt; and iv) the occurrence of geomagnetic storms is once or twice a month during solar cycle maximum and several times a year during solar minimum, while substorms are relatively frequent – often several events occurring only a few hours apart. Substorms can be more intense and occur more frequently during a geomagnetic storm when one substorm may start before the previous one has been completed.

The source of the magnetic disturbances observed at the Earth's surface during geomagnetic storms is the ring current, whereas the magnetospheric substorms are associated with the release of a large amount of energy in the magnetospheric tail. A typical current system forms, named substorm current wedge, which provokes perturbation of the Earth magnetic field, namely negative bays in the X component at auroral latitudes and positive bays at midlatitudes [13,14]. The sources of magnetic disturbances observed on the ground during substorms are electric currents in the ionosphere at high latitudes [15]. Hence the importance of studying the behaviour of various geophysical parameters in the conditions of geomagnetic storms or substorms for Space Weather science is evident.

Influence of geomagnetic storms on the ionosphere. As it was mentioned, geomagnetic disturbances have a significant impact on the electron density of the ionosphere, which in turn finds practical application in various types of communication and navigation systems [16]. The knowledge of the variations of the components of the Earth's magnetic field can serve to estimate the spatial variation of the field and its response to influences of solar origin [17]. On the other hand, tracking the influence of the equatorial ring current on the field components can be used in the analysis to justify the ionospheric response during geomagnetic storms [18–20].

Everything described so far also illustrates the importance of the research carried out in the present work, namely tracking the spatial distribution of variations in the X component due to the Dst variations of the Earth's magnetic field in the case of the geomagnetic storm that occurred on February 3, 2022.

Data. In the present study data of the geomagnetic activity indices, Dst and Kp are used from the Goddard Space Flight Center (`https://omniweb.gsfc.nasa.gov/`); the values of Bz-component of the Interplanetary Magnetic Field (IMF) are taken from the same webpage. The data for the X component of the Earth's magnetic field for all stations are obtained from the INTERMAGNET database (`https://www.intermagnet.org/data-donnee/dataplot-eng.php#`).

Results. The main idea of the present investigation is to trace the spatial distribution of variations caused by the equatorial ring current. The influence of the geomagnetic storm presented by the Dst index behaviour on the X component, is named further Dst variation. To evaluate the Dst variation at individual stations, they were divided into three sectors (see Table 1).

For this purpose, stations close to each other in latitude, longitude and inclination were selected. Based on these three areas, the analyses are made and the spatial influence of Dst variations is determined. The north-south component of the interplanetary magnetic field (Bz) is the most important ingredient of the interplanetary conditions for auroral activity. When the north-south component (Bz) of the interplanetary magnetic field is oriented southward, it will connect with the Earth's magnetosphere which points northward. Figure 1 (bottom panel) shows the Bz component of the interplanetary magnetic field (IMF).

Table 1

Individual regions of geomagnetic observatories used in the present work, namely: i) Eastern Europe (top sector), ii) Western Europe (middle sector), and iii) Eastern Asia (bottom sector)

	Code	Name	GLAT	GLON	MLAT	MLON	INCL
i)	NUR	Nurmijarvi	57.70	24.70	55.90	113.20	72.13
	BOX	Barox	58.03	38.97	53.30	124.10	73.15
	BEL	Belsk	51.84	20.79	50.20	105.20	67.92
	GCK	Grocka	44.30	20.77	43.30	102.40	61.45
	PAG	Panagjurishte	42.52	24.18	40.70	105.00	59.96
	PEG	Pedeli	30.08	23.93	36.40	103.70	43.62
ii)	LER	Lerwick	60.13	−1.18	62.00	89.00	72.68
	ESK	Eskdalemuir	55.32	−3.20	57.80	83.80	69.35
	HAD	Hartland	51.00	−4.48	53.90	80.20	65.88
	DOU	Dourbes	50.10	4.60	51.40	88.90	65.55
	BFO	Black Forest	48.33	8.33	49.10	88.20	64.25
	EBR	De L'Ebre	40.82	0.49	43.20	81.30	55.92
	SFS	San Fernando	36.67	5.95	40.10	73.20	51.16
	TAM	Tamanrasset	22.79	5.52	24.70	81.80	26.93
iii)	PET	Paratunka	52.97	158.25	46.60	222.90	65.09
	KHB	Khabarovsk	47.61	134.69	39.20	203.60	63.69
	MMB	Memembetsu	43.90	144.20	35.40	211.30	58.14
	KAK	Kakioka	36.23	140.18	27.40	208.80	50.10
	KNY	Kanoya	31.42	130.88	21.90	200.80	45.56

The graph of Dst (middle panel) shows that the main phase of the geomagnetic storm begins at about 2 UT on February 3. From this moment until about 10 UT, a sharp decrease of Dst and of Bz, (see Fig. 1, middle and bottom panels) and a corresponding increase in Kp (see Fig. 1, upper panel) are observed. At 2 UT on February 3, the Bz component is seen to start to have values below 0 (see Fig. 1, bottom panel). At the same time, Dst has negative values (see Fig. 1, middle panel), while Kp begins to increase smoothly and exceeds the defined criterion for quiet conditions. Maximum storm manifestation is observed in all three quantities between 8 UT and 10 UT. Dst reaches about −75 nT, determining this storm as moderate by the Dst classification. The Bz component has negative values reaching less than −15 nT in the hours between 8 UT and 10 UT (when it is the maximum of Kp and the minimum of Dst), which allows the coupling between the IMF and the Earth's magnetosphere. The maximum value of Kp $> 5^+$ (Minor storm by Kp index classification) reached around 10 UT on February 3, 2022. At the same time, in the main phase of the storm, the Dst index has a value reaching almost −80 nT. Positive Bz values are observed around 12 UT on February 3, indicating that the coupling is ending. The recovery phase continues from 12 UT to the end of the day, when Dst becomes 0 (its value before the disturbance) and Kp reaches a minimum.

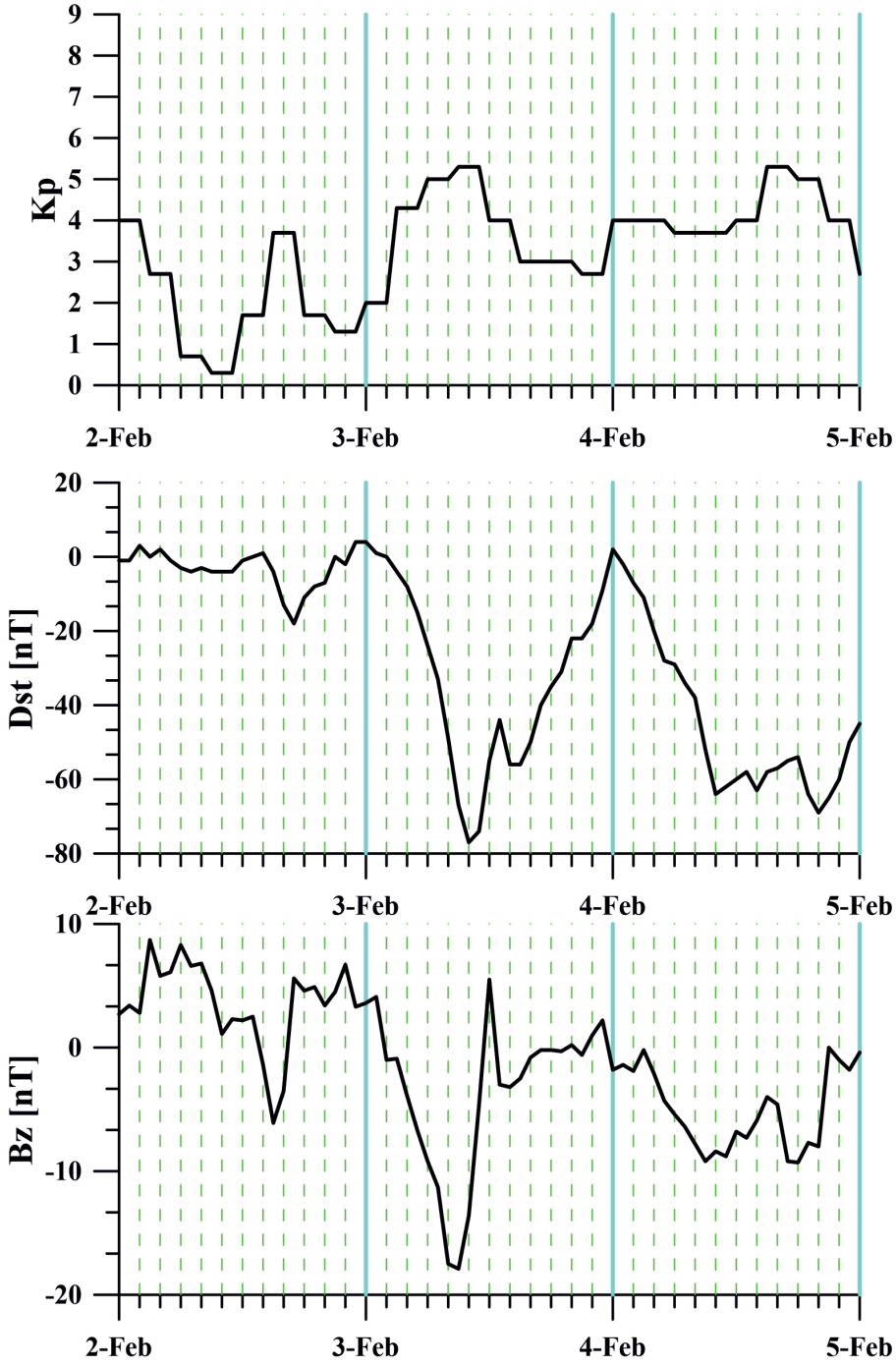


Fig. 1. Parameters describing the geomagnetic storm: (top panel) 3-hourly Kp-index; (middle panel) Dst index and (bottom panel) Bz component of IMF for the period 2–5 February 2022

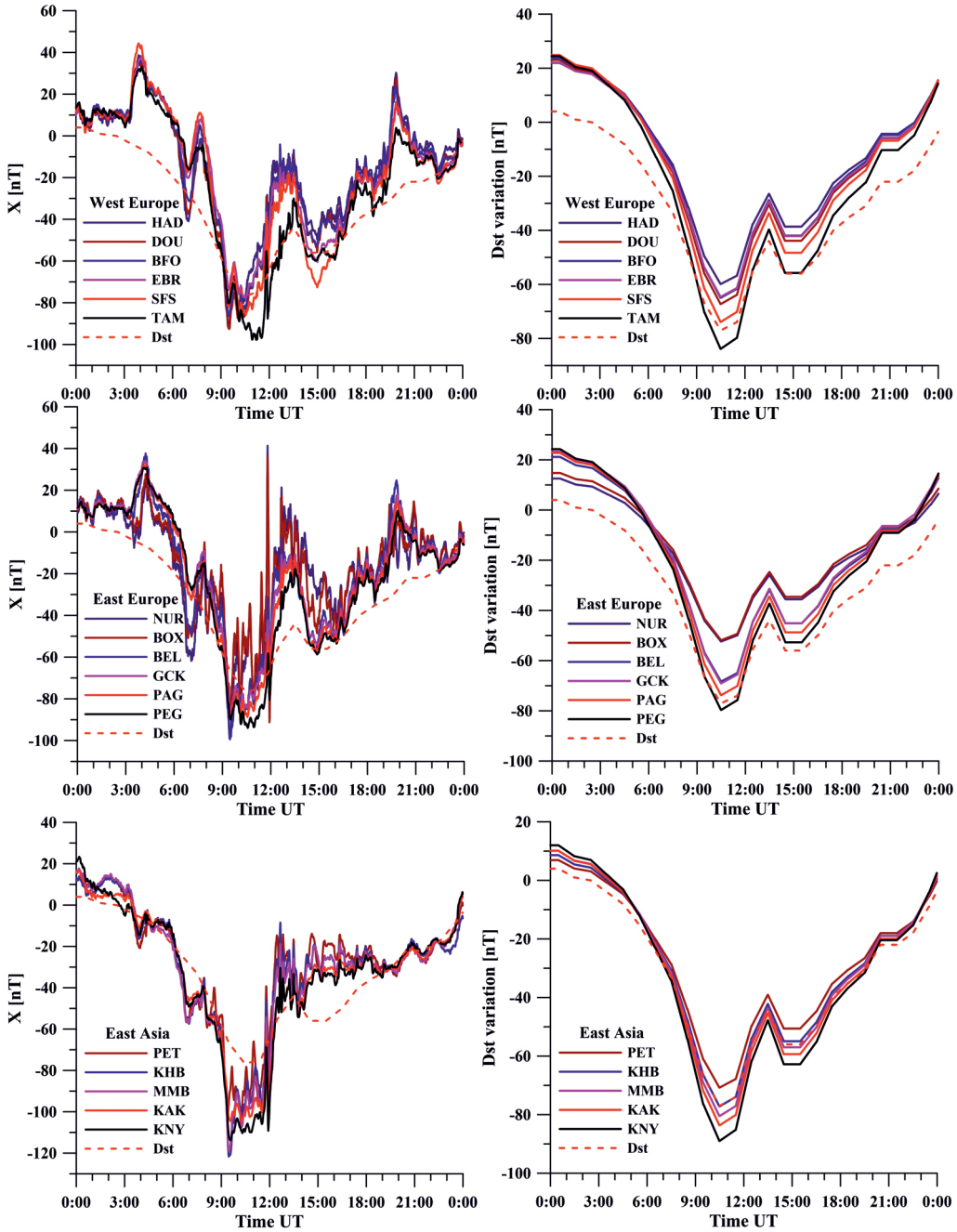


Fig. 2. Left panel – Behaviour of the X component of the Earth's magnetic field for different regions (raw data); Right panel – Influence of the equatorial ring current on individual regional stations (Dst variation)

Figure 2 (left panel) shows the raw data variation of the X component of the Earth's magnetic field for the period from 00 UT to 24 UT on February 3, 2022 and the Dst variations with the quiet conditions removed (five days defined by GFZ German Research Centre for Geosciences). Accordingly, the top panel presents the Western Europe region; middle panel – Eastern Europe region and bottom panel Eastern Asia. The graph shows the influence of the equatorial ring current in the behaviour of the X component for each of the considered regions. To assess this influence, Fig. 2 (right panel) shows the values of Dst variations for each station of the respective region, obtained by linear regression between Dst and the midlatitude magnetograms shown in Fig. 2. It is clear from Fig. 3 that with increasing latitude the influence of Dst decreases, which can be used to explain the basic physical mechanisms influencing the response of a number of atmospheric processes on Earth.

Based on the obtained raw data in each station of the three selected regions (see Fig. 2, left panel), a regression based on the method of least squares was made between the raw values of X component of the Earth's magnetic field and the Dst. The regression coefficients presented in Fig. 3 characterize the magnitude of influence of the equatorial ring current on the midlatitude variations of the X component in individual regions. Station TAM (Tamanrasset) has the highest coefficient of linear regression and station NUR (Nurmijarvi) has the lowest. Station TAM is the lowest latitude station on the list, while station NUR is the most northerly on the list. From above, together with the graph, it can be see that as you move away from the equator and go north, the influence of the equatorial ring current decreases.

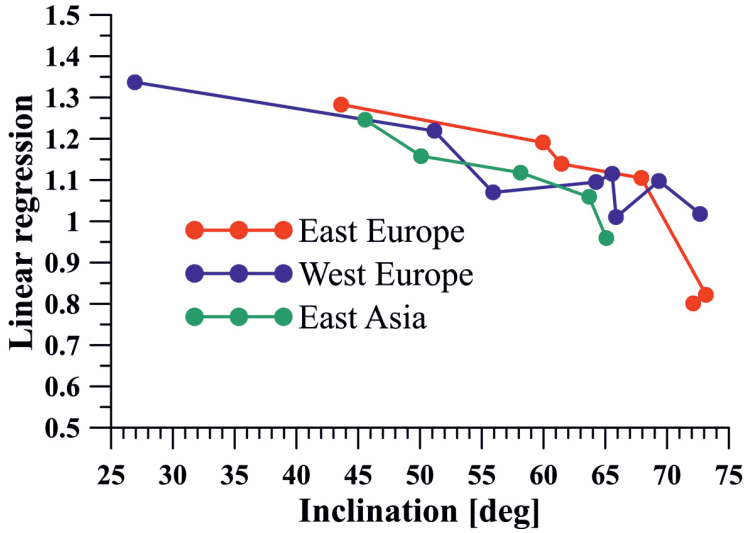


Fig. 3. Linear regression coefficient between midlatitude stations and equatorial index Dst

Conclusion. The Dst variations in the X component of the Earth's magnetic field and their latitudinal distribution in the conditions of geomagnetic disturbance on February 3, 2022 were studied on the basis of data from geomagnetic observatories divided into three regions: i) Eastern Europe, ii) Western Europe, and iii) Eastern Asia. The influence of the equatorial ring current on individual regional stations, obtained by linear regression by the method of least squares between Dst and the midlatitude magnetograms, is illustrated. The results show that with increasing of the latitude the influence of Dst decreases. A regression analysis was made between the values from the stations and the equatorial ring current. The analysis showed that the influence of the equatorial ring current weakens moving away from the equator. The proposed methodology makes it possible to separate the influence of the ring current from the currents in the polar oval. The results of the present study have implications in the field of solar-terrestrial relationships and their physical mechanisms.

REFERENCES

[1] Gonzalez W. D., J. A. Joselyn, Y. Kamide, H. W. Kroehl, G. Rostoker et al. (1994) What is a geomagnetic storm?, J. Geophys. Res. Space Phys., **99**(A4), 5771–5792.

[2] Piddington J. H. (1960) Geomagnetic storm theory, J. Geophys. Res., **65**(1), 93–106.

[3] Iyemori T. (1990) Storm-time magnetospheric currents inferred from mid-latitude geomagnetic field variations, J. Geomagn. Geoelectr., **42**(11), 1249–1265.

[4] Rastogi R. G., W. Winch (2001) Longitudinal effects in geomagnetic disturbances at mid-latitudes, Earth Planets Space, **53**(10), 969–979.

[5] Iyemori T., D. R. K. Rao (1996) Decay of the Dst field of geomagnetic disturbance after substorm onset and its implication to storm-substorm relation, Ann. Geophys., **14**, 608–618.

[6] Feldstein Y. I., A. Grafe, L. I. Gromova, V. A. Popov (1997) Auroral electrojets during geomagnetic storms, J. Geophys. Res. Space Phys., **102**(A7), 14223–14235.

[7] Häkkinen L. V., T. I. Pulkkinen, H. Nevanlinna, R. J. Pirjola, E. I. Tanskanen (2002) Effects of induced currents on Dst and on magnetic variations at midlatitude stations, J. Geophys. Res. Space Phys., **107**(A1), SMP-7.

[8] Loewe C. A., G. W., Prölss (1997) Classification and mean behavior of magnetic storms, J. Geophys. Res. Space Phys., **102**(A7), 14209–14213.

[9] Temerin M., X. Li (2015) The Dst index underestimates the solar cycle variation of geomagnetic activity, J. Geophys. Res. Space Phys., **120**(7), 5603–5607.

[10] Rostoker G. (1972) Geomagnetic indices, Rev. Geophys., **10**(4), 935–950.

[11] Boberg F., P. Wintoft, H. Lundstedt (2000) Real time Kp predictions from solar wind data using neural networks, Physics and Chemistry of the Earth, Part C: Solar, Terrestrial & Planetary Science, **25**(4), 275–280.

[12] Tassev Y., P. I. Velinov, D. Tomova, L. Mateev (2017) Analysis of extreme solar activity in early september 2017: G4–severe geomagnetic storm (07–08.09) and GLE72 (10.09) in solar minimum, C. R. Acad. Bulg. Sci., **70**(10), 1437–1444.
[13] Matzka J., C. Stolle, Y. Yamazaki, O. Bronkalla, A. Morschhauser (2021) The geomagnetic Kp index and derived indices of geomagnetic activity, Space Weather, **19**(5), e2020SW002641.
[14] McPherron R. L. (1979) Magnetospheric substorms, Rev. Geophys., **17**(4), 657–681.
[15] Rostoker G. (1996) Phenomenology and physics of magnetospheric substorms, J. Geophys. Res. Space Phys., **101**(A6), 12955–12973.
[16] Gonzalez W. D., B. T. Tsurutani, A. L. Clúa de Gonzalez (1999) Interplanetary origin of geomagnetic storms, Space Sci. Rev., **88**(3), 529–562.
[17] Bojilova R., P. Mukhtarov (2020) Forecasting the propagation of HF radio waves over Bulgaria. In: Int. Conf. on Environmental Protection and Disaster RISKs, Springer, Cham, 309–324.
[18] Guineva V., R. Werner, I. Despirak, R. Bojilova, L. Raykova (2021) Mid-latitude positive bays during substorms by quiet and disturbed conditions, C. R. Acad. Bulg. Sci., **74**(8), 1185–1193.
[19] Bojilova R., P. Mukhtarov (2019) Response of the electron density profiles to geomagnetic disturbances in January 2005, Studia Geophys. et Geod., **63**(3), 436–454.
[20] Bojilova R., P. Mukhtarov (2019) Response of total electron content to the three G4–severe geomagnetic storms in January 2005 associated with cosmic ray events GLE 68 and GLE 69, C. R. Acad. Bulg. Sci., **72**(9), 1244–1250.

National Institute of Geophysics,
Geodesy and Geography
Bulgarian Academy of Sciences
Akad. G. Bonchev St, Bl. 3
1113 Sofia, Bulgaria
e-mails: rbojilova@geophys.bas.bg
engpjm@abv.bg