Space Research in Africa
Some Achievements from 2007 to 2012

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Abstract This article presents the results of a research network Europe Africa established in 1995 after the International Electrojet Equatorial Year (1992-1994). During the last decade, this research network has been involved in two international projects: the International Heliophysical Year (2007-2009) and International Space Weather Initiative (2010-2012).The participation in these international projects increased the number of PhD and multiplied the number of scientific papers. Many scientific results have been obtained. Teaching and working methods have been also developed. We emphasize in this article the last two points.

Keywords: Space Research, Africa, AMMA, SCINDA, GPS

Introduction

It was at the Vancouver conference in 1987, that the Inter divisional Commission for Developing Countries ICDC of International Association for Geomagnetism and Aeronomy (IAGA) has asked the international community to develop studies on the equatorial electrojet and International Equatorial Electrojet Year (IEEY) was organized to answer to this attempt. Instruments were deployed in West Africa (Amory-Mazaudier et al., 1993) and many scientific results obtained (Amory-Mazaudier et al, 2005). This first project has trained researchers of Benin Senegal Ivory Coast and France. Research teams have been formed in various African countries and research continued. In 2005, researchers of the International Group Europe Africa have been contacted by the international community to develop Heliophysics (http://ihy2007.org) and Space Meteorology in Africa (http://iswi-secretariat.org).This paper presents the organization of the work in these two last projects and includes in three parts: 1) deployment of scientific GPS instruments, 2) training and 3) results. The three projects IEEY, IHY and ISWI are part of the United Nations Basic Space Science Initiative program (http://www.oosa.unvienna.org).

Deployment of scientific instruments

Under the first IHY project (2007-2009), the work of international coordination began in 2005. A fundamental objective was to identify the different African institutions and scientists capable of maintaining scientific instruments and data sharing. The principle is to distribute a large number of few expensive scientific instruments, to develop networks of geophysical measurements in Africa, (Harrison et al., 2005; Davila et al., 2007; Kitamura et al., 2007).

We report here on the GPS networks .Two GPS networks participated in IHY project:

1) AMMA network (http://www.amma-international.org)

2) SCINDA network (http://www.fas.org.org/spp/military/program/nssrm/initiatives/scinda.htm).

To facilitate the work and the sharing of data it was recommended to equip laboratories with dual frequency GPS receiver 4004B and use the standard RINEX format for the data. It was also recommended to facilitate the exchanges, to put the data on the web. GPS data are interesting for different communities (radio navigation, geodesy, ionosphere, atmosphere etc ...), so it seemed important to work in an interdisciplinary framework.

This international project has identified communities interested in using GPS and helped to increase the number of GPS data shared via the internet. In 2007 Amory-Mazaudier et al. (2008) identified 35 GPS stations in Africa (20 on the web) from different networks (SCINDA: 9, AMMA: 6, UNAVCO+NOAA+IGS: 19, Telecom Brest: 1). Figure 1 shows the number of GPS stations shared on the web in early 2012, more than 100. In figure 1, the red points represent the stations installed in 2011 (23 stations). The AMMA GPS network is now on the web included in the IGS network (IGS International Geodetic Survey). The significant increase of GPS stations in Africa is due to the UNAVCO. There is now an open archive for African GPS data in RINEX format: www.afrefdata.org. AFREF is the African geodetic Reference Frame.

We must note here that many existing GPS stations are not yet shared via the internet (*Egypt: 9 GPS, Morocco: 15 GPS, South Africa: 50 GPS, Algeria: ~ 50 GPS etc ...*).

This is a next goal: the sharing of all GPS data from Africa.

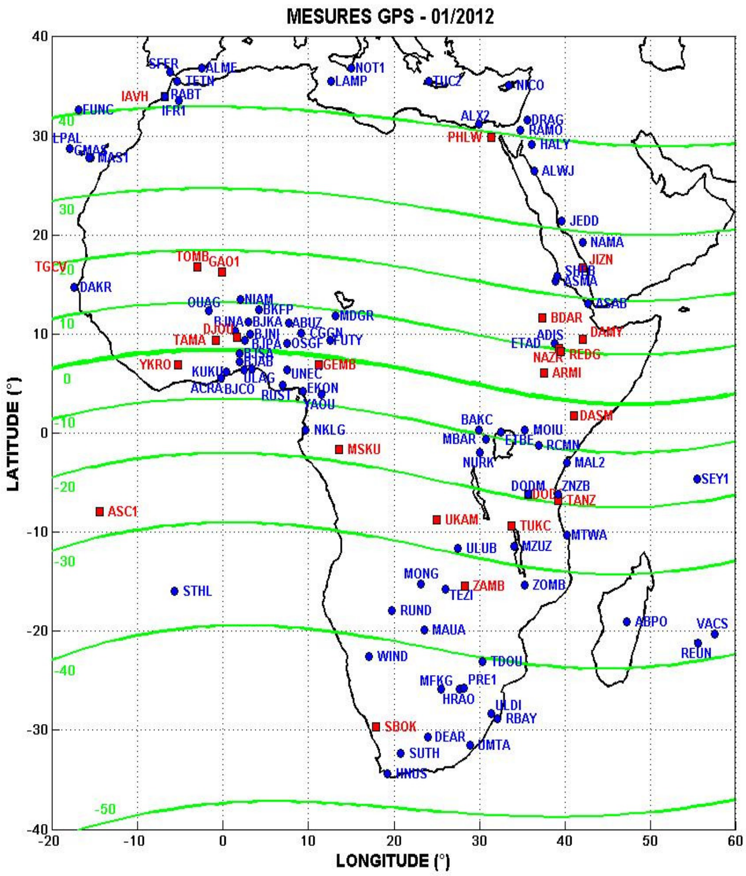

Figure 1: GPS receivers in January 2012 (from Rolland Fleury)

GPS websites

IGS:

http://sopac.ucsd.edu
http://cddis.gsfc.nasa.gov **http://igs.ensg.ign.fr**

NOAA and UNAVCO

http://www.ngs.noaa.gov/CORS
http://www.unvaco.org

Training

Training was one of the major objectives of the program UNBSSI. This led to the formation of many scientists in the Space Sciences in Africa and the creation of many research teams. In this part we present the training developed in the IRGGEA network.

The main objective of IRGGEA schools is to improve the level of research in the countries concerned and to enable African scientists to participate in and contribute to international projects.

The key points are:

- the competence to use existing data sets and tools related to studies of Space Weather.
- the use of data recently collected in Africa by African scientists, and the data existing in the database. It is estimated that the use of existing data within 10%.
- Use the results of space weather combining ground data and satellite data, research and sustainable development (eg use of GPS for geophysical studies, navigation, etc ...)

To achieve these objectives, the course included:

- Lectures on the scientific understanding of the measures, information that can be extracted from the data and examples of applications in Space Weather.
- Computer labs for the use of existing databases as SPIDR, IRI, IGRF, etc ...

To meet these objectives, the school has:

- Understand the solar physical processes and their actions on the environment near Earth: magnetosphere, ionosphere, atmosphere,

Knowing the recent discoveries about the sun, *Study the impact of the Sun on the Earth's plasma environment,*

Understand the sun's influence on Earth's atmosphere,

Knowing other uses of measuring instruments useful for the development as GPS for navigation

- Use the existing relevant data in different databases and the old data with the instruments deployed within the current International Projects data.

Table 1 present the different schools organized within the framework of this research network. There are three types of training.

1) Schools introducing to Space Weather, with training on the use of GPS, GIS, databases and new technologies; students attending these schools come from different disciplines and exercises are organized by grouping students according to their discipline.

2) Highly specialized schools on GPS data processing: the training is provided by the institute of Telecommunications at Brest. Few PhD students participate in the school with their own data

3) Schools on the physical relationship of the sun earth system, trying to highlight the impact of the sun on the Earth's electromagnetic environment. The training is for students in M2

All schools include lectures on fundamental physics and practical work in small groups.

Except for the school in Morocco, organized with the CRASTE-LF, all the schools organized in a country are financially supported by the country. Column 4 gives the percentage of the contribution of the country. In general the students participating to a school are mainly from the country where the school took place, only few students are coming from closer countries.

One of the schools was organized in the United Center CRASTE-LF at Rabat in Morocco. The interest is that students from different African countries were financially supported by United Nations and NASA. The figure 3 shows the country of the participants to the ISWI school in Morocco.

In these schools, more than fifty teachers taught in French and English about 300 students. Following each school students are mentored to theses by professors teaching in schools. To defend their thesis students must have published several articles in international journals. Figure 4 shows the number of papers and PhD since 1990 at the beginning of the first project: the International Equatorial Electrojet Year. We must recall here that the IRGGEA is also working in Asia and that the publications concern all the students from Africa and Asia. From 1990 to 2006 there are 48 papers (~3 per year) and 10 PhD (1 PhD each 2 year) and 2 schools. Since 2007 there are 54 papers (~9 per year) and 11 PhD (~2 per year) and 7 schools.

Table 1 : IRGGEA Schools

Scientific project	Country/year	Training Organizer in the country	Participants	Main financial supports
IEEY	France 1992	Physical process in the Sun earth system + technical training in laboratories PhD students / 6 weeks Christine Amory-Mazaudier	5	France ~100%
IEEY	Côte d'Ivoire 1995	Physical process in the Sun earth system/2 weeks Students M2 Antoine Achy Séka	30	Côte d'Ivoire ~ 50% France
IHY	Congo 2009	GPS, GIS and Introduction to Space Weather/ 7 days Bienvenue Dinga	30	Congo ~ 18% France Microsoft
ISWI*	Egypte 2010	GPS, GIS, new technologies Data base and Introduction to Space Weather/2weeks Ayman Marhous	50	Egypte ~50% France Microsoft
ISWI*	DRC 2011	GPS, GIS, new technologies Data base and Introduction to Space Weather/2weeks Bruno Kahindo	90	DRC ~75% France Microsoft
ISWI	France 2011	GPS data processing PhD students / 5 days Roland Fleury	4	Participants (ticket) France
ISWI*	Morroco CRASTE-LF 2011	Physical process in the sun earth system Student M2/2 weeks Christine Amory-Mazaudier; Abderramahmane Touzani Nicole Vilmer	28	France NASA UN
ISWI	France 2012	GPS data processing PhD students/5days Roland Fleury	4	Participants (ticket) France
ISWI	Nigeria 2013	Physical process in the sun earth system Babatunde Rabiu	20	Nigeria 100%
ISW*I	Algeria 2013	Physical process in the Sun earth system Students M2/2weeks Naima Zaourar	30	Algeria ~90% France

* : the reports on these schools are available on the site www.iswi-secretariat.org

The participation to the international IHY and ISWI projects boosted the IRGGEA. The fact that many scientific instruments were deployed all over the world obliged to train the students in the use of data collected during the IHY or ISWI projects.

Room of OFSAC

Figure 2.a shows the class rooms used for the practical work during the school in DRC, in 2011. Each student has a computer to perform the exercises proposed by the professor. In general the training is made in computer centers

Room of ERAIFT

Figure 2.b: Class rooms for practical work in ISWI school in DRC (September 2011)

Figure 3: countries of the participants to the school in Morocco

The concept of Heliophysics has brought together different communities (solar physics, magnetosphere, ionosphere, atmosphere etc…) and leads to analyze very large databases because solar activity is linked to the solar cycle of about 20 years. Major results on the relations between the solar magnetic field and the equatorial ionosphere were obtained by African scientists during the last decade. In the IRGGEA network the first authors of publications are very often students from Africa or Asia (Amory-Mazaudier 2012). This figure does not list all the publications made in Africa in the context of IHY and ISWI projects. There are also other publications by researchers from South Africa, Kenya, Nigeria etc …

With the ISWI program, we have now to add the impact of the Sun on technological systems.

The instruments deployed are very useful. GPS receivers can estimate changes in the total ionization (TEC), and we know that this ionization is responsible for the modification of the signals from the satellites to the earth, useful signals for air navigation. Networks magnetometers will estimate the ionospheric electric currents and the induced currents in the earth which are causing damage transformers.

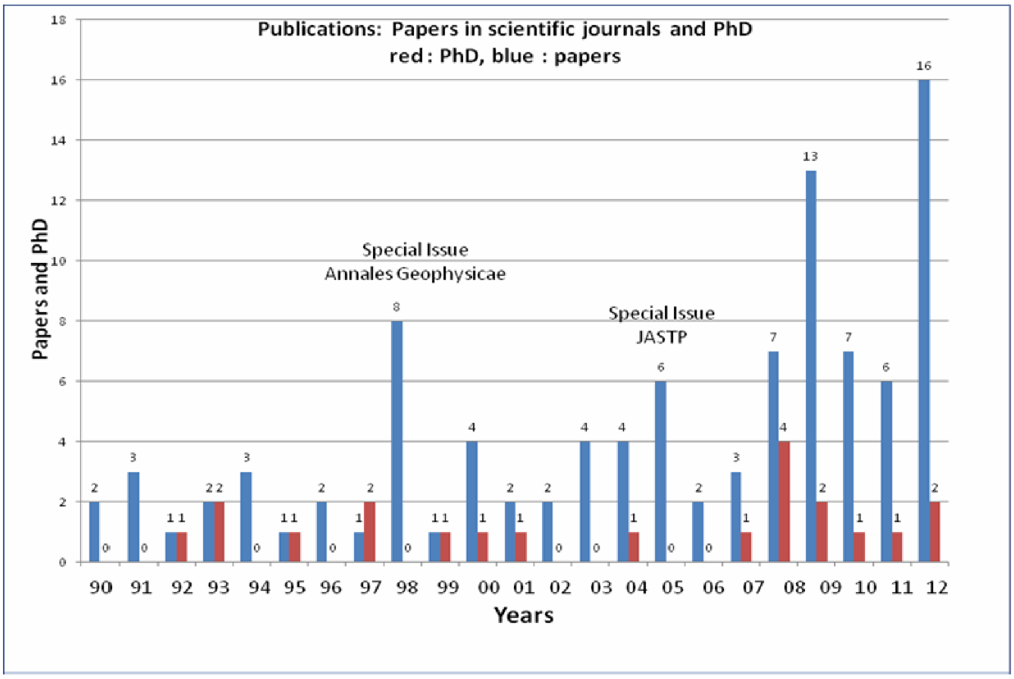

Figure 4: Publications in the IRGGEA

Results

One of the results that we wanted to achieve, by developing the network of GPS, was to study the phenomenon of Equatorial Fountain in Africa. Figure 5 shows the physical processes at the origin of the equatorial fountain. At the magnetic equator the terrestrial magnetic field is horizontal as well as the movement of the neutral atmosphere. The ionospheric dynamo produces a vertical electric drift **ExB/B²** which transports electrons to high altitudes. At high altitudes (several hundred kilometers), the forces related to the pressure gradient and gravity produce a shift of the motion of the electrons towards lower latitudes. It thus forms a hole density at the equator and two maxima density at magnetic latitudes 15 ° N and 15 ° S (see Figure 5).

Through the deployment of GPS stations in Africa, it is now possible to establish maps of ionization (VTEC) in the equatorial region. Figure 6 shows such a map recorded on October 21, 2012. We see two maxima of density and the equatorial through at the magnetic equator which is above the geographic equator.

There are other possible studies with GPS stations, which are studies of scintillations. The scintillation phenomenon is observed by rapid variations in amplitude and phase of the signal transmitted by the satellite signal to Earth. This phenomenon is a significant source of error in the positioning performance.

The Equatorial Fountain and scintillations are observable phenomena in the equatorial zone, and many studies on these phenomena remain to be done.

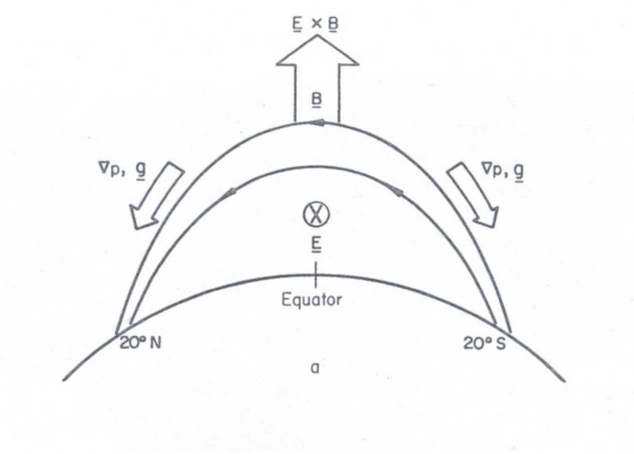

Figure 5: Equatorial Fountain

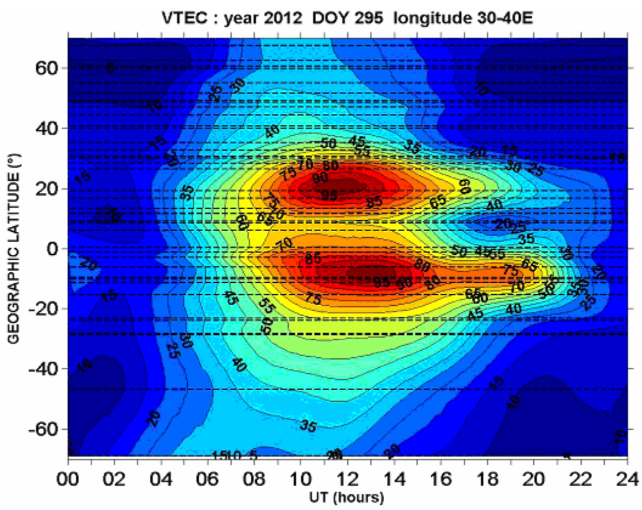

Figure 6 : First map of the VTEC

Conclusion

This presentation shows the importance of international cooperation to develop scientific research in all countries. In the past many measures have been made in the North and few in southern countries. The modeling of geophysical phenomena on a global scale requires deploying instruments all over the world. Such a deployment of scientific instruments does not just be led by a single country. The support of the United Nations in such global program is essential.

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