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Sq and sfe currents at equatorial stations along the western and eastern African sectors

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The paper describes the daily variations in the Sq and sfe induced ionospheric current at the equatorial stations of Addis-Ababa (Inclination: 1.0°; Declination: 1.5°) and M'Bour (Inclination: 9.0°; Declination: −9.3°). At Addis-Ababa, the diurnal SqH loop as well as sfe H currents aligned fairly well with the direction of declination. At M'Bour, the SqH as well as the sfe H vector were along the direction of about 30°W. Thus, in the region of an abnormally large declination at equatorial stations, the daily Sq current does not follow a direction normal to the declination.

Key words: Solar flare currents, meridional ionospheric currents.

1. Introduction

The enhancement of the daily range of the horizontal component of the geomagnetic field, H, over the equatorial electrojet belt has drawn the attention of very large number of scientists with the aim of studying the latitudinal, longitudinal, lunar, and storm-time variations of H at equatorial latitudes. Comparatively speaking, very little attention has been paid to the declination (D) or the eastward field (Y) data. The daily variations in the eastward field (Y) are much smaller than corresponding variations in the H field. Further, at most of the stations, the sensitivity of D magnetometers has been much smaller than that of the H magnetometers.

Rastogi and Stening (2002) studied in detail the solar daily and seasonal variations of the eastward geomagnetic field (Y) at all equatorial stations operating in 1958. The daily variations of Y in the Central Asian sector (Trivandrum and Addis-Ababa and Koror) showed a forenoon maximum and afternoon minimum during the June solstices and an entirely opposite variation during the December solstice. The daily variation of Y at Huancayo showed a strong daytime peak during each of the seasons.

McNish (1937) studied the direction of the solar flare current at a number of stations around the world and found it to be almost the same as the direction of the pre-flare normal daily current. Kuwashima and Uwai (1985) studied magnetic variations due to solar flare (sf) at the Japanese stations situated around the latitude of the solar quiet daily variation (Sq) focus. They showed that the solar flare effect (sfe) current vectors were aligned along the pre- disturbed current vectors at any of the stations. Rastogi *et al*. (1997) studied the sfe at the chain of nine low-latitude stations in India during the intense solar flare of 15 June 1991. The flare current direction changed with latitude in perfect coordination with the change in direction of the normal current at the time of flare onset. Thus, as regards the direction, sf current can be taken as a reference of the ionospheric current at that hour of the day.

With the availability of digital magnetograms of M'Bour and Addis-Ababa on the WDC websites it was decided to check the sfe in the X and Y fields at the two stations to confirm if the abnormal minimum of ΔY in the African sector corresponds to corresponding Sq variations. The present paper describes the results of this study.

2. Data

The coordinates and the parameters of the geomagnetic field at M'Bour (MBO) and Addis-Ababa (AAE) are given in Table 1.

It can be seen that AAE was very close to the center of the equatorial electrojet (EEJ), with an inclination of only 1°N and a declination of 1.5°E. MBO was close to the edge of the EEJ with an inclination of 9.0°N and a declination of 9.3°W. The solar flare impulses were scaled from the 1-min magnetograms downloaded from the website of WDC at Copenhagen. All of the available data from 1996 to 2003 were used for the analysis. ΔX and ΔY at any time t were taken as the deviations of the parameter from the LT value at 00:00 hour as it is assumed that there is no ionospheric current at the midnight hours. The ΔXt=Xt−Xoo, ΔYt=Yt−Yoo and the direction of the H component east of north is θ (τ=$\tan^{-1}$ΔYt/ΔXt. The daily ranges of X and Y at noon are indicated as RX and RY, respectively. The amplitude of sf-induced changes in X and Y are indicated as ΔXsfe and ΔYsfe, respectively, and the direction of the sf H field is given by θsfe=$\tan^{-1}$ (ΔYsfe/ΔXsfe).

3. Quiet-Day Solar Daily Variations of the X and Y Components

Figure 1(a) shows the yearly average solar daily variations of the X and Y component of the geomagnetic field

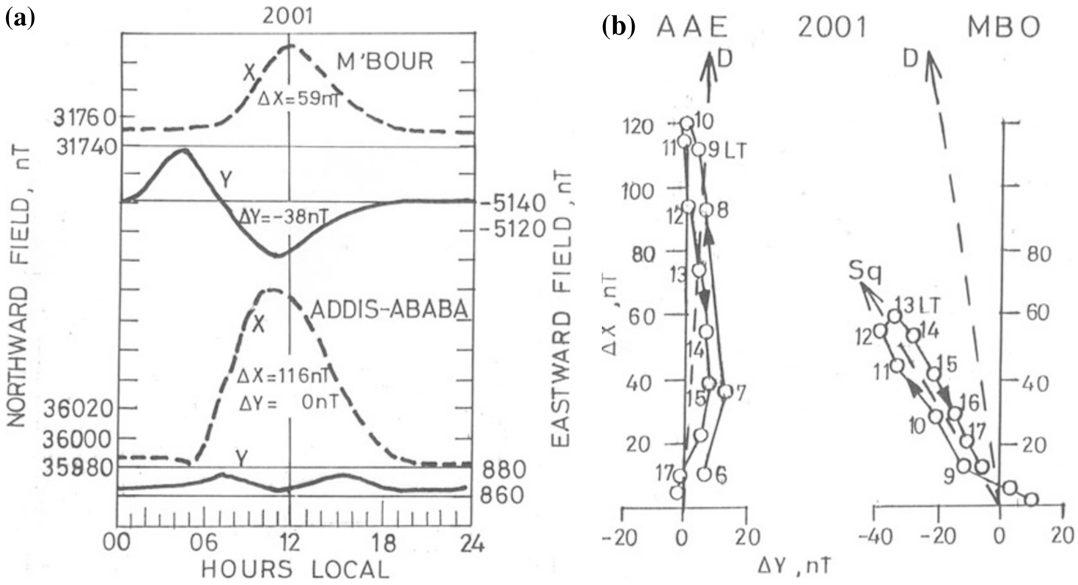

Fig. 1. (a) Yearly mean solar quiet day variations of northward (X) and eastward (Y) components of the geomagnetic field at Addis-Ababa and M'Bour for the year 2001. (b) Daily variations in the direction of the horizontal field at Addis-Ababa and M'Bour for the year 2001.

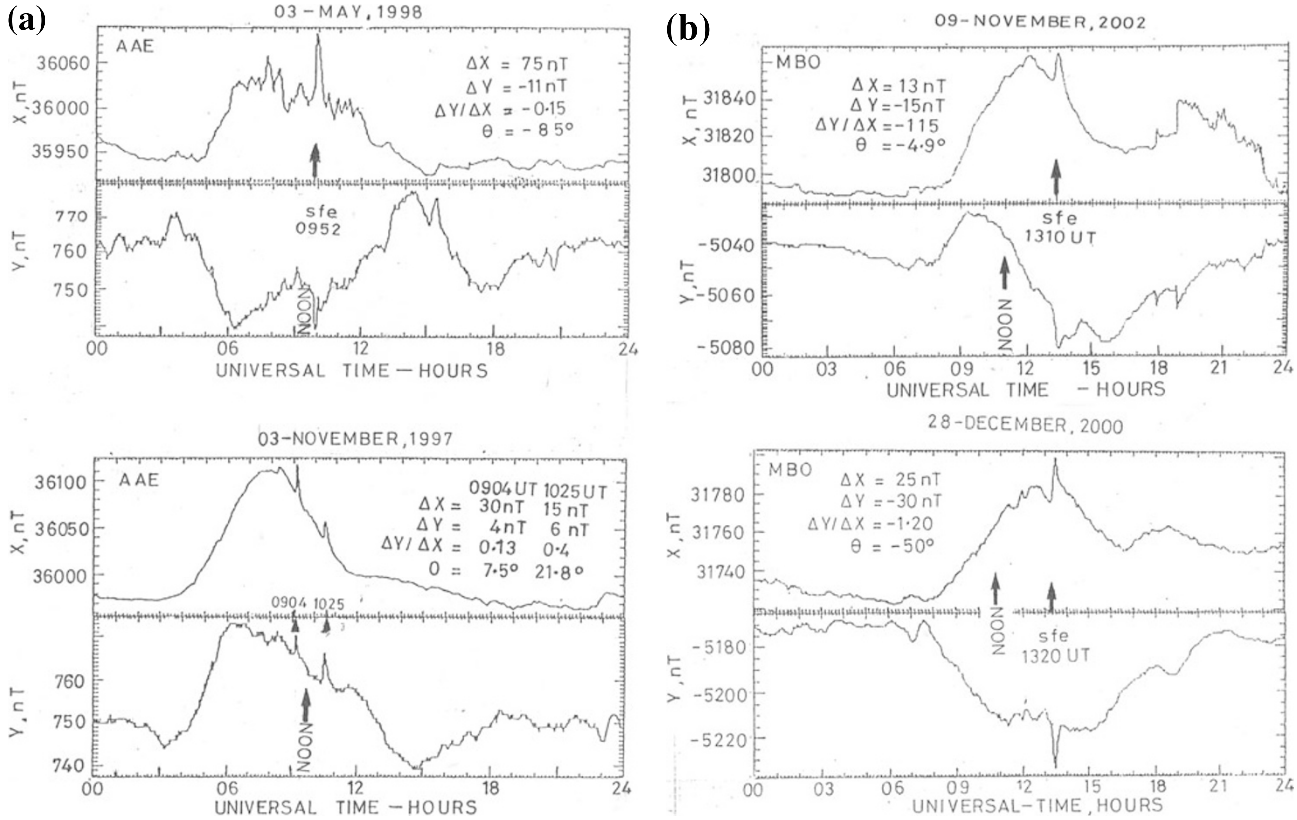

Fig. 2. (a) X and Y magnetograms at Addis-Ababa showing examples of solar flare effects on November 27, 1997 and May 08, 1998. (b) X and Y magnetograms at M'Bour showing examples of solar flare effects on December 28, 2000 and November 09, 2002.

at Addis-Ababa (AAE) and M'Bour (MBO) for 2001. The daily range of X at AAE was 116 nT with a midday maximum. The SqY at AAE showed two minor peaks in the morning and evening hours, with ΔY being almost zero at noon. The Sq X at MBO showed a midday peak of 59 nT, which is less than that of AAE because MBO is situated farther from the magnetic equator than AAE. The Sq Y at MBO showed a maximum of 40 nT at the pre-sunrise hour and a minimum of −40 nT around 11 LT. This is a very abnormal behavior compared to other equatorial stations. Kane and Trivedi (1982) showed a large mid-day minimum of the Y field at the same time as the daily maximum of the H field at Eusebio, when the dip equator was close to the station.

Table 1. Coordinates of stations used in the 2001 analysis.

Station	Addis-Ababa	M'Bour
Code	AAE	MBO
Geog. Lat. °N	9.0	14.4
Geog. Long. °E	38.8	343.0
Magnetic field X, nT	35408	31672
Magnetic field Y, nT	911	−5200
Magnetic field Z, nT	592	5092
Inclination °N	1.0	9.0
Declination °E	1.5	−9.3
Mean Y/X	+0.026	−0.164
Mid-Day Daily Range, RX, nT	116	59
Mid-Day Daily Range, RY, nT	0	−38
Range Y/Range X	0	−0.6
$\tan^{-1}$ (RY/RX)	0	−32.8
Means $\theta°$ sfe	+2.0°	−2.9°

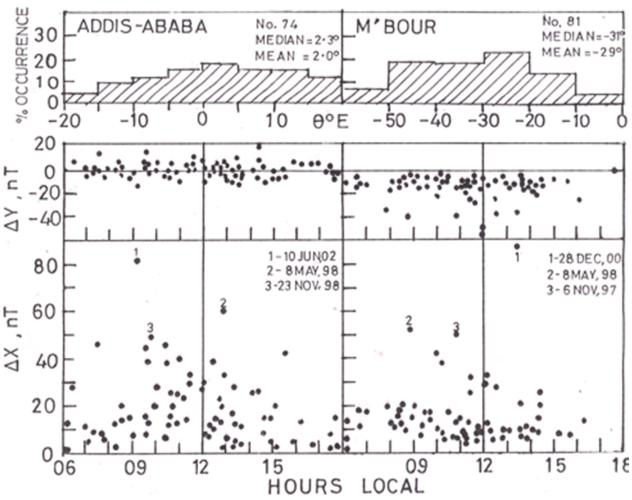

Fig. 3. Mass plots showing the amplitudes of sfe in X and Y components of the geomagnetic field and the direction of sfe H vector at equatorial stations Addis-Ababa and M'Bour.

Figure 1(b) shows the daily variation of the SqH vectors at AAE and MBO derived from the data shown in Fig. 1(a).

At Addis-Ababa, the declination is only 1.5°E, and the magnetic equator in this region is aligned fairly eastward. It is seen from the figure that the direction of the daily variation H component is also fairly aligned northward, suggesting that the equatorial electrojet current flows in the direction normal to the declination. Using an extended antenna system with a separation of 480 m (4 λ) in the north-south direction and 60 m (0.5 λ) in the east-west direction and with full correlation analysis, Rastogi *et al.* (1972) showed that the E region irregularities at Thumba are aligned along the declination (3°W) and thus the electrojet current in India flows eastward in a direction normal to declination.

M'Bour is situated in the abnormal region between Eastern Brazil and Western Africa where the magnetic equator with increasing longitude swings very much towards north of the eastward direction. The permanent declination at M'Bour was 9.3° West in 2001. It is interesting to note that the directions of the daily Sq H vectors at M'Bour deviate very wildly from the direction of permanent H (i.e., D). The direction of the H field during 1000 hours was=$\tan^{-1}$ (RY/RX)=$\tan^{-1}$ (−38/59)=−32.2°. This indicates that the ionospheric current at noon was flowing in a direction of 32° north of east or in a direction of (32-9)=23° northward of the direction of the magnetic equator. The theoretical explanation of this anomaly is still to be understood. It seems that in addition to the zonal electrojet current dictated by the abnormally large Cowling conductivity at a latitude close to the magnetic equator along a direction perpendicular to the direction of mean H field, there is additional meridional current dictated by the large declination at MBO. This further modifies the observed X and Y fields at MBO. The D is fairly small at other equatorial stations, and any effect of the meridional current is too small to be detected in average SqH variations.

4. Signatures of Magnetic Crochets on X and Y Fields

Some of the signatures of magnetic crochets on the northward (X) and eastward (Y) components of the field at the two selected stations are presented. These charts have been downloaded from the website of WDC at Copenhagen and suitably combined together. Examples of X and Y magnetograms at AAE and MBO, respectively, are shown in Fig. 2(a) and (b); these have been reformatted to bring X and Y traces close to each other.

Referring to Fig. 2(a), a solar flare was recorded at Addis-Ababa at 0952 UT (1252 LT) on May 18, 1998. The daily variational Y field had a minimum in the forenoon and a maximum in the afternoon hours. The flare had occurred when the ΔY due to Sq was −12 nT and the sfe impulses were ΔX=75 nT and ΔY=−11 nT. The ratio of ΔY/ΔX due to sfe was −0.15, corresponding to the sfe vector of 8.5°W. A set of two flares had occurred at 0904 UT and 1025 UT on November 03, 1997, when both the SqH and SqY were positive with respect to the midnight value; the direction of the sfe vector was 7.5°E for the first sfe and 21.8°E for the second one.

Referring to Fig. 2(b) for M'Bour, a sfe had occurred at 1310 UT (1210 LT) on November 09, 2002 when the SqH was positive and SqY was negative. The sfe impulses were ΔX=13 nT, ΔY=−15 nT, yielding ΔY/ΔX=−1.15, which corresponds to the direction of the sfe H field being 49° west of north. Another sfe at MBO had occurred at 1320 UT (1220 LT) on December 28, 2000 when again SqH was positive and SqY was negative. The sfe impulses were ΔX=25 nT, ΔY=−30 nT, yielding ΔY/ΔX=−1.20, which corresponds to the sfe H vector being included to 50° west of north.

5. Amplitudes of Solar Flare Effects in X and Y Fields at M'Bour and Addis-Ababa

Figure 3 shows the mass plot of the amplitudes of solar flare effects ΔX, ΔY fields, and the direction ΔH for all the flares in the years for which the data were available.

At AAE, the ΔXsfe varied from 0 to 80 nT, with a distinct maximum around 1000 hours LT. The amplitudes of ΔXsfe at MBO were comparatively smaller than at AAE because a higher dip latitude, a weak forenoon maximum of the amplitude, was also indicated. The amplitude of ΔYsfe at AAE varied from -20 to $+20$ nT, while at MBO these impulses were always negative, ranging from 0 to -60 nT. For each event the direction of the sfe impulse in H, sfe, were computed as $\tan^{-1} \Delta Y/\Delta X$, and these individual values are also plotted in Fig. 3. The medium value of the sfe impulse vector was 2.3° east at Addis-Ababa and $-31°$ west at MBO. It is to be noted that the direction of the SqH vector and sfe H vector at Addis-Ababa are close to the direction of mean H (i.e., Declination). At MBO the declination is $-9°$, the SqH vector direction is $-33°$, and the direction of sfeH is -29, which is close to that of the SqH vector and not towards the declination. Thus, it can be concluded that in the anomaly region between South America and West Africa, the daily ionospheric current direction is not normal to the average direction of H. The solar flare current follows the directions of the pre-flare ionospheric current direction and, consequently, the solar flare effect is the temporary intensification of the existing ionospheric current.

6. Discussion

The enhancement of the ionosphere conductivity at stations close to the magnetic equator is due to the interaction of the northward magnetic field with the eastward electric field. The situation becomes complex when the magnetic field deviates significantly from the northward direction and the magnetic equator does not align with the east-west direction. The analysis of Sq variation of H and by the solar flare effects in the anomalous region between 0° and 45°W longitudes shows that the current around the mid-day hours deviates by more than 15° westward from the declination. This suggests a strong meridional current flowing northward in this region which modified the conventional electrojet current.

Similar analyses of data from electrojet stations in this anomalous region, Freetown, Tatuoca and Sao Louis/ Alcantra are strongly recommended.

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References

Kane, R. P. and N. B. Trivedi, Comparison of equatorial electrojet characteristics at Huancayo and Eusebio (Fortelaza) in South American region, *J. Atmos. Terr. Phys.*, **44**, 785–792, 1982.

Kuwashima, M. and T. Uwai, Solar flare effects on magnetic variations, *Mem. Kakioka Magn. Observ.*, **21**, 1–14, 1985.

McNish, A. G., Terrestrial magnetic variations and ionosphere, *Terr. Magn.*, **42**, 109–122, 1937.

Rastogi, R. G. and R. J. Stening, On the eastward geomagnetic field variations of electrojet stations, *Indian J. Rad. Space Phys.*, **31**, 67–74, 2002.

Rastogi, R. G., D. R. K. Rao, S. Alex, M. Pathan, and T. S. Sastry, An intense SFE and SSC in geomagnetic H, Y and Z fields at the Indian observatories, *Ann. Geophys.*, **15**, 1301–1308, 1997.

Rastogi, R. G., H. Chandra, and R. K. Misra, Features of the ionospheric drift over the magnetic equator, *Space Res.*, **12**, 982–992, 1972.

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