J. Ind. Geophys. Union (April 2006)
Vol.10, No.2, pp.63-68

Declination effects on magnetospheric ring current over the magnetic equator

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ABSTRACT

It has been shown that the magnetospheric ring current has a very significant effect on the storm time variations of the Eastward component (Y) besides the horizontal component (H) at ground magnetic observatories. The storm time variation of H is a depression at low and middle latitude at any of the longitudes, roughly following the variations of Dst index. The storm time variation of the Y at equatorial electrojet region shows a large depression in East Brazil longitudes and a large increase in East African longitudes, and only small changes in the Pacific longitudes. These changes are shown to be related to the index $\sin^{-1}$ (ψ - D) where ψ and D are the dipole and dip declination at the stations. At equatorial stations the ionospheric Sq current flows along the dip equator while the disturbance ring current flows along the dipole equator.

INTRODUCTION

Storms in geomagnetic horizontal field (H) have been studied since the beginning of regular recordings of the magnetic field (Broun 1861, Adams 1892, Moos 1910 and Chapman 1918). Sugiura & Chapman (1960) described the results of an extensive study of magnetic storms at a large number of observatories covering the period 1902-1945. They defined a new term "Storm-time variation" denoted by Dst variation, which is the disturbance change in an hourly mean of H during the storm hours minus the mean H corresponding to the same local hour on five International Quiet days (Sq H). They found that large changes were observed in the horizontal field (H) but no significant effects were noticed in the declination (D) component of the geomagnetic field.

Rastogi (1992) found that the Dst variation of D (westerly) and the H field at the equatorial station, Kodaikanal and at the low latitude station Alibag were remarkably similar to each other and followed the corresponding variation of the ring current index (Dst). Later similar decreases in H and D (easterly) were found at the equatorial station Huancayo (Rastogi 1993). This required an explanation of the storm time variation of Declination at two equatorial electrojet stations with opposite sense of the Declinations. Comparing the Dst variations at middle latitude stations Alibag, Lunping, Chichijima and Kakioka, Rastogi, Winch & James (2001) suggested that the particles trapped in the earth's magnetic field are guided by the dipole declination (ψ) at the ring current altitudes and do not respond to the direction of ground declination (D). The disturbance vector $\Delta Y/\Delta H$ was shown to be given by sin (ψ-D). The storm-time variations of declination component showed negative excursions at Alibag but positive excursions at Lunping and Chichijima, confirming the above suggestion. Later, Rastogi (2005) examined the storm-time variations of declination at the chain of 16 stations along the Indo-Russian longitudes extensing from 0° to 60° dip latitude. The relationship $\Delta Y = \Delta H \sin(\psi\text{-}D)$ was shown to be quantitatively followed. James, Rastogi & Winch (2004) indicated a very significant longitudinal variations of (ψ-D) with a value of +15.0° at Tatuoca and -11.5° at Addis-Ababa and only 1.4° at Jarvis. They showed that daily mean values of H field decreases linearly with decreasing Dst index. But the variations of ΔY with Dst index showed significant longitudinal variation. ΔY at Tatuoca increased with decreasing Dst index but ΔY at Addis Ababa decreased with increasing Dst. Good correspondence between $\Delta Y/\Delta H$ and sin ψ-D was seen for all stations. The present paper discusses the storm time variations of H and Y at pairs of equatorial and low latitude along same longitude.

RESULTS OF ANALYSIS

Description of the data set

First of all, in Fig. 1 are shown the distribution of the parameters (ψ-D) round the world. Moving eastward along the magnetic equator, the parameter (ψ-D) is less than -10° in Central African region between 0 and 45° geographic lontitudes. (ψ-D) is close

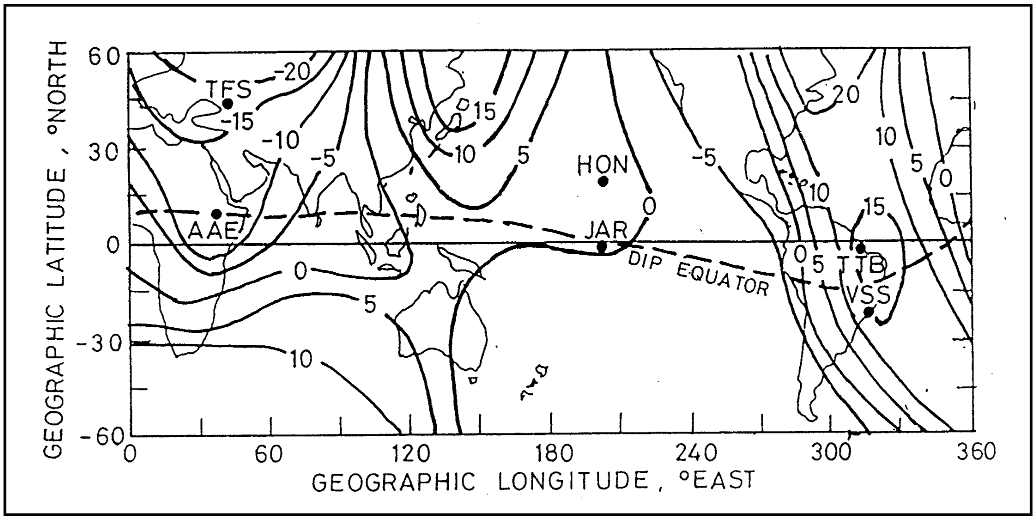

Figure 1. Global distribution of the parameter dipole declination, ψ and the dip declination D i.e. (ψ-D).

Table 1. Coordinates of stations used in the analyses

Station	Vassasoaras	Tatucoa	Tbilisi	Addis-Ababa	Honolulu	Jarvis	Guam
Code	VSS	TTB	TFS	AAE	HON	JAR	GUM
Geog. Lat. °N	-22.4	-1.2	42.1	9.0	21.3	-0.4	13.6
Geog. Long. °E	316.4	311.5	44.7	38.8	202.0	200.0	144.9
Geom. Lat. °N	-13.1	8.4	36.8	5.3	21.6	-0.1	5.3
Geom. Long. °N	26.4	23.3	123.8	269.5	271.6	271.6	215.7
Mean X nT	19500	27677	23900	36062	27800	34020	35800
Mean Y nT	7800	7000	605	-100	5600	5550	
Inclination I° N	-33.5	17.2	60.5	0.5	38.2	2.2	12.3
Dip Declination D° E	-21.8	-19.4	60.5	1.3	10.9	9.2	1.6
Dipole Declination ψ° E	-5.1	-4.2	5.4	-10.1	11.2	10.5	6.1
(ψ-D)° E	+16.7	15.2	-11.7	-11.4	0.7	1.2	4.5
Mean daily range X, nT		76	-17.1	131		166	
Mean daily range Y, nT		-27		0		10	
Range Y / Range X		-0.36		0.0		0.06	
Tan^{-1} ΔY/ΔX		-19.6		0°		3.4°	

to zero in Indian and Pacific ocean i.e. from 60° to 270° longitude. (ψ-D) is greater than 15° in Eastern part of Brazil (315° longitude). We have chosen pairs of an electrojet and a low latitude station outside the electrojet belt in these three longitude belts. These are Honolulu (HON) and Jarvis (JAR) for Pacific sector, Tatuoca (TTB) and Vassouras (VSS) in Brazil sector. For East African sector there were no low latitude station just outside the electrojet belt and we have chosen Addis-Ababa (AAE) and Tbilisi (TFS) in this sector. The coordinates of these stations are given in Table 1.

Average solar daily variations of X and Y at equatorial stations

In Fig.2 are shown the yearly mean daily variations of X and Y components at the equatorial stations Jarvis (JAV), Addis-Ababa (AAE) and Tatuoca (TTB). At Jarvis D = 9.2° and ψ is 10.5° and thus ψ - D = 1.2°. Being close to the magnetic equator, Jarvis recorded the daily range of X = 166 nT and range of Y = 10 nT. Thus the current vector at noon was only 14° south of East at Jarvis. At Addis Ababa D = 1.3° but ψ = -10.1° and

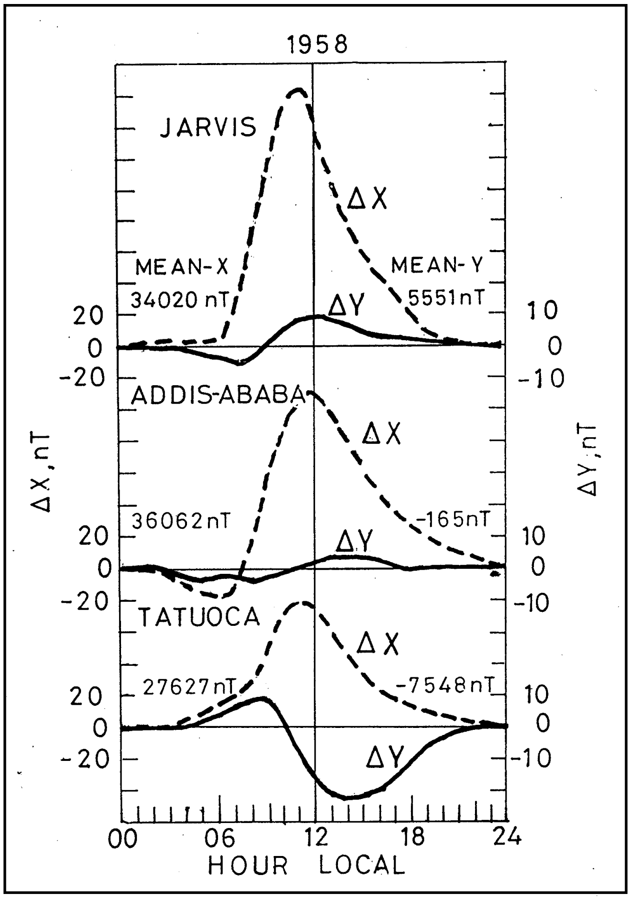

Figure 2. Yearly average Quiet Days solar daily variations of X and Y components of the magnetic field at Jarvis, Addis-Ababa and Tutuoca.

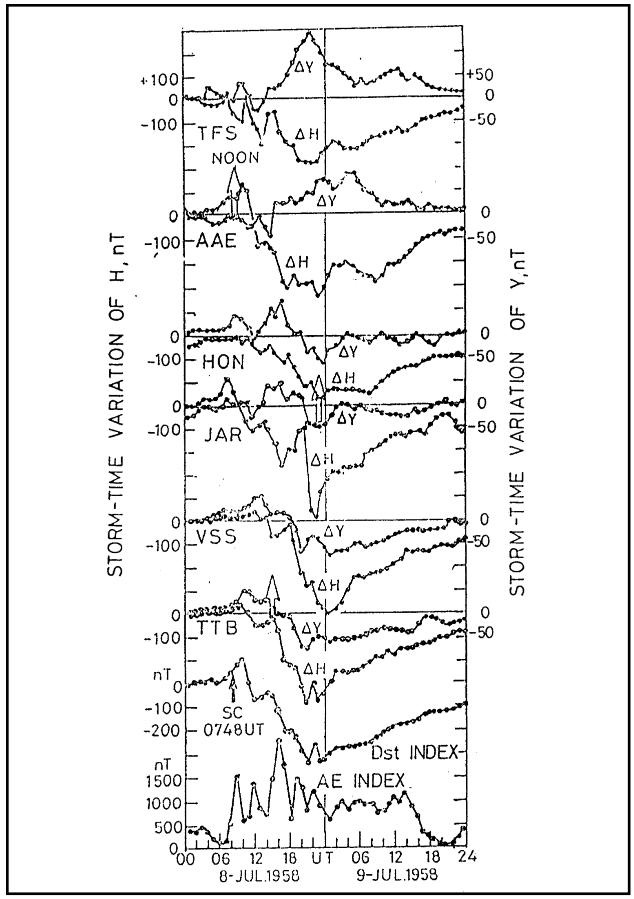

Figure 3. Storm time variation of H and Y fields at different stations following a SC at 0748 UT on 8 July 1958.

thus ψ - D = -11.4°. The daily range of X was 131 n and the noon derivation of Y was 0 nT. Thus the midday current sector at Addis-Ababa was close to the Eastward direction.

At Tatuoca, D was -19.4°, ψ was -4.2 and thus ψ - D was +15.2°. The station (Inclination I = 17.2) was outside the equatorial electrojet belt in 1958 and thus the daily range of X was comparatively lower = 76 nT but the noon derivation of Y was large being equal to -27 nT. The noon current vector direction was thus around $\tan^{-1} \Delta Y/\Delta X = 27°$ north of east. It may be noted that the magnetic equator in the eastern part of Brazil swings fairly north of east.

Thus the equatorial electrojet current follows fairly well the direction of the magnetic equator in any longitude sector.

Magnetic storm of 8-9 July 1958

An intense magnetic storm with SC at 0748 UT, main phase onset at 1130 UT, and the minimum Dst index = -327 nT at 2030 UT had occurred on 8 July 1958.

The storm-time variations of H and Y at different stations are shown in Fig.3. The AE index was high during the whole storm duration. It is seen that the storm time variation in H field at any of the stations was very similar to the progress of Dst index. Comparison to the minimum Dst index of -327 nT, the minimum value of ΔH were -368 at TTB (local time 17 hr), -490 nT at Jarvis (local time 13 hr) and -399 nT at Addis Ababa (LT = 23 hr). The minimum value of Dst at 2030 UT corresponded to 18LT at TTB, 23 LT at AAE and 10 LT at JAR. This shows that the storm time decrease in H at equatorial station is most pronounced at the midday longitude sector.

The storm-time variations of Y at TTB and VSS show decreases analogous to that of Dst index. At JAR and HON storm time variation of Y showed a small decrease around the time of maximum disturbance. At AAE and TFS, the storm time variation of Y shows a maximum during the storm opposite in nature to the corresponding storm time variation of the H field.

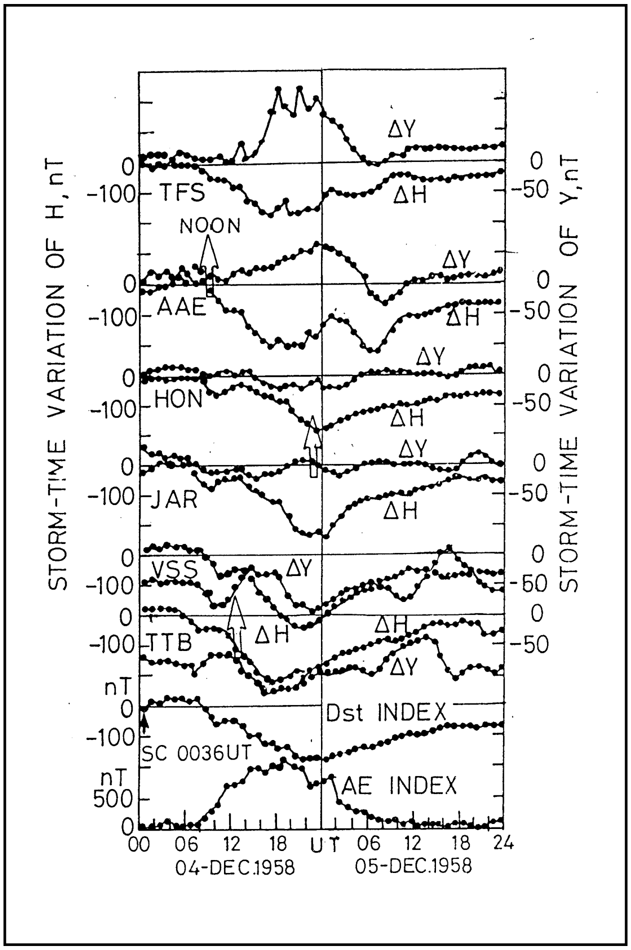

Figure 4. Storm time variations of H and Y fields at different stations following a SC at 0036 UT on 4 December 1958.

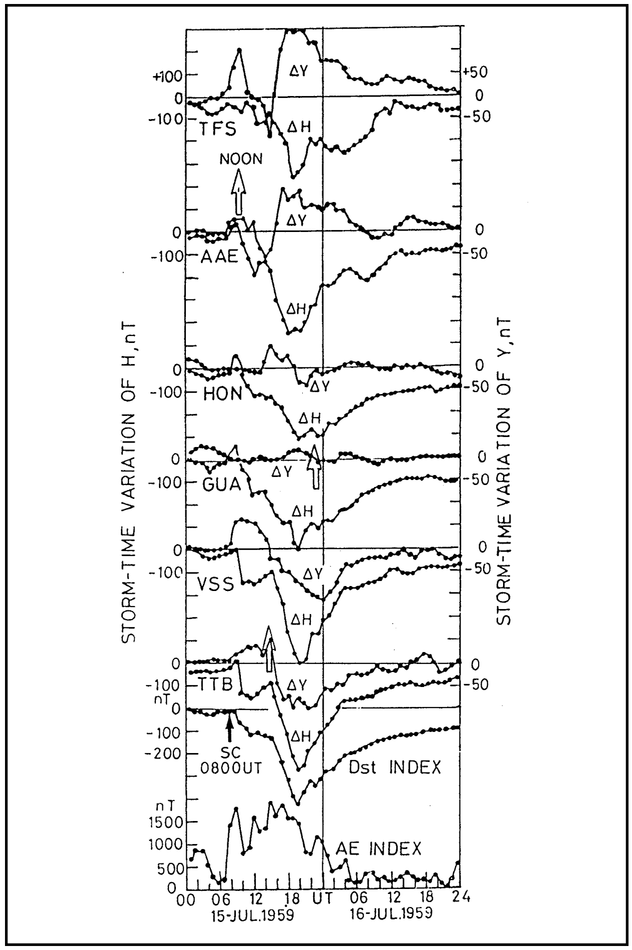

Figure 5. Storm time variations of H and Y fields at different stations following a SC at 0800 UT on 15 July 1959.

Thus it is seen that ΔY/ΔH is positive for stations with positive values of (ψ-D) and is negative at stations with negative value of (ψ-D).

Magnetic storm of 4-5 December 1958

This storm started with a SC at 0036 UT and the main phase onset was at 1430 UT on 4 December. The maximum phase of the storm was with Dst = -176 nT at 0500 UT on 5 December 1958. The storm time variations of H and Y at different stations are shown in figure 4.

The storm time variation of H at any of the stations followed the corresponding variation of Dst index. Comparing the minimum Dst = -176 nT at 05 UT, the minimum storm time decrese of H was -230 nT at TTB, -243 nT at JAR and -213 nT at AAE. The local times at the maximum phase was 02 hr at TTB, 08 hr at AAE and 18 hr at JAR, thus none of the stations were close to the latitude of local noon and no equatorial enhancement of DH was noticed.

The storm time variation of Y field at VSS and TTB were very similar to the corresponding storm-time variations of H field at the station. At HON and JAR, the Y field remained unaffected by the magnetic storm. The storm time variation of Y at AAE and TFS showed a positive phase almost opposite to the corresponding variation of the H field.

Magnetic storm of 15-16 July 1959

The storm time variations of H and Y at different stations are shown in Fig. 5. This storm started with SC at 0800 UT and the main phase onset was at 10.5 UT on 15 July and the maximum phase was at 19.5 UT on 15 July 1959. As the station JAR was not operative in 1959, we have chosen Guam in its place.

The storm time variation of H at any of the stations was similar to the variation of Dst index. Compared to the minimum value of Dst = -425

Table 2. Details of magnetic storms analysed

	DsT min		VSS	TTB	TFB	AAE	HON	JAR	GUM
	Mag.	Time UT							
Storm of 8 July 1958	-327	20.5 hr LT	17.6	11.3	23.5	23.0	9.8	9.8	
ΔH nT			-375	-368	-280	-399	-272	-490	-
ΔY nT			-74	-60	+57	50	-58	-51	-
$\sin^{-1}$ ΔY/ΔH			11.40	9.3°	-11.7	-7.2	12.3	6.8	-
Storm of 4 Dec 1958	-176	0.5 hr LT	21.6	21.3	3.6	3.0	13.8	13.8	
ΔH nT			-497	-469	-374	-447	-315	-	-396
ΔY nT			-12.6	-9.7	156	95	-39	-	+18
$\sin^{-1}$ ΔY/ΔH			14.7	11.9	-247	-12.3	7.1	-	+2.6
Mean ($\sin^{-1}$ ΔY/ΔH)			+16.1	+15.4	-24.3	-11.1	8.7	+10.4	
(ψ - D)			+16.0	+15.0	-17.1	-11.5	0.7	1.9	

nT, the minimum ΔH was -469 nT at TTB (LT = 17 hr), -447 nT at AAE (LT = 23 hr) and -396 nT at GUA (LT = 06 hr). No equatorial enhancement of storm time DH were noticed at any of these stations.

The storm time variations of Y showed a strong decrease at TTB and VSS, practically no variation at GUA and HON and a strong increase at AAE and TFS during the main phase of the storm.

DISCUSSION

The variation of the direction of the ground horizontal geomagnetic field from the geographic meridian is indicated by the dip declination D. The anomalies at the ionospheric height are controlled by the corresponding abnormalities of the actual magnetic coordinates at ground level and not by the dipole coordinates (Rastogi 1962). The geomagnetic field at the altitude of the ring current is devoid of the ground abnormalities of the magnetic field and is practically a dipole field. The motion of charged particles in ring current regions are controlled by the dipole field lines. Thus the ring current follows the dipole equator and not the dip equator. Thus the storm time variations in the Y field is dictated by the dipole declination y. The monthly tabulations of hourly mean values of Y field at any station are measured with the mean value at the dip declination D. Rastogi et al. (2001) suggested that during a magnetic storm DY/DH is given by sin (ψ-D). Thus the storm time variations of H and Y would be similar in nature at stations with positive (ψ-D) as at East Brazillean region. The storm-time variations of H and Y would be opposite in nature at stations with negative value of (ψ-D) as in East African longitudes. No significant changes would be experienced at stations with (ψ-D) being close to zero as in Central Pacific longitudes.

The details of the three magnetic storms and the observed changes in X and Y fields at different stations at the time of the maximum phase of the storm are collected in Table 2. It can be seen that the mean disturbance vector at Vassouras was 16.1° which is very close to (ψ - D) at the station. Similarly the $\sin^{-1}$ (ΔY/ΔH) and (ψ - D) at Tatuoca were +15.4° and +15.0° respectively.

At Addis-Ababa where (ψ - D) = 11.5, the value of $\sin^{-1}$ (ΔY/ΔH) at the maximum phase of the storm was -11.1°. At Jrvis there are some difference between $\sin^{-1}$ (ΔY/ΔH) and (ψ - D) and this may be because of the maximum phase of the storm of 8 July 1958 occurred during local noon at Jarvis. Besides the magnetospheric currents, there are additional enhancements of the magnetic storms at equatorial stations around local noon. Thus ΔY/ΔH does not represent entirely the effect of ring current (Rastogi 2004).

It is concluded that during normal quiet conditions the low latitude currents in the ionosphere follow the dip equator. During magnetic storm conditions the magnetospheric ring current follows the dipole equator and not the dip equator.

ACKNOWLEDGEMENT

The data used were downloaded from the websites of the World Data Centres at Kyoto and Copenhagen. The work was done during the author stay in Australia. The author is pleased for the assistance by Master Rohan Bansal during the analyses on his personal computer.

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(Accepted 2005 December 24th. Received in original form 2005 November 15th)

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His initial interests were various aspects of ionosphere and was responsible for establishing vertical ionosondes at Ahmedabad and Trivandrum, ionospheric drift recorders at Thumba, Trichy, Madras, Ahmedabad and Udaipur. He organized the Beacon Satellite Observations at number of stations in India and established most sophisticated ATS-F receiving station at Ootacamund. He worked in almost every equatorial ionospheric experiment and guided Ph.D. to more than twenty-five students.

Joining Indian Institute of Geomagnetism, he transformed the magnetic observatory programs in to a major research institute. He established the first equatorial geomagnetic research laboratory at Tirunelveli and another centres at Allahabad, and Kolhapur. He organized permanent geomagnetic observatories at Pondicherry and Nagpur. His important contribution to research in the universities was the proposition, establishment and guidance of various experiments under All India Coordinated Ionospheric and Thermospheric Program of Department of Science and Technology, Government of India.

He has been post-doctoral fellow at National Research Council of Canada, and at High Altitude Observatory at Boulder, USA. He was guest worker at Central Radio Propagation Laboratory, Bounder, USA and NRC resident senior fellow at Air-Force Geophysics Laboratory, Boston, USA. He worked at the famous Radar facilities at Jicamarca, Peru.

He has numerous publication exceeding 400 papers on almost every aspects of Ionosphere, Geomagnetism and Solar-ionospheric-magnetospheric relation. He is the first to discover the longitudinal variation of equatorial electrojet, effect of interplanetary magnetic field on equatorial ionosphere, role of geomagnetic declination on ionosphere storms.

He was the first Indian to be selected in the Executive Council of International Association of Geomagnetism and Aeronomy (IAGA). He was founder Chairman of Inter-Divisional Commission on Developing Countries. He was the Director of International Workshop on Geomagnetic Data Processing at Pune, India and of the International School of Geomagnetism and Aeronomy at ICTP, Trieste, Italy.