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Sudden commencements in the X and Y fields at equatorial stations in the African sector

R. G. Rastogi

Physical Research Laboratory, Ahmedabad 380009, India

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This paper describes the mean direction of the H vector due to Sq (solar quiet) and SC (sudden commencement) at equatorial stations Addis-Ababa (geographical longitude: 39°E) and at M'Bour (17°W). The Sq (H) vector aligns fairly well with the direction of the dip declination (D), and the SC (H) vector aligns along the dipole declination (Ψ) minus the dip declination D. At M'Bour, which is situated in the Atlantic Anomaly region, both the Sq (H) and the SC (H) vectors were along 32°W of N, while the dip as well as the dipole declinations were 9°W. Thus, the normal and the disturbance current in the Atlantic region is modulated by some additional meridian currents, resulting in a large increase in the westward Y, the source of which cannot be currently estimated from only one station, M'Bour. This problem requires further investigation.

Key words: Equatorial sudden commencements, meridional electrojet current.

1. Introduction

Solar flares are characterized by a temporary enhancement of solar UV, X-rays and other types of radiation, all of which cause a temporary increase of ionization in the ionosphere of the sunlit hemisphere. The resultant increase in the ionospheric current is found to occur essentially in the same direction as that of the pre-flare Sq (solar quiet) current (Rastogi *et al.*, 1997 and references therein).

Sudden commencements (SCs) of magnetic storms are caused by the impact of solar plasma 1 or 2 days after the occurrence of solar flare or upon the arrival of coronal mass ejection (CME) plasma. Jacobs and Obayashi (1956) conducted the first global study of SCs and found a distinct concentration of current in the inner polar and equatorial regions during SC. Obayashi and Jacobs (1957) subsequently suggested the enhancement of electrical conductivity in the polar region as the dominant cause of the geomagnetic variations during SC.

Rastogi (2006) demonstrated that the midday Sq current vector at Addis-Ababa aligns fairly well with the direction of the dip declination (=1.5°E). At M'Bour (dip declination: 9.3°W), the midday Sq current vector was along 30°W of N. This anomaly was suggested to be due to an additional trans-equatorial meridional current that was superimposed over the quiet time planetary current system. The effects of SC at these two stations, Addis-Ababa and M'Bour (MBO), are discussed in the present article.

2. Data and Analysis

The coordinates and magnetic parameters of the stations chosen, Addis-Ababa (AAE) and M'Bour (MBO), are given in Table 1. The components of the magnetic field are aligned with respect to the geographic coordinate system. These are: (1) the northward field, X; (2) the eastward field, Y; (3) the horizontal field, H, which is equal to $(X^2 + Y^2)^{1/2}$. The dipole declination, Ψ, is the angle between the geographic and geomagnetic meridians through the station measured positive eastward from the geographic north and calculated from the dipole terms in the tenth-generation International Geomagnetic Reference Field (IGRF). The dip declination D is the angle between the geographic and magnetic meridian at ground through the station and measured positive eastward from the geographic north. As seen from the table, AAE, with inclination (I)=1.1°N and declination (D)=1.5°E, was close to the dip equator, with the magnetic meridian in practically a north-south direction. Thus, the Cowling conductivity would be at a maximum along the geographic eastward direction, and the normal ionospheric current over AAE would be fairly eastward. M'Bour (MBO), with I=9.1°N and D=9.2°W, was near the northern fringe of the equatorial electrojet, and the identification of the direction of the equatorial electrojet current over MBO is open to question.

Figure 1 shows the daily variation of the H vector at MBO using the hourly mean values of ΔX and ΔY for the year 2001. H was along the declination (9°W) at 0900–1000 LT, then started shifting westward and was at 30°W around midday and along 45°W in the evening hours. This is the most anomalous daily variation of ionospheric current at any equatorial station reported to date. Kane and Trivedi (1982) found that the direction of the H vector was inclined at 15°W of N at Eusebio (I=3.5°N, D=20°W). These results indicate a strong meridian current superposed over the zonal ionospheric current in the anomalous region between 45°W and 0° longitudes.

The impulses in the X and Y components at MBO and AAE were scaled from the 1-min magnetogram downloaded from the website of the Word Data Center (WDC)

Table 1. Coordinates and Geomagnetic parameters of the stations.

Station Code	Addis-Ababa (AAE)	M'Bour (MBO)
Geographical latitude (Θ_g)°N	9.0	14.4
Geographical longitude (λ_γ)°E	38.8	343.0
Geomagnetic latitude (θ_m)°	5.3	20.1
Geomatnetic longitude (λ_μ)°	111.6	57.5
Northward field (X) nT	35,000	31,750
Eastward field (Y) nT	820	−5138
Vertical field (Z) nT	650	5092
Inclination (I)°N	1.1	9.1
Dip declination (D)°E	1.5	−9.2
Dipole declination (Ψ)°E	−9.8	−8.9
(Ψ-D)°E	−11.3	+0.3
Tan^{-1} (RY/RX)°E	−4.9	−32.2
Mean SC ΔX	48.90	30.2
Mean SC ΔY	−9.5	−15.4
Mean SC (ΔY/ΔX)	−0.2	−0.5
Tan^{-1} (ΔY/ΔX)°E	−11.5	−30.0

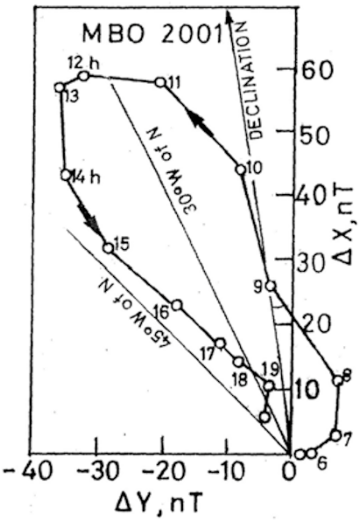

Fig. 1. Daily variation of the direction of the H vector due to the variations of ΔX and ΔY at M'Bour on five international quiet days in 2001.

at Copenhagen, Denmark.

Figure 2(a) shows the recordings of 1-min magnetic field components X and Y at AAE and MBO during the SC at 1648 LT on October 21, 2001. The SC impulses at AAE were ΔX=70 nT, ΔY=−20 nT, and the direction of SC H to the 16°W of N. At MBO the impulses of SC were H=65 nT, Y=−42 nT and θ (SC)=33°W of N.

Figure 2(b) shows similar recordings for the SC at 1315 UT on March 18, 2002. The SC impulses at AAE were ΔX=146 nT, ΔY=−22 nT, and θ (SC)=14°W of N. The SC impulses at MBO were ΔX=84 nT, ΔY=−46 nT, and θ (SC) was 29°W of N.

Figure 3 shows the mass plots of ΔX, ΔY and θ (H) for all of the SCs at MBO and AAE for all of the events for which the data were available between 1997 and 2002. At AAE, a station near the centre of the electrojet belt, ΔX showed a maximum in the forenoon hours, with a mean value of 49 nT. AT MBO, a station close to the fringe of electrojet belt, no significant daily variation in the amplitude of ΔX was evident. The mean value of ΔX at MBO was 30 nT, which was less than that of ΔX at AAE, as the MBO station was farther from the dip equator than AAE. ΔY (SC) at AAE ranged from 0 to −40 nT, with a mean value of −15 nT. The direction of the SC vector, θ (SC), showed a large scatter, with a mean value of 13°W of N. The direction SC (H) vector at MBO showed a larger scatter between 0 and −50°, with a mean value of −22°. A closer examination of points for MBO indicated larger deviations during the daytime than during the nighttime hours.

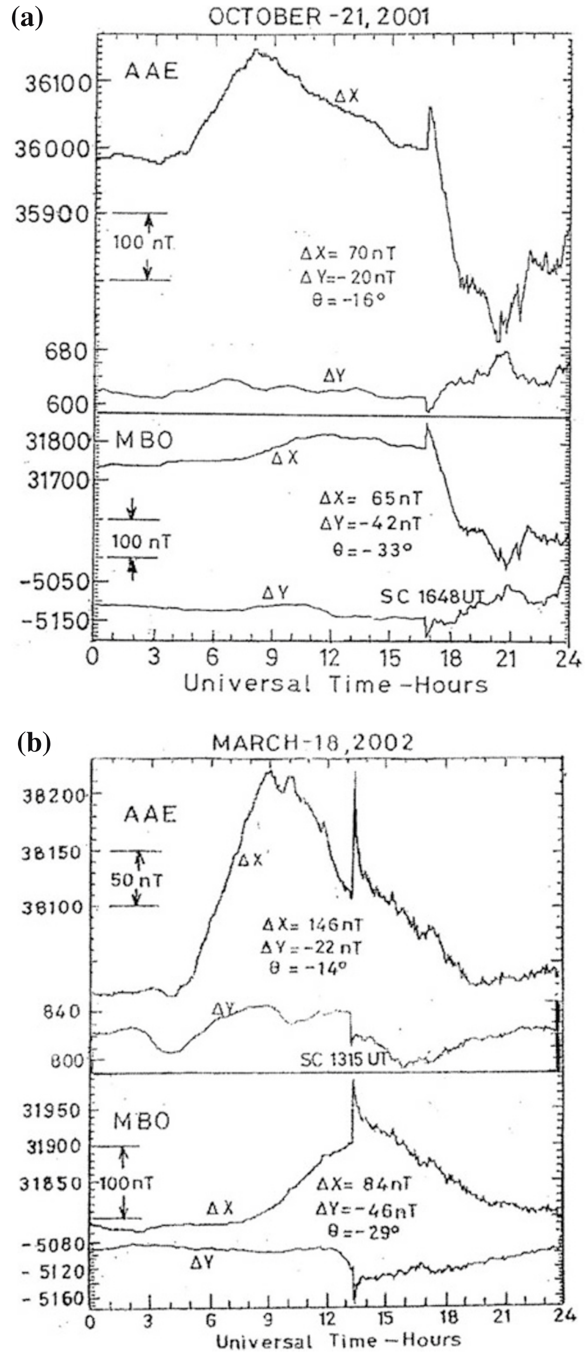

Fig. 2. (a) One-minute magnetograms of ΔX and ΔY at AAE and MBO showing the signatures of SC at 1648 UT on October 21, 2001. (b) One-minute magnetograms of ΔX and ΔY at AAE and MBO showing the signatures of SC at 1315 UT on March 18, 2002.

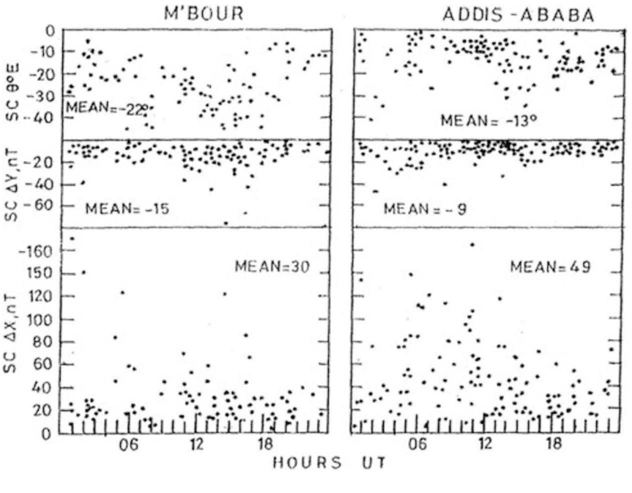

Fig. 3. Mass plots of the amplitudes of ΔX, ΔY and the direction (θ) of the ΔH due to the SC for the stations M'Bour and Addis-Ababa.

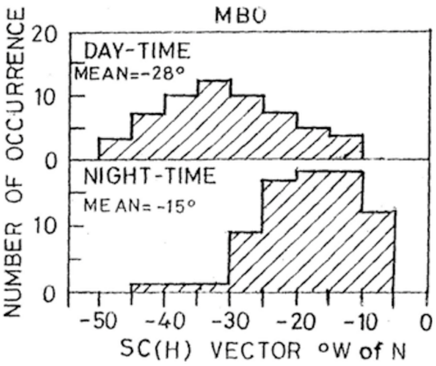

Fig. 4. Histograms of the θ (SC) H vector during the daytime and nighttime SCs at MBO.

Figure 4 shows the histograms of the SC (H) vector at MBO separately for the daytime and nighttime hours. The mean value of θ was 15°W for the nighttime and 28°W for the daytime, suggesting the effect of additional meridional currents at MBO during the daytime hours.

Figure 5 shows the average directions of dip declination (D), dipole declination (Ψ) and (Ψ-D) compared with the direction of Sq (H) and SC (H) vectors at Addis-Ababa and M'Bour.

At AAE, the quiet time ionospheric current was fairly consistent along the direction of dip declination, as expected from the theory of the electrojet. The direction of the SC (H) vector was aligned along the direction (Ψ-D), as suggested by Fukushima (1966) for Kakioka.

At MBO, the normal quiet day ionospheric current is tilted by about 20° westward of the direction of the dip declination. The direction of the SC (H) vector is tilted eastward but lies in between the directions of Ψ (or D) and of Sq (H). Thus, the effects of both the ionospheric and magnetospheric currents are seen at MBO during the sudden commencements of magnetic storms.

3. Discussion

Burlaga and Ogilvie (1969) attributed the SCs to sudden increases in dynamic pressure on the magnetosphere by the plasma ejected from the sun following solar flares caused, for example, by coronal mass ejection. The imposition of an eastward electric field on the equatorial ionospheric E region during SC was first shown by Rastogi (1975) on the records of signal strength of the VHF forward scatter taken in Peru during IGY and subsequently on the appearance of equatorial sporadic E irregularities on the ionograms at Huancayo (Rastogi, 1976). Reddy *et al.* (1981) showed a sudden increase in the signal strength and in the Doppler shift of VHF backscatter echoes at Thumba during the SC period.

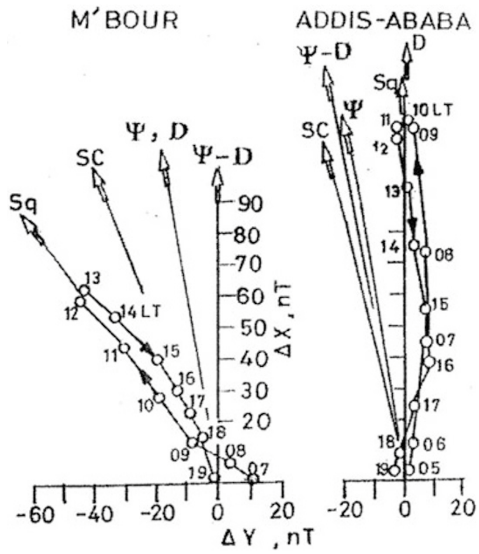

Fig. 5. The directions of the dip declination (D), dipole declination (Ψ) and (Ψ-D) compared with the directions of Sq (H) and mean SC (H) at MBO and AAE.

Rastogi and Patel (1975) showed that a sudden change in the interplanetary magnetic field (IMF)-Bz causes an immediate sudden impulse in H at Huancayo and in the Doppler shifts in VHF backscatter signals at Jicamarca. They suggested that an electric field $E = -v \times Bz$ that is equivalent to solar wind velocity, v, crossing Bz is transmitted through the open field lines first to the polar and then to the equatorial latitudes. The electric field imposed horizontally on the polar ionosphere has been shown to be transmitted instantaneously to low latitudes by electromagnetic waves in the zero-th order TM (transverse magnetic) mode in the wave guide between the Earth and the ionosphere (Kikuchi *et al.*, 1978; Kikuchi and Araki, 1979a, b).

Araki (1977) discussed the global structure of geomagnetic sudden commencements and suggested two types of interaction between the magnetosphere and the shock or discontinuity in the solar wind during a sudden storm commencement (SSC). He suggested that the preliminary impulse during SC is caused by the dusk-to-dawn polar electric field transmitted along the magnetic lines of forces by anisotropic hydro-magnetic waves from the compressional wave front, which moves tailward in the dayside magnetosphere. However, he did not explain why only a fraction of SCs have a preliminary reverse impulse. Rastogi (1978) showed that the SCs with preliminary reverse impulse are seen only on those SC event in which the associated solar plasma bubble has a leading edge with strong northward IMF. As the electric field transmission is faster than the velocity of the compression wave, the negative impulse arrives earlier than the effect of compassion wave (Rastogi, 1980).

Jacobs and Obayashi (1956) showed that a positive impulse in SC (Y) is observed at stations whose magnetic north is deviated westward from the geomagnetic meridian. They suggested that the movement of the magnetic vector is likely to be towards the geomagnetic meridian at the time of SC. Fukushima (1966) described the declination change of SC at Kokioka (D=6.5°W, Ψ=6.3°W) and found the average direction of SC (Y) to be 18.2° eastward from the local magnetic meridian. He identified a systematic local time dependence of the deviation angle. Rastogi *et al.* (2001) described the SC (Y) at Kakioka (Ψ-D=13.0°) and at Alibag (Ψ-D=−6.4°) for the same period (1958–1961). At both stations, the tilt of SC (Y) vector was towards the geomagnetic dipole meridian at the station. Rastogi (2003) described the effect of SC in the H, Y and Z fields at Huancayo (D=5.0°, Ψ=0.17°), and the average deviation of impulse in Y during SC was found to be +10.8°, which is opposite to the expected value of Ψ-D being −4.3°. A very strange diurnal variation in the deviation of the SC (Y) vector was found, with a maximum around the midday hour. It should be pointed that this feature is similar to the diurnal maximum of Sq (Y) at Huancayo (Rastogi and Stening, 2002). Thus, the SC impulses in both the X and Y components of the geomagnetic field at equatorial stations are affected in accordance with the normal Sq (X) and Sq (Y) during the local time of the events.

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R. G. Rastogi (e-mail: profrgrastogi@yahoo.com)