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On equatorial geophysics studies: a review on the IGRGEA results during the last decade

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Abstract

During the years 1993–1994, a continuous campaign of measurements has been held in the frame of the International Equatorial Electrojet Year (IEEY) with a network of 10 magneto-telluric stations and a network of three ionosondes. Other instruments have participated during shorter periods, HF radar and optical Fabry-Perot 630 nm interferometer.

After the IEEY campaigns, the International Group of Research in Geophysics in Europe Africa (IGRGEA created in January 1995), has organized the research in geophysics. This paper report the main results of the IGRGEA during the last decade at local, regional and planetary scales.

At a local scale, the HF radar data highlighted the complex structure of echoes in the equatorial zone and allowed to explain the "necklace" echoes as due to oblique propagation into the type I instability levels. This radar observed

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atmospheric storm electric field discharges at Es layer for the daytime and Equatorial Spread F at night-time. A series of original results concern Doppler spectra and the electric field change on plasma drifts across the ionosphere, gravity waves effects as well the ESF multi-process sources.

At a regional scale, magnetic data were used to parametrize the Equatorial Electrojet (EEJ). Ionospheric data, magnetic data and UARS satellite were brought together as input parameters of the Richmond's EEJ model to reproduce the EEJ and the magnetic field variations associated to EEJ. The comparisons between magnetic data, and the magnetic field computed from the physical model and from the parametrization of the EEJ are all in good agreement. Ionosonde data were included in the IRI. Ionosonde data revealed the field aligned f_0F_2 crests of ionization at mid morning and early afternoon hours. Measurements of equatorial night-time wind variations, obtained for the first time over African equatorial zone with the Fabry-Perot interferometer, shown the strong variability of atmospheric winds.

At a planetary scale, the parametrization of the EEJ was done using the magnetometers chain involved during IEEY in the three longitude sectors. Finally, we present the results on electrodynamic coupling between high and low latitudes with overshielding or shielding events.

0. Introduction

It was at the VANCOUVER Assembly of IAGA (Interdivisional Commission in 1987) that the *I*nterdivisional *C*ommission on *D*eveloping *C*ountries (*ICDC*) commission requested to intensify International Electrojet studies in the frame of International Equatorial Electrojet Year (IEEY) projects. After IGY and programs that followed it, the IEEY is for the first time a planetary experiment to be handled largely by scientists from developing countries.

The west African network results have been remarkably regular, allowing to fill the gap between Asian and American series, and to study multiples scales phenomena.

In two preceding papers, Mazaudier and Cohen (1991) and Mazaudier et al. (1993) presented the scientific objectives of the internal and external geophysics communities, involved in the project, and the experimental campaign planned for the African sector.

In this review, we describe the campaign and the scientific results obtained during the decade 1992–2002.

There are five sections. Section 1 presents the details of the experimental campaign. Sections 2, 3 and 4 are respectively devoted to the scientific results at a local, regional and planetary scales. Section 5 highlights the development of geomagnetism and aeronomy in Africa in the IGRGEA group for the next decade.

1. The campaign

Fig. 1 gives the experimental sites in West Africa, Table 1 the various experiment operated during the IEEY and Table 2 the location of these experiments.

Several instruments were brought to Africa for the IEEY experiment:

- a network of ten geo-magneto-telluric stations, from November 1992 to October 1994;
- a HF radar at Korhogo during two campaigns in 1993 and 1994;
- an ionosonde at Korhogo installed in November 1992;
- a Fabry Perot interferometer at Korhogo operating since November 1994.

The interferometer and the ionosonde are now permanent tools of the Korhogo observatory.

All the observations made during the IEEY were compiled in a final catalog including the three longitude sectors (Amory-Mazaudier et al., 1996).

2. Scientific results at a local scale

At the local scale, the HF radar echoes were used to study the instabilities in the equatorial ionosphere, the night-time spread F and daytime sporadic E (Section 2.1), and the electron drift measurements (Section 2.2).

2.1. Instabilities in the equatorial ionosphere, night-time spread F and daytime sporadic E

Ionospheric measurements were performed with the LDG radar (LDG: Laboratoire de Détection Géophysique du Centre à l'Energie Atomique) during two campaigns in April–July 1993 and October–December 1994. The experiments were specifically defined for the study of, irregularities over short period-time (2–25 min) with intensive measurement modes, and large scale disturbances with longer duration modes (8–10 h). The

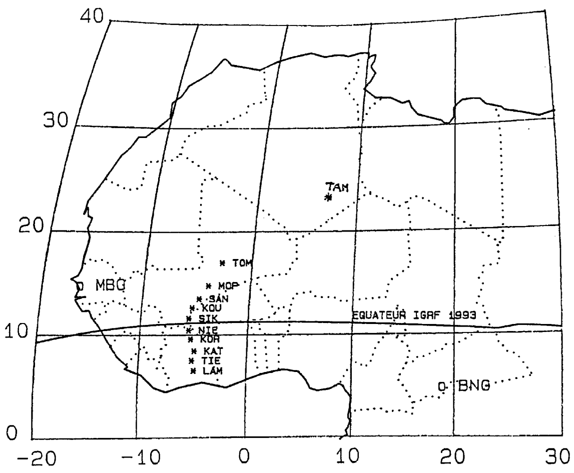

Fig. 1. Experimentation sites of the African sector during the IEEY project.

Table 1
Periods of measurement of the various equipments involved in the International Equatorial Electrojet Year, in the European–African sector

Tools/ Laboratory	Operating periods
Magnetometer and telluric network	From November 20th, 1992
(10 stations), ORSTOM/France	To October 26th, 1994
Ivory Coast and Mali	
1 magnetometer	
M'Bour observatory/Senegal	Permanent
1 magnetometer	
Bangui observatory RCA	Permanent
HF radar	From April 8th, 1993
CEA/France	To July 23th, 1993
	From October 10th, 1994
	To November 27th, 1994
Interferometer	From November 5th, 1994
UCL/England	To May 5th, 1995
Korhogo observatory/Ivory Coast	Permanent tool now
Ionosonde network	
France-Télécom-CNET/France	From October, 1992
Korhogo observatory/Ivory Coast	Permanent tool now
Canbérène observatory/Senegal	Permanent tool
Ouagadougou obs./Burkina Faso	Permanent tool −> closed in 1999
1 magnetometer	Permanent
Awolowo University/Nigeria	
1 magnetometer	Catalogue of data not yet available
IGP/France	
Tamanrasset observatory/Algeria	
1 magnetometer	Catalogue of data not yet available
Kyushu University/Japan	
Tamanrasset observatory/Algeria	
1 magnetometer and 1 ionosonde	Permanent
EBRE Observatory/Spain	

radar mainly operates at a vertical incidence; it gives echo amplitude, Doppler spectra and echolocation in a large height range with a height resolution of 1.5 km (Blanc et al., 1996).

Previous oblique radar measurements showed, during daytime, the presence of the level of type I instabilities associated with two-stream jet and type II instabilities associated with cross field drift (Hanuise and Crochet, 1977, 1981). During the present experiment, strong scattered signal was received from irregularities characterized by broad spectra typical of type II instabilities. Simultaneous high-resolution echo measurements revealed that these irregularities are subjected to turbulence and wave structures, with kilometer scale size and they fluctuated over time periods of 1 s or less. At frequencies of 2–8 MHz, the radar receives scattered signal from 100 to 20 m irregularities, probably acting as tracers of large scale motions. Kilometric irregularities have also been observed in the same height range by the Jicamarca incoherent scatter radar sensitive to 3-m-scale irregularities (Farley et al., 1994). Surprisingly the present measurements also point out that the region where kilometric irregularities are observed is not limited to the electrojet but rather extends up to the F region trace (Blanc et al., 1996). The scale of the irregularities is a few kilometers in the electrojet range and several kilometers in the F region. In addition scattering arises from specific oblique propagation around the E layer peak whereby the type I irregularity mode is evidenced (Fig. 3 in Farges et al., 1999). Similar echoes have also been obtained in the same region by the Jicamarca radar (Kudeki and Fawcett, 1993). It has never been observed previously with HF radar, sensitive to larger scale irregularities. Farges (2000) compared daytime series of these "necklace" shaped echoes which characterize the day-to-day change in the electric field regimes of the EEJ. Farges (2000) shows, for the first time that 150 km echoes result from oblique propagation on type I irregularity fronts.

Fig. 2 shows an example of HF echoes observed on May 28, 1993. Complex scattered signal arises from the 100–150 km height range. The "necklace" echo trace between 150 and 170 km ranges can be clearly identified in Fig. 2. On the same figure the irregularities in the F1 region appear as a broadening of the radar echoes. In parallel, height oscillations with a period of 15–30 min are produced by gravity waves. The HF echoes is the combination of oblique and vertical scattered signals due to the broad beam of the antenna. The echo location

Table 2
Location of the equipments involved in the International Equatorial Electrojet Year, in the European–African sector

West Africa		
Site	Geographic coordinates Lat. N/Long.W	Instrument
Tombouctou (Mali)	16°44′00″/3°00′00″	1 magnetometer + Telluric
Mopti (Mali)	14°30′30″/4°05′14″	1 magnetometer + Telluric
San (Mali)	13°14′00″/4°52′00″	1 magnetometer + Telluric
Koutiala (Mali)	12°21′00″/5°27′00″	1 magnetometer + Telluric
Sikasso (Mali)	11°21′00″/5°42′00″	1 magnetometer + Telluric
Nielle (Mali)	10°13′00″/5°38′00″	1 magnetometer + Telluric
Korhogo (Ivory-Coast)	9°20′00″/5°26′00″	1 magnetometer + Telluric
Katiola (Ivory-Coast)	8°11′00″/5°03′00″	1 magnetometer + Telluric
Tiebessou (Ivory-Coast)	7°13′00″/5°14′30″	1 magnetometer + Telluric
Lamto (Ivory-Coast)	6°14′00″/5°01′30″	1 magnetometer + Telluric
M'Bour (Senegal)	14°20′00″/16°55′00″	permanent magnetometer
Bangui (R.C. Africa)	4°24′00″/ − 18°37′00″	permanent magnetometer
Dakar (Senegal)	14°46′00″/17°25′00″	permanent ionosonde
Korhogo (Ivory-Coast)	9°27′00″/5°38′00″	permanent ionosonde CEA HF radar UCL Interferometer
Ouagadougou (Burkina Faso)	12°22′00″/1°32′00″	permanent ionsonde
Ile-Ife-Awolowo University Nigeria	7°17′00″/5°08′00″	permanent magnetometer
Tamanrasset (Algeria)	22°56′00″/5°30′00″	permanent ionosonde permanent magnetometer + 2 magnetometers

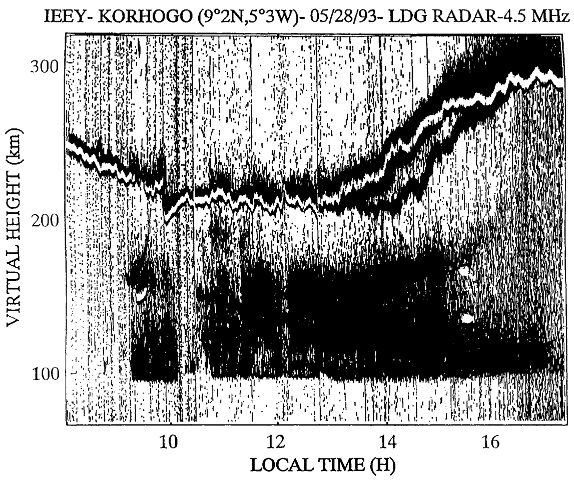

Fig. 2. Variations of the virtual height of the LDG radar echoes at Korhogo (9°N, 5°3W) at the 4.5 MHz frequency on May 28, 1993.

records allow their separation and show that their amplitude is comparable. The Doppler signals characteristic of oblique scattering in the electrojet and F region irregularities reveal horizontally moving plasma flow at a velocity of about 100 m/s in the electrojet region at 105 km and 130 m/s in the F region at 210 km (Blanc et al., 1996). This plasma flow is mainly controlled by the electric field in the electrojet region and by the neutral winds in the F region.

The large scale daytime motions of the F region are mostly dependent on the electrojet electric fields. Characteristic drifts have been measured at the bottom of the F region and in the upper F_2 region. Frequently, in the post sunset hours, rapid height increases of the lower F region suggest prereversal enhancement of the electric field before sunset. On the other hand, the upper F region is most of the time subjected to very large vertical plasma flows, upward in the morning and downward in the afternoon, related to the equatorial fountain process (Blanc and Houngninou, 1998; Houngninou, 2004).

The night-time ionosphere is commonly affected by the presence of density irregularities manifested as spread radar echoes in the F region in a large height range. Incoherent scatter radars showed the presence of very large plasma plumes extending up to the altitude of the satellite (Kelley and Mc Clure, 1981). Similar spread F structures were observed during the present experiments. These plumes are known to be related to the development of density depletion or bubbles arising from the lower part of the F region. After sunset, the F layer undergoes an enhanced eastward electric field and rises to altitudes where the collision frequency is sufficiently low to allow the triggering of a Rayleigh Taylor instability resulting in the equatorial spread F. During the present experiments, a few examples of very large scale oscillations of the spread F echoes (100 km/2 h) were observed and explained by the passage of bubbles in the radar field of view. The measured height and horizontal velocity of these bubbles decreases from 350 km and 140 m/s at 22.00 LT to 250 km and 60 m/s at 05.00 LT, (Cécile et al., 1996). On some occasions a different kind of spread F event was also observed, correlated with intense sporadic E echoes, in post midnight hours. An analysis of these echoes brought evidence that the wind shears visualized by the presence of metallic ions in the lower ionosphere, are at the origin of these events (Cécile, 1997).

The HF radar measurements also suggested a new hypothesis for daytime sporadic E and night-time ESF: the intense high altitude electric discharges from storm clouds (Roussel-Dupré and Blanc, 1997).

2.2. Electron electrojet and drift measurements

Sow (1999) derived the saturation speed of the electrons from the HF radar measurements. From the spectrum one can deduce the Doppler shift Δf (related to the radial drift V_r by the equation $V_r = c\Delta f/2f$, where f is the transmitted frequency).

The radial drift variation is connected to the saturation speed of electrons following the expression $V_r = V_s \cos\varphi = V_s(1-(h_0/d)^2)^{1/2}$ with $\varphi = \pi/2 - \theta$, where φ is the angle between wave vector and the horizontal plane, between 30° and 90°, V_s is the saturation electron drift circulating in the East–West direction in the EEJ, h_0 is the altitude where irregularities have the stronger intensity in the EEJ. Echoes are obtained by oblique reflections characterized by the distance d between the radar and the irregularity targets. h_0 and d are deduced from radar propagation time, taking into account the characteristics of the radar antenna.

Fig. 3 shows comparison between the H component of the Earth's magnetic field and the saturation speed for 2 days: May 8, 1993 (a disturbed magnetic day) and May 21, 1993 (a quiet magnetic day). The variations of electron saturation speed and of H component agree closely.

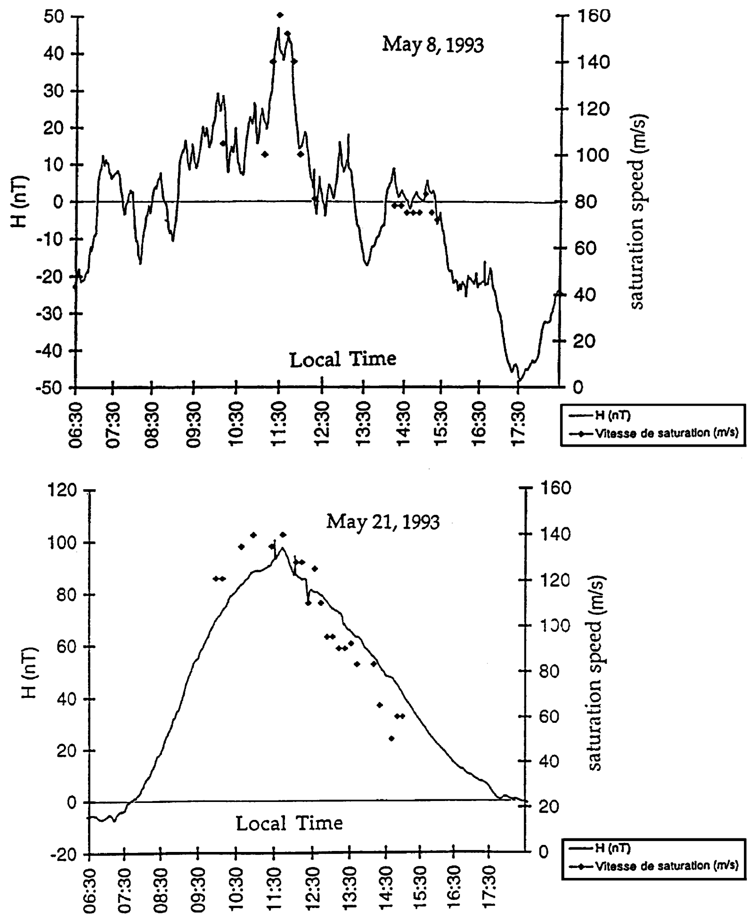

Fig. 3. Comparison between daily variation of horizontal speed of irregularities and the H component of the magnetic field: (a) magnetic quiet day and (b) magnetic disturbed day (from Sow, 1999).

3. Scientific results at regional scale

At the regional scale, our fields of research are transient magnetic field variations and the modeling of the equatorial electrojet (Section 3.1), the electromagnetic field (Section 3.2), the morphology and the dynamics of the ionospheric F_2 layer (Section 3.3).

3.1. Transient magnetic field variations and global modeling including Equatorial Electrojet

The network of 10 magnetotelluric stations have been maintained between November 1992 and November 1994 along a 1200 km long meridian profile, between Lamto (Ivory Coast latitude 6.2) to the south and Tombouctou (Mali, latitude 16.7) to the North. These stations, digitally measuring the three components of the magnetic field and the two components of the telluric field have continuously operated for 24 months.

Using a current model of a uniform ribbon at ionospheric altitude, Doumouya, 1995 and Doumouya et al. (1998) analysed 20 months interval of data, during quiet magnetic periods. With an inversion procedure, they provided an estimate of the position, width (a) and intensity of the eastward electrojet current (I_0). These parameters may be obtained for each hour of a quiet day.

These results on equatorial electrojet and counter electrojet were compared with those obtained during previous experiments of the same kind (Gouin and Mayaud, 1967; Mayaud, 1976a, b, c). All results agree closely.

Using Richmond's electrojet model (1973), Obrou (1997) computed the ionospheric current densities and the magnetic field H and Z components. The originality of this work was to introduce in the computation the winds from WINDII experiment (UARS, Shepherd et al., 1993) for local wind profiles, below 120 km. Above 120 km, the HMW model of Hedin et al. (1991) was used to complete the local wind profile. By successive computations of the Richmond's model, the initial electric field value was determined as the best fit with the latitudinal profile of the observed H component of the Earth's magnetic field.

The eastward ionospheric current density $J\varphi$ at the center of the electrojet was compared to the density current (I_0) computed from the inversion of magnetic observations using a parabolic model ($I_0 = \Delta H/0.4\,\mathrm{arctg}(a/h)$; ΔH: amplitude of the H component, a: width of the equatorial electrojet, and h: altitude of the equatorial electrojet) (Doumouya, 1995). Table 3 shows a good agreement between these two estimations of ionospheric current densities. The ratio $I_0/J\varphi$ is greater than 1 for the weak amplitudes of ΔH. At strong amplitudes, greater than 100 nT, the ratio is less than 1. The mean value of the ratio $I_0/J\varphi$ is 1.04 with a square of 0.3.

Table 3
Comparison between I_0 and $J\varphi$ at the center of the electrojet

Jours	ΔH (nT)	I_0 (A/Km)	$J\varphi$ (A/Km)	$I_0/J\varphi$
22/01/93	67	136	110	1.24
23/01/93	65	159	105	1.51
24/01/93	68	131	100	1.31
26/01/93	83	171	170	1.01
27/01/93	107	221	250	0.88
28/01/93	102	186	280	0.66
29/01/93	106	209	209	0.70
$\langle I_0/J\varphi \rangle = 1.04, \sigma = 0.3$				

I_0: eastward electric current density derived from magnetic observations; $J\varphi$: eastward electric current density computed with the physical model Richmond 1973, from Obrou 1997.

3.2. Electromagnetic field at equatorial latitude in the West African sector

The main sources of telluric electric fields are the variations of the external electric currents circulating in the Sun Earth's system, mainly the quiet time ionospheric electric currents, the disturbed ionospheric and magnetospheric electric currents. The behavior of the Earth potentials at dip latitudes is in fact a matter of debate. To our knowledge, very few experiments involving direct observation and recording of the Earth potential variations at dip latitudes have already been reported (Hutton and Wright, 1961; Hutton, 1962), and simultaneous observations of both electric and magnetic fields, transient variations along a chain of equatorial stations have never been made.

The Earth potential experiment carried out on African longitudes in the frame of the IEEY is actually an original contribution to the equatorial electrojet studies.

Also the question of the induction in Equatorial Electrojet region remains difficult. As for magnetic storm variations, it was theoretically addressed by many authors (Srivastava, 1965; Peltier and Hermance, 1971; Schmucker, 1970), who derived impedance tensor estimates by introducing a source field geometry in the magnetotelluric equations. However, the lack of simultaneous observations of both electric and magnetic fields variations at a chain of equatorial stations made it impossible to assess the validity of the theoretical results. As for the Solar regular variation (S_R), the almost complete lack of data does not permit one to have any experimental result on the induction for S_R frequencies at low dip latitudes. Ducruix et al. (1977), theoretically addressed the question of the induction by the S_R variation in Equatorial Electrojet region in terms of

Earth rotation below the ionospheric currents of fixed geometry and intensity. They showed that induced Earth potential variations only exist in presence of North–-South ionospheric currents, and are therefore expected to be negligible if not null around LT noon. More generally the theoretical results established by Ducruix et al. (1977) clearly shows that the analysis of the Earth potential will provide information on the ionospheric current connected to the Equatorial Electrojet.

In order to get experimental information on the induction problem at dip latitudes, transient variations of telluric potentials were recorded together with those of the magnetic field. Telluric potentials variations were recorded by means of electrodes installed at the ends of two NS and EW lines of 200 m length. Fig. 4 presents an example of observed telluric potential variations.

The analysis of the observed Earth potentials and magnetic variations enable one to address experimentally to the question of the induction in Equatorial Electrojet regions. It is likely to provide information on the primary inducing field i.e. the electromagnetic field of external origin on the one hand, and on the medium in which induction takes place, i.e. the crust and the upper mantle below the stations on the other hand.

The first results obtained from the IEEY telluric potentials data are presented by Vassal et al. (1998). These authors address in particular the question of the induction at S_R frequencies and consider data from magnetically quiet days. They showed that the transient variations exist in the telluric potentials at these frequencies. But they demonstrate that these variations are not correlated with those generated in the magnetic field by the Equatorial Electrojet, see Doumouya et al. (1998), for a description of these magnetic variations). The telluric potentials are induced in the solid conductive Earth by transient magnetic variations of ionospheric primary sources. The results established by Vassal et al. (1998) therefore raise the question of the actual sources of the diurnal variation observed in the telluric potentials: which primary ionospheric source,

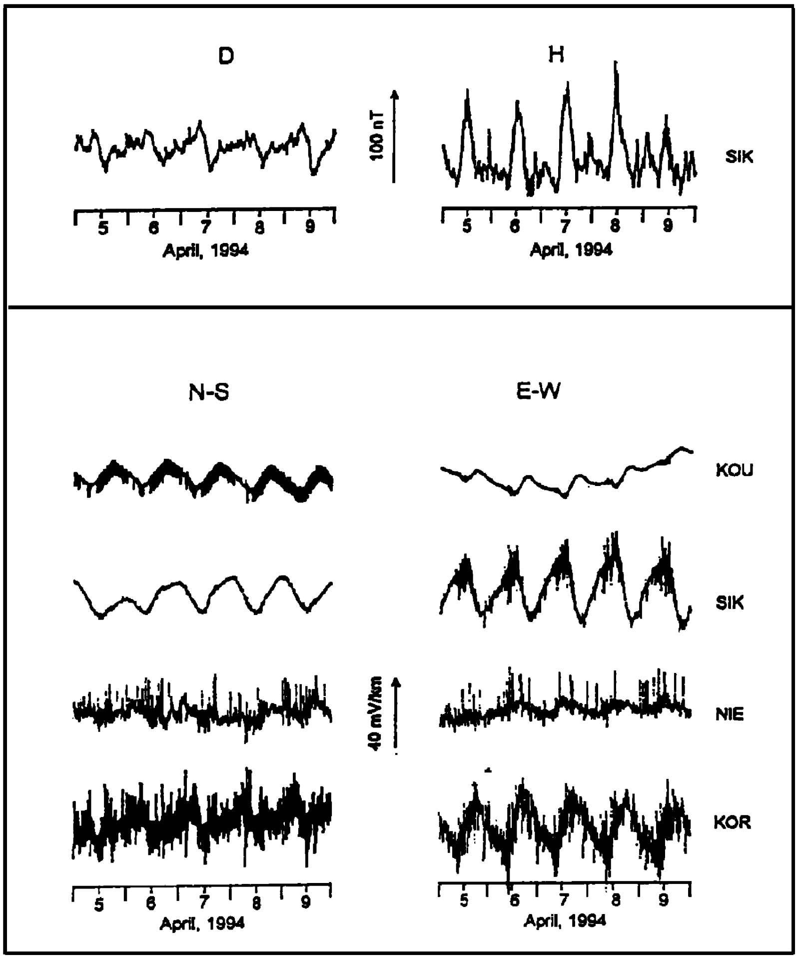

Fig. 4. Telluric potentials and magnetic field associated, observed at four stations of the electromagnetic profile.

and to what extent the observed variations in the telluric potentials are distorted by local regional features of the distribution of conductivity?

Models are presently developed to interpret these observations.

3.3. Morphology and dynamics of the equatorial plasmas

In low latitudes dynamics, there are many interactions with very different space and time scales.

Different physical processes of forcing are found in our preliminary results:

(1) The atmospheric tides and its global S_R quiet-time dynamo (Mayaud, 1965) and all the mesospheric wind disturbance processes which modulate the equatorial currents.
(2) Penetration of the magnetospheric electric fields from high to low latitudes (Vasyliunas, 1970; Peymirat and Fontaine, 1994).
(3) The thermosphere motions, with subauroral sources of "quiet" and storm time winds which include mesoscale complex dependance of the equatorial zonal jet (Blanc and Richmond, 1980; Richmond et al., 1992; Richmond, 1973).
(4) Non stationarity of the plasma rise velocity.

Fig. 5 (Sambou et al., 1998) shows the latitude versus local time of f_0F_2 variations for three successive days in March, 1993 (bottom panels), and the variations of the H magnetic field component (top panels).

On March 27 and 28, we observed an f_0F_2 enhancement from 10 LT to 12 LT across the magnetic equator. This illustrates a transient phase of fountain slowdown at peak F_2 layer levels. There is accumulating plasma due to a deficient transmission of the electric field from low to high altitudes.

Surprisingly, our IEEY ionograms do not show the rising strata observed in comparable declining solar

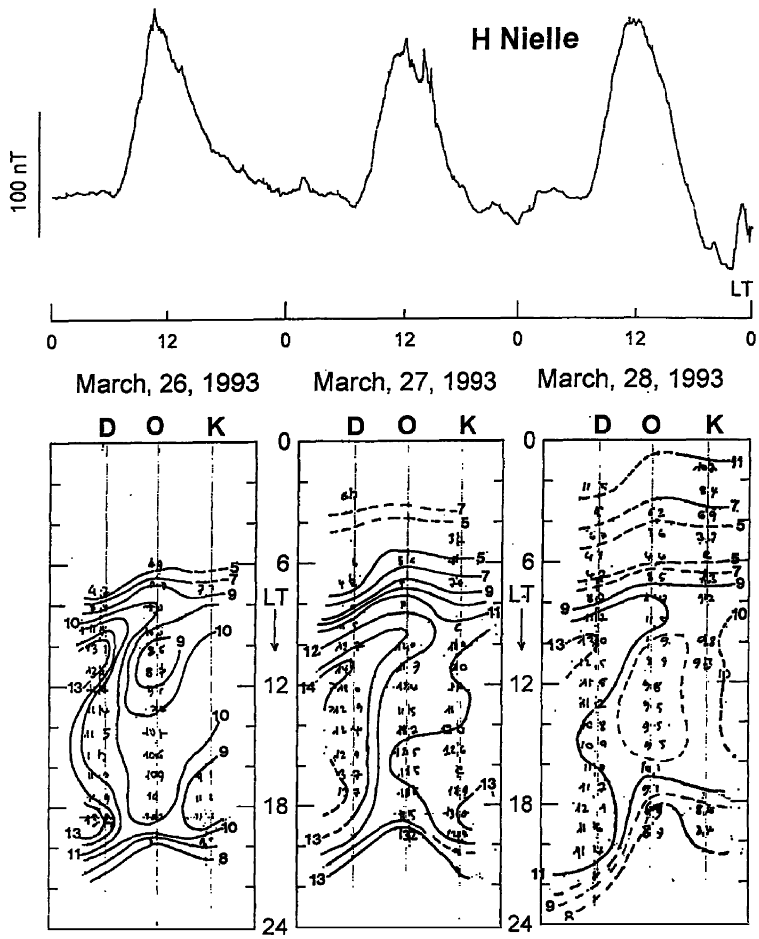

Fig. 5. Evolution of the f_0F_2 (bottom panels) and H component of the Earth's magnetic field (top panels), D is for Dakar, O for Ouagadougou and K for Korhogo (from Sambou et al., 1998).

cycle years (Faynot and Vila, 1979). These discrepancies are not yet understood.

Simple and dip latitude-uniform ExB drift variations (according to the Appleton "fountain" scheme, 1946; Lyons and Thomas, 1963) are not enough to explain the plasma flow control of such F_2 peak intensities. Even when it remains the dominant feature of the $f_0F_2(\Phi, t)$ contours, the trough itself is frequently abnormal in its latitude changes (Abur-Robb and Windle, 1969).

The most spectacular distortions are local crest enhancements, and total magnetic field-aligned dome events filling-in the trough zone for 2 to 5 h, with abrupt onset; these abnormal f_0F_2 distributions (Fig. 5, bottom panels) are studied in Sambou et al. (1993, 1998).

3.4. *Further types of equatorial distortions: night-time* F_2 *layer*

Equatorial Spread F (ESF) results from quarterly hourly ionograms (Farges and Vila, 2003), during the December 1994 to November 1995, a period of lower declining solar flux have received a particular attention. They cover the great variability of scales from faint seed echoes to the various patch producing mechanisms. Also the field-aligned diffusion effects between Ouagadougou and Dakar make Ouagadougou results more indicative of ESF sources. Our detailed sequences establish that classical Rayleigh Taylor rise events (plume or bubble) are frequently combined with wave shear triggers, but the rising patch scheme is frequently invalid, while inner layer coupling instabilities also produce a number of ESF events. The horizontal dynamics have been observed with the Fabry-Perot interferometer located at Korhogo which measured horizontal winds of the F_2 layer sub peak (Vila et al., 1998).

Seasonal study of ESF occurrence in the Brazilian sector has been done by Sobral et al. (2002) and comparison with the African sector is in progress.

Finally, the data of the ionosonde of Korhogo contributed in the progress of IRI (Bilitza et al., 2000; Obrou et al., to appear).

4. Scientific results at a Planetary scale

At this scale, two main fields of research were developed: the planetary parametrization of the equatorial (Section 4.1), and the electrodynamic coupling between high and low latitudes (Section 4.2).

4.1. *Local time and longitudinal variations of the Equatorial Electrojet for the determination of the main field and the lithospheric field*

The magnetic effects of ionospheric current systems are sources of disturbance for satellite borne of the Earth's interior magnetic field measurements (main field and lithospheric field). Near the dip equator the equatorial electrojet (EEJ) creates a strong magnetic field which needs to be removed for an accurate description of the internal field. Doumouya and Cohen developed a correction method from the EEJ contamination, using ground based data and an empirical model of the EEJ. They studied the local time and longitude dependance on EEJ and built a planetary parametrization of EEJ. They used data from the three equatorial chains of magnetic stations (India, Africa and Brazil) operating during the IEEY in addition to three stations closed to the dip-equator (Ancon in Peru, Mokolo in Cameroon and Yap in the Pacific). Fig. 6 from Doumouya et al. (2003) show the Heliosynchronous view of the EEJ at 12 LT at the altitude of 450 km.

4.2. *The equatorial electrojet as part of a global ionosphere magnetosphere current system: electrodynamic coupling between high and low latitudes*

Kobéa et al. (1998) and Kobéa, 2001 analysed the storm event of May 27, 1993. On May 27, a magnetospheric disturbance generated a Westward electrojet in the morning sector and the connection between the auroral and equatorial electrojets was detected, which coincided with the disappearance of plasma irregularities (Blanc and Houngninou, 1998). Kobéa et al. (2000) analysed two types of DP disturbances observed on May 27th 1993 using a large geomagnetic data set. Fig. 7 from Kobéa et al. (2000), shows the electric potential, on May 27, 1993 at 12:30 and 12:45 UT, associated to the "Magnetic Fluctuation Event", the first type of disturbance. These potential maps, derived from data, using AMIE program (Richmond and Kamide, 1988), reproduce the well known pattern of the two convection cells of DP2 current system (Nishida, 1968). For the second type of disturbance analysed as "Overshielding event", Kobéa et al. (2000) have been able to clarify certain aspects of the penetration of the electric fields and current from high to low latitudes, and showed that after a rapid decline of auroral activity a westward perturbation of the equatorial electrojet can be observed during 3 h without any shielding effect. With the MTIEGTM model (Peymirat et al., 1998), Peymirat et al. (2000) were able to reproduce the main features of the observations.

5. Conclusion

The International Equatorial Electrojet Year provides a large data set of magnetic, ionosonde, HF radar and interferometer data. From these observations many

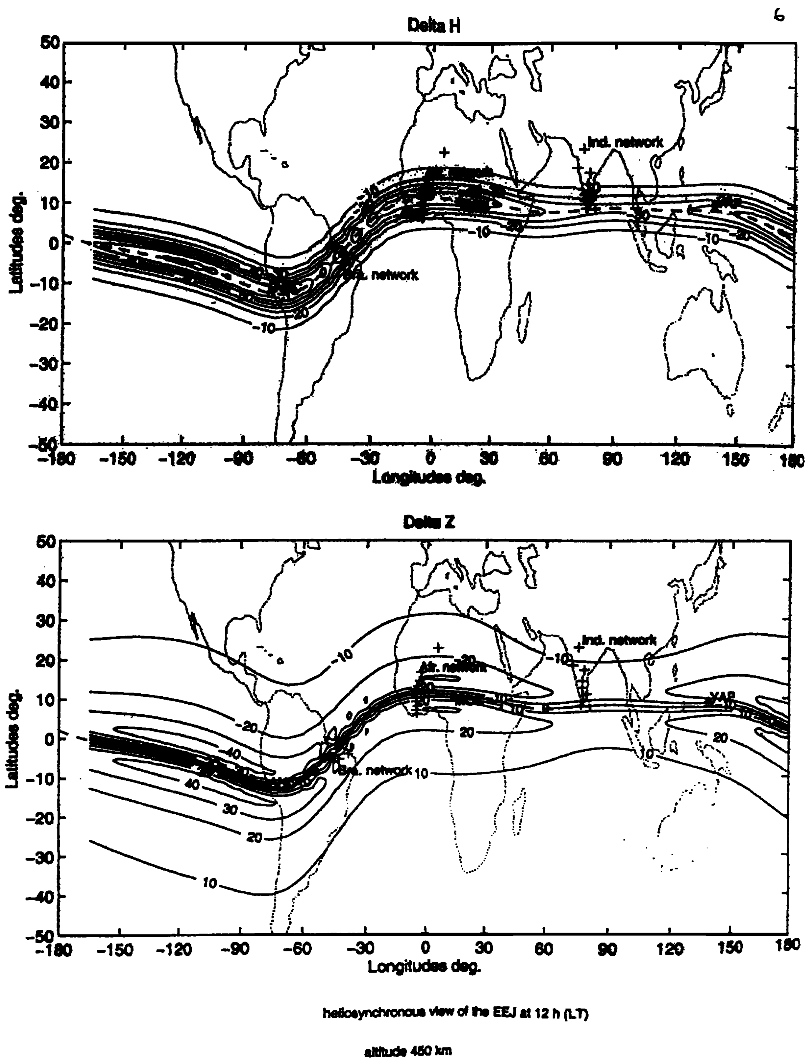

Fig. 6. Heliosynchronous view of the EEJ at 12 h (LT) at the altitude of 450 km (from Doumouya and Cohen, this issue).

topics of research were possible which lead to the following results:

- explanation of the "necklace" echoe as a consequence of oblique propagation;
- observations of the storm electric field discharges at Es layer for the daytime and ESF for the night-time;
- observations of gravity waves effects and ESF multi-process sources;
- determination of electron speed in the EEJ;
- observations of night-time winds in the African equatorial zone;
- observations of telluric electric fields in African equatorial zone;
- a parametrization of the EEY at a regional and at a planetary scale from magnetic data and comparison with satellite data (OERSTED, CHAMP);
- modelization of the EEJ at a regional scale using ionospheric data and the Richmond's physical model of EEJ;
- contribution to the IRI;
- study of equatorial crests anomalies;
- clarification of the electrodynamic coupling between high and low latitudes through shielding and over-shielding events and modelization with the MTIEGCM.

A positive consequence of the IEEY in West Africa has been the development in two University departments of geophysical research groups and the creation of two ground-based observatories at Korhogo (Ivory Coast) and Dakar (Senegal).

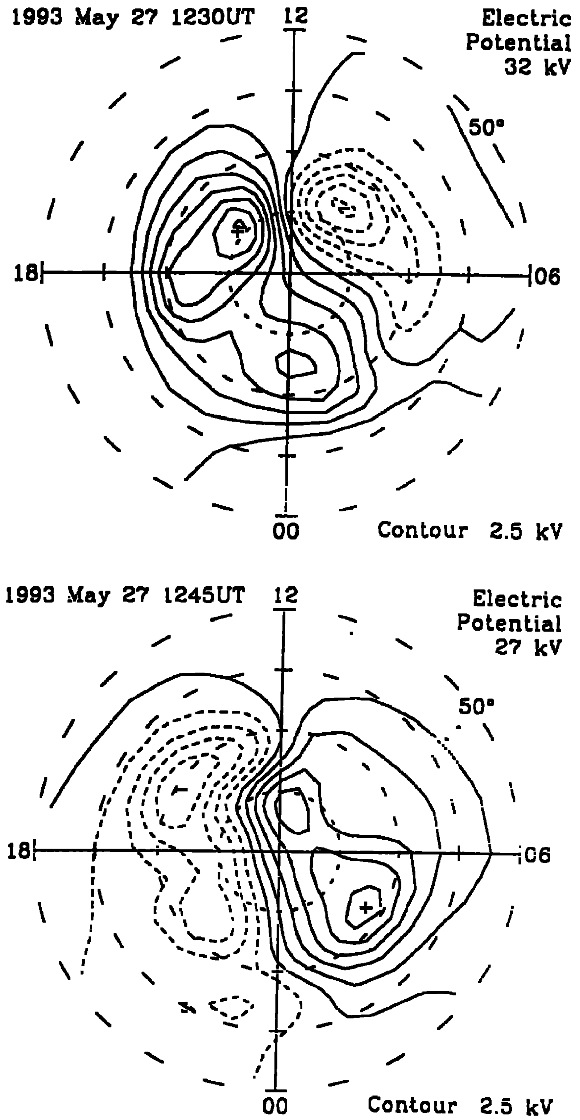

Fig. 7. Electrical potentials at 12.30 and 12.45 UT on May 27, 1993. The contour interval is 2.5 kV (from Kobéa et al., 2000).

Future Prospects for the IGRGEA

Three instruments are actually being set up before regular observations:

(1) At Dakar (Senegal) a SCIPION research HF radar able to deliver ionograms and Doppler spectra at any reflection frequency (LeRoux et al., 1998).
(2) At Korhogo (Ivory Coast) an HF STUDIO multi azimuth sensitive HF radar with proximal mono-static functions for research and with distant back-scatter mode possibilities for propagation studies.
(3) At Korhogo a new 630 nm Fabry-Perrot interferometer for night-time interferometry, amplitude and temperature measurements.

We now need to develop detailed comparisons with Indian and American longitude sectors.

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