Sources of Geomagnetic Activity at Mid-Latitudes: Case Study – European Observatories

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Abstract The geomagnetic activity is a result of the interaction of the magnetosphere-ionosphere system with the solar wind and with the heliospheric magnetic field. It is described by means of geomagnetic indices, specifically designed as proxies for several current systems that form in that environment, such as Dst, for the magnetospheric ring current, and AE, for the ionospheric auroral electrojet, or reflecting the general disturbed behavior of the geomagnetic field at midlatitudes (the aa index) or at planetary (Kp, Ap) scales. The present paper investigates the contribution of the ring current and auroral electrojet variability to the geomagnetic activity at local scale, on data from 29 European observatories.

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Keywords: magnetic field, Dst magnetospheric ring current, AE ionospheric auroral electrojet

Introduction

Geomagnetic activity has long been known to be correlated with solar activity (Snyder et al., 1963; Russel and McPherron, 1973; Garret et al., 1974; Feyman and Crooker, 1978; Du et al., 2011); it results from variable current systems formed in the magnetosphere and ionosphere, such as the magnetospheric ring current and the ionospheric auroral electrojet, which are strongly modulated by solar activity via the interaction of the magnetosphere with solar wind and heliospheric magnetic field (Feyman, 1980; Legrand and Simon, 1989a, b; Fares Saba et al., 1997; Demetrescu and Dobrica, 2008; Du et al., 2011). Legrand and Simon (1989a) classified the geomagnetic activity in four classes: the magnetic quiet activity, the recurrent activity, the fluctuating activity, and the shock activity. At mid-latitude, the geomagnetic activity is sensitive both to the auroral phenomena (particle precipitations, substorms and auroras) which are at the origin of the auroral electrojet activity, and to the magnetospheric ring current which is the source of the geomagnetic storms (Fares Sabba et al., 1997; Legrand and Simon, 1989a, b). Two geomagnetic indices, namely AE and, respectively, Dst, are specifically designed as proxies for the two current systems.

The AE index is an index related to the auroral electrojets. It was introduced by Davis and Sugiura (1966) as a measure of activity in the global electrojets in the auroral zone. This index provides an overall measure of the horizontal current strength in the northern auroral zone. Large deviances from a nominal daily baseline in the AE index are called magnetospheric substorms.

The Dst index (Sugiura, 1964) represents the axially symmetric disturbance magnetic field at the dipole equator on the Earth's surface. Major disturbances in Dst index are negative, indicating decreases in the geomagnetic field. These field decreases are mainly produced by the magnetosphere equatorial current system, called the ring current. Positive variations in Dst are mainly caused by magnetopause currents when the magnetosphere is compressed during solar wind pressure increases.

In the present paper we assess the contribution of the two current systems – the ring current and the auroral electrojet – to the geomagnetic activity as recorded at the European network of geomagnetic observatories.

Data and method

One minute averages of the northward geomagnetic component, X, in the time interval 1-10 August 2010, from 29 European geomagnetic observatories were used. The time interval was chosen so as to encompass a moderate geomagnetic storm, accompanied by substorms, and its recovery phase. The geographical distribution of observatories is given in Fig. 1 and their geomagnetic coordinates in Table 1. Data were downloaded from the Intermagnet website http://www.intermagnet.net. In Fig. 2, we give, as an example, the recorded X at the Romanian observatory, Surlari, IAGA code SUA, and for completeness, the recorded east and vertical components, Y and Z.

In order to infer the geomagnetic disturbance variation, SD, the solar quiet variation Sq was subtracted from the recorded data. Sq has been determined for each observatory as the average of the five quietest days of the month indicated by the website http://wdc.kugi.kyoto-u.ac.jp/cgi-bin/qddays-cgi, namely 30, 22, 21, 29, and 20 August 2010. The disturbance variation, SD, for each observatory was compared to the Dst variation by means of the correlation relationship

$$SD(t)=a+aDst(t) \qquad (1)$$

where t is the time in the interval 1-10 August 2010, that allows deriving a and a by a least squares procedure. Then the residuals (RES1(t)=SD(t) minus the calculated

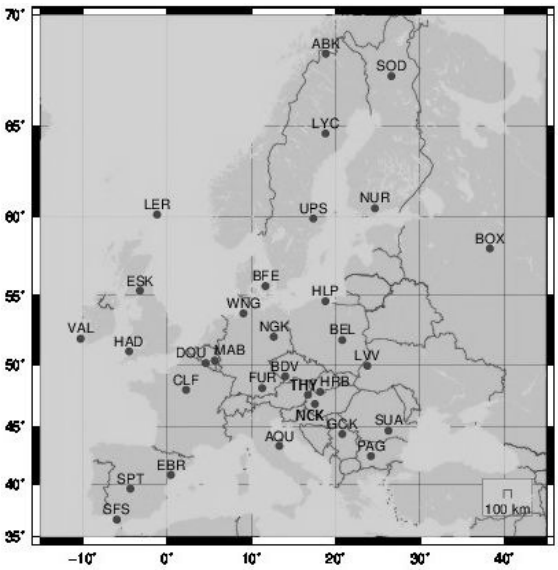

Fig. 1 Geographical distribution of geomagnetic observatories used in this study

Table 1. Geomagnetic coordinates of the 29 European Observatories

No.	Observatory	λ(degrees)	φ(degrees)
1	SFS	73.68	39.92
2	PAG	105.09	40.44
3	SUA	107.68	42.2
4	SPT	76.13	42.46
5	GCK	102.45	42.86
6	EBR	81.43	42.88
7	THY	100.19	45.84
8	HRB	101.17	46.66
9	NCK	99.68	46.68
10	FUR	96.66	48.14
11	BDV	97.65	48.55
12	CLF	85.37	49.65
13	BEL	105.18	50.06
14	DOU	88.91	51.16
15	MAB	90.06	51.17
16	NGK	97.63	51.66
17	HLP	104.59	53.06
18	BOX	123.59	53.32
19	HAD	80.17	53.6
20	WNG	94.95	53.89
21	BFE	94.81	55.25
22	VAL	74.61	55.47
23	ESK	83.66	57.52
24	NUR	113.05	57.74
25	UPS	106.16	58.35
26	LER	88.78	61.74
27	LYC	110.82	62.35
28	SOD	119.75	63.87
29	ABK	114.33	65.98

(a+aDst(t))) were compared to the AE index according to the relationship:

$$RES1(t)=b+\beta AE(t) \qquad (2)$$

The coefficients b and β are calculated by least squares and finally RES2(t) is derived (RES2(t)=RES1(t) minus calculated (b+βAE(t))), in order to evaluate the degree to which the observed geomagnetic disturbance is produced by the two sources.

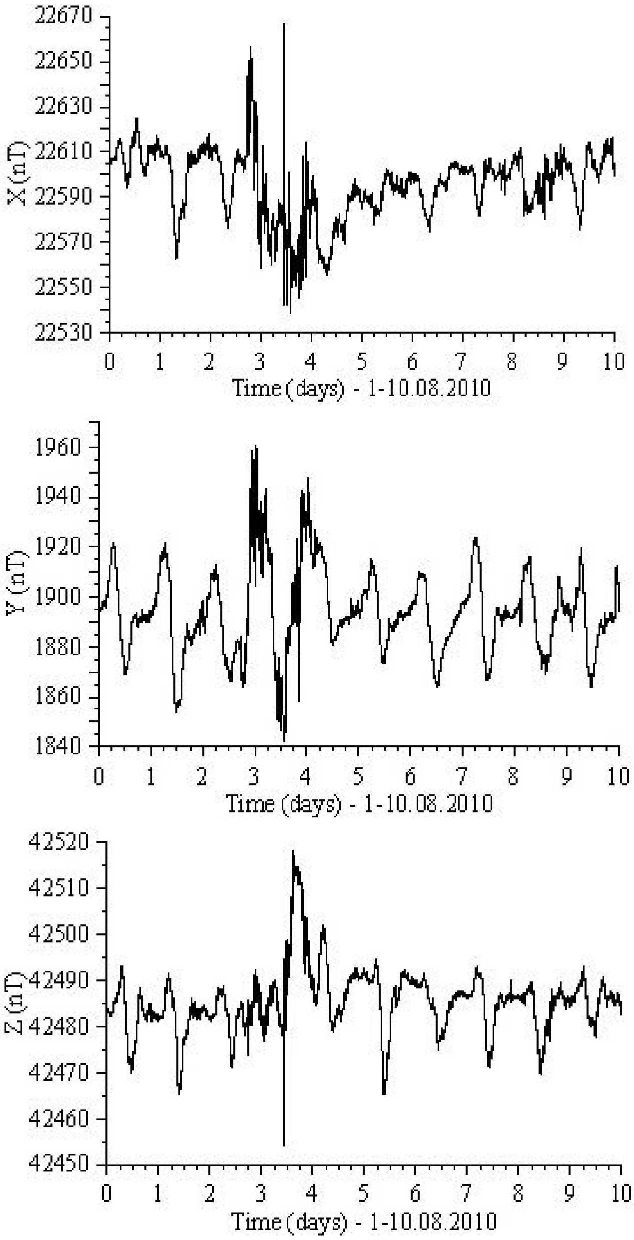

Fig.2 Recorded geomagnetic field elements at SUA in the time interval August 1-10, 2010

Results and discussion

The Sq in the study time interval for the 29 observatories is shown in Fig. 3 in local time. Generally, except for the three northernmost observatories (LYC, SOD and ABK), the curves show no longitudinal dependence, as expected. The amplitude of the daily variation is of 25-65 nT, depending on latitude.

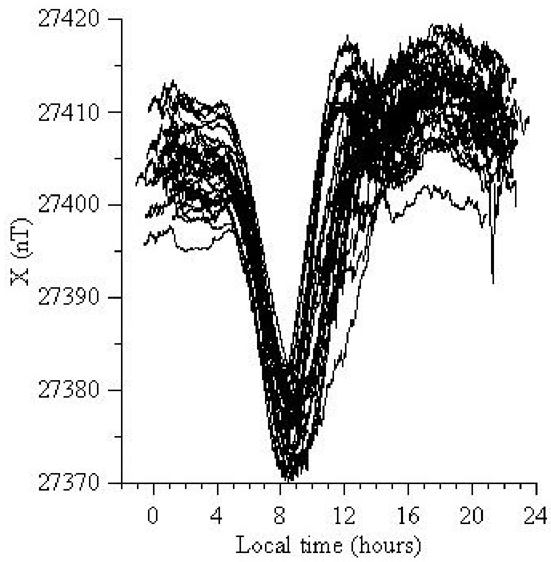

Fig.3 The Sq for August 2010 at the study observatories

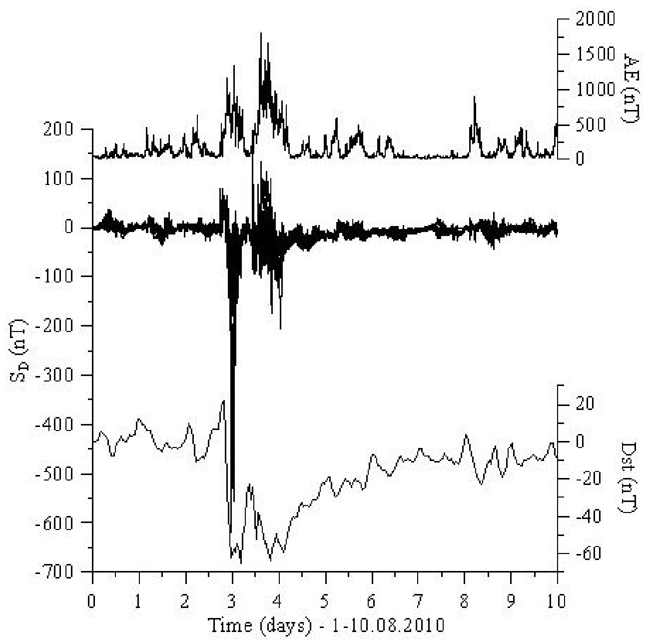

Fig.4 The disturbance variation (S_D) for the 26 mid-latitudes observatories and Dst, AE indices in the time interval August 1-10, 2010

The disturbance variation for 26 observatories (no. 1-26 of Table 1) is shown in Fig. 4, along with Dst and AE. We did not plot here the disturbances for LYC, SOD, and ABK, that reach at storm times values of -1000 nT.

The successive processing steps mentioned above are illustrated for a mid-latitude observatory (NGK) in Fig. 5. From top to bottom, we show the recorded values, Sq, S_D, Dst, RES1, AE, RES2. The Sq plot is displaced by 40 nT, for clarity. Accounting for ring-current-related variations in data reduced the amplitude range of S_D (the third panel of Fig. 5) from (-60 ÷ 60 nT) to (-40 ÷ 40 nT) for RES 1 (the fifth panel of Fig. 5). Accounting further for auroral-electrojet-related variations in RES 1, RES 2 shows an amplitude range of (0 ÷ 10 nT) (the last panel of Fig. 5). The rms S_D for the 26 sub-auroral observatories is shown in Fig. 6. The values range between 8 nT and 48 nT, the larger ones, of 30-48 nT, concerning NUR, UPS, and LER (identification number 24-26). In case of the three northernmost observatories, namely LYC, SOD, and ABK, the rms geomagnetic disturbances (not shown) is much larger, in average of 109.7 nT. By modeling the mid-latitude geomagnetic activity via Dst and AE geomagnetic indices, the rms variation drops to between 0.1 and 2.9 nT (Fig. 7); for NUR, UPS and LER, the rms of the final residuals is at most 1.3 nT. The overall reduction for 26 observatories is from 16.3 nT to 1.2 nT (93%).

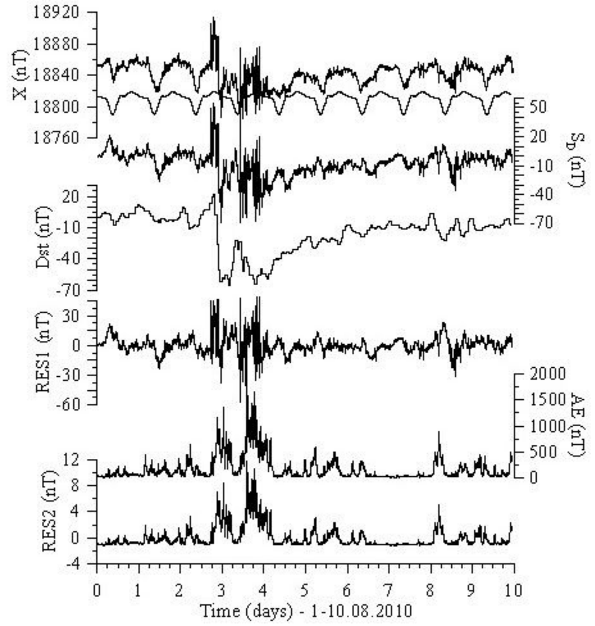

Fig. 5. Illustration of processing steps for NGK data. From top to bottom X, Sq, S_D, Dst, RES1, AE, RES2

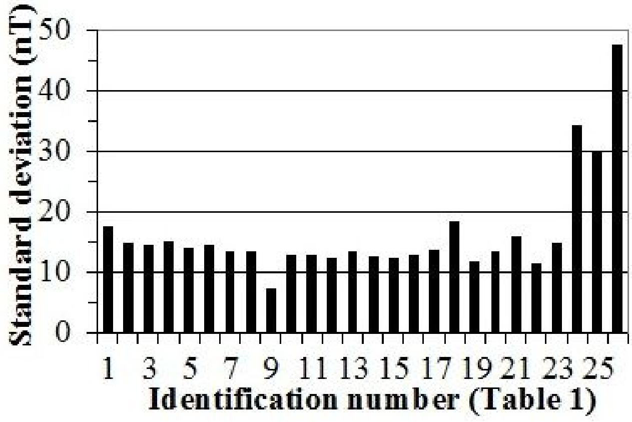

Fig. 6. The rms S_D at observatories no. 1-26 of Table 1

It is clear from these results that the magnetospheric ring current and the ionospheric auroral electrojets control the disturbed field observed at mid-latitude observatories. The results for LYC, SOD, and ABK indicate the presence of additional effects from currents in the polar cap area.

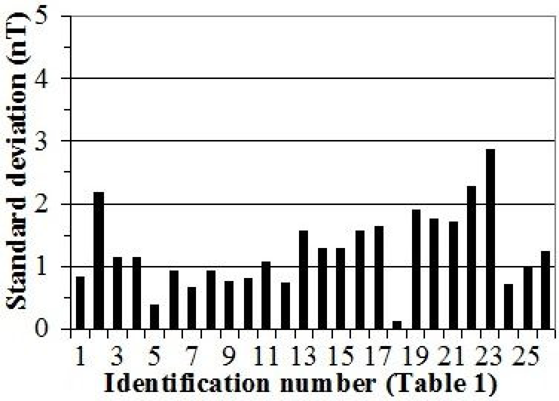

Fig. 7. The rms residual disturbances

Conclusions

We investigated, on the case of 29 European observatories distributed in a latitudinal range of between 40°N and 66°N geomagnetic latitude, the degree to which the recorded geomagnetic activity is produced by two of the external sources of the recorded variability, namely the magnetospheric ring current and the auroral electrojets. The geomagnetic indices Dst and respectively AE were used as proxies for the two current systems.

Except for three northernmost observatories (LYC, SOD, ABK) the recorded geomagnetic activity is shown to be produced entirely by the two above mentioned current systems. Successively linearly correlating the recorded geomagnetic disturbance with Dst index and the corresponding residuals with the AE index results for the 26 observatories in an overall reduction of the rms disturbance from 16.3 nT to 1.2 nT (93%). Additional effects, produced by polar cap processes, might be present in case of LYC, SOD and ABK geomagnetic observatories.

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