



# Training on GNSS and Space Weather in Africa in the framework of a North-South scientific network GIRGEA

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# Outlines

- The UNBSSI program
  - IEEY, IHY, ISWI => ISWI network
- The scientific network GIRGEA
- Science and GNSS
  - Use of GNSS for research
  - Geodesy - Tectonic plates\*, atmospheric studies\*, Space Weather
  - Integration of Physical processes from the Sun to the Earth
- the working method
  - Schools on GNSS or Training on GNSS in school on Space Weather\*
  - PhD students (use of GNSS)
    - PhD defended (5)
    - PhD in progress (9)
- Conclusion
  - The success
  - The problems that are still to be solved

# UNBSSI

## United Nations Basic Space Science Initiative

1992-1994

IEEY : International Equatorial Electrojet Year

2007-2009

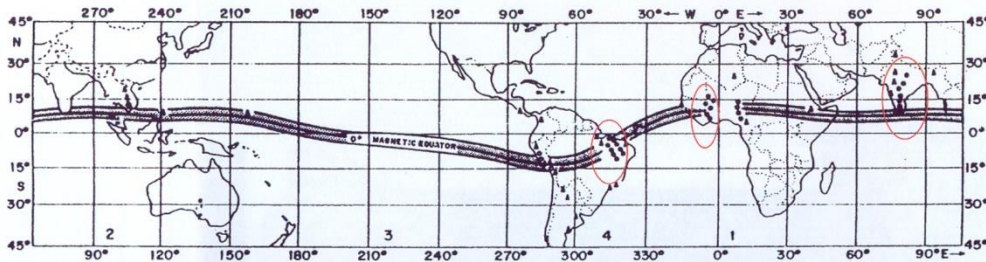
IHY : International Heliophysical Year

2010-2012

ISWI : International Space Weather Initiative

# IEEY : International Equatorial Electrojet Year 1992-1994

## International Equatorial Electrojet Year 1992-1994



Brazil, 1992



**LEADERS :** M.A. Abdu (Brazil)/ America, B.A. Arora (India)/Asia, A. Onwumechili and S. Ogunade (Nigeria)/Africa, O. Fambitakoye (Niger)/West-Africa/Europe

In the framework of the IEEY projects we train 4 students: they are now Professors

Observatory at Korkogo  
Côte d'Ivoire 1992-2002)



Main Building



Antenna of the HF radar

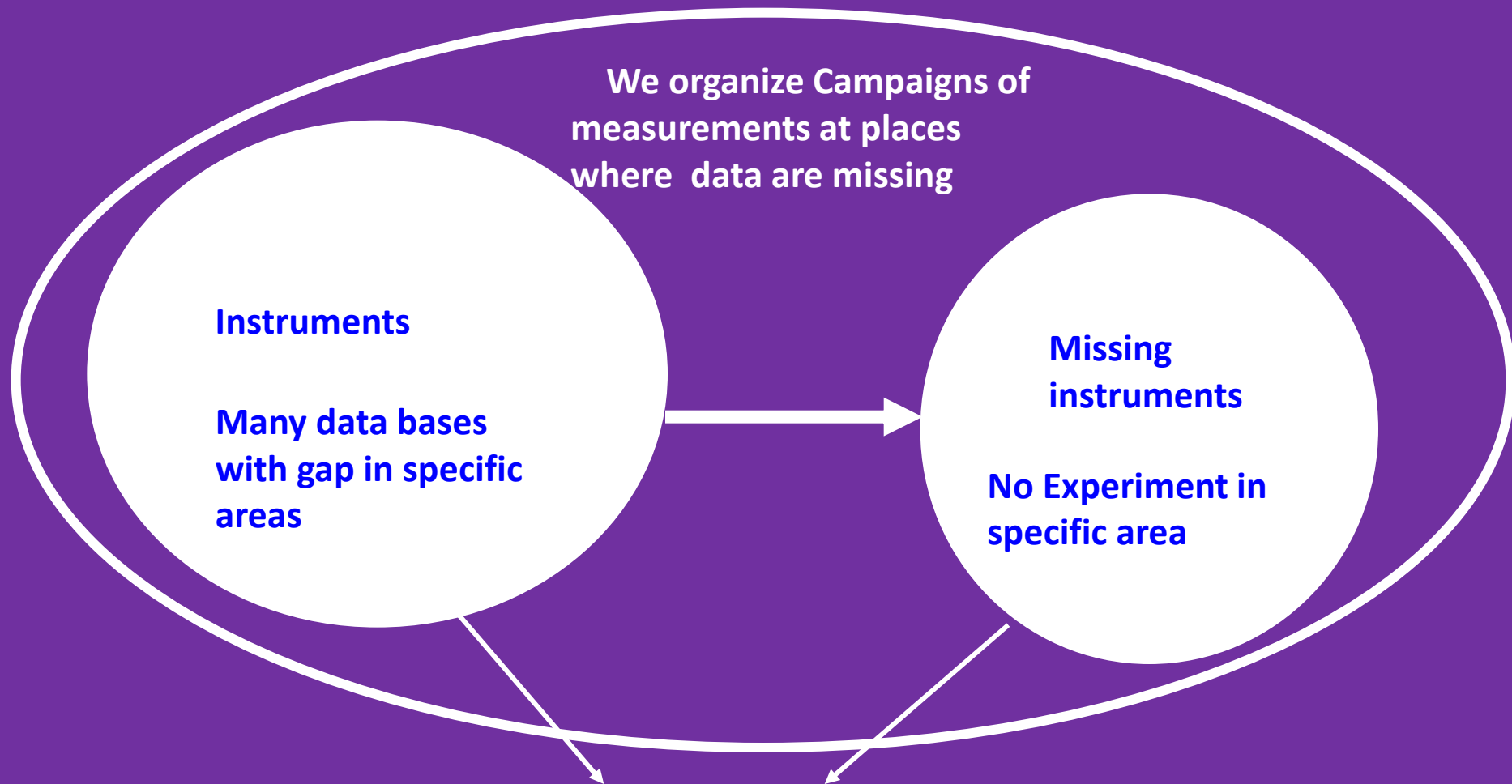
Interferometer



**GIRGEA founded 1st January 1995**

**Work in an International Laboratory : International programmes**

**Observation of the whole planet (satellite and ground measurements)**

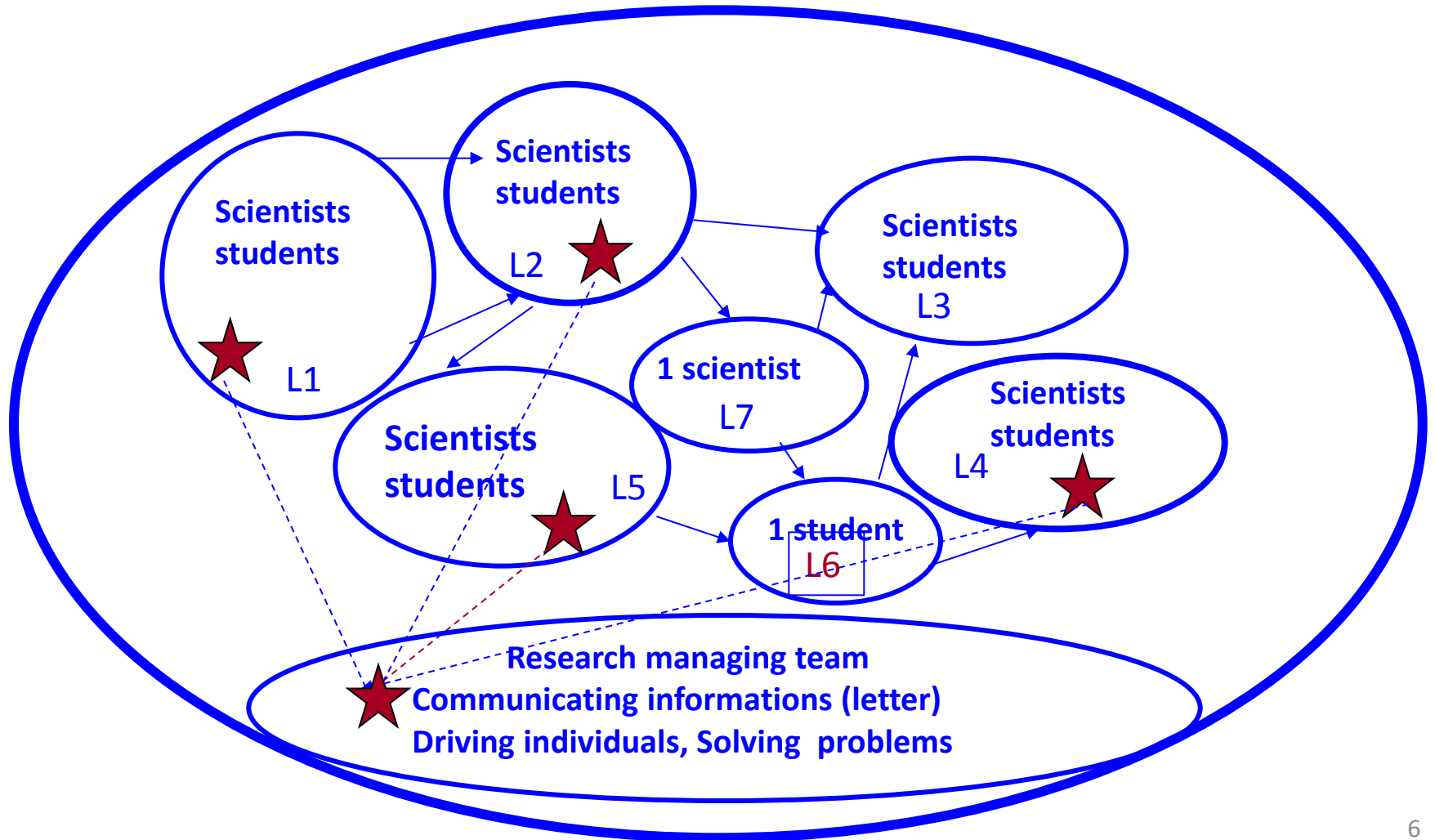


Large data bases with a good coverage of the whole planet  
There is a necessity for global studies in Earth's environment

# Work in an International Laboratory : LWB

## To share data and knowledge

- Personnel in an open structure of existing laboratories



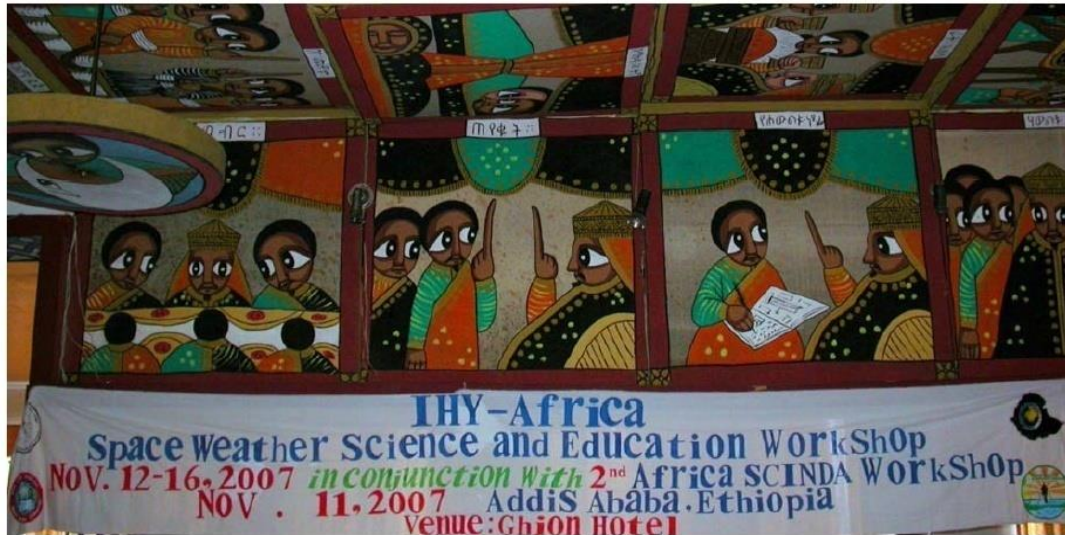


# International Heliophysical Year 2007-2009

a turning point in the participation of African countries

## WHOLE AFRICA

### IHY-Africa Space Weather Science and Education Workshop Report



The Ethiopian Physical Society

in conjunction with



Addis Ababa University and Bahir Dar University

#### *African Countries Represented (20): (72 representatives)*

Algérie  
Bénin  
Burkina Faso  
Cameroon  
Cape Verde  
Côte d'Ivoire  
Démocratique République du Congo  
Egypt  
Ethiopia  
Kenya  
Liberia  
Libya  
Mozambique  
Namibia  
Niger  
Nigeria  
République du Congo  
Sénégal  
South Africa  
Uganda

#### *Other Nations Represented (9): (56 representatives)*

Australia  
Austria  
Canada  
France  
India  
Italy  
Japan  
UK  
USA

Request of the international community: to train in French

# ISWI project 2010-2012

ISWI network: <http://www.iswi-secretariat.org>

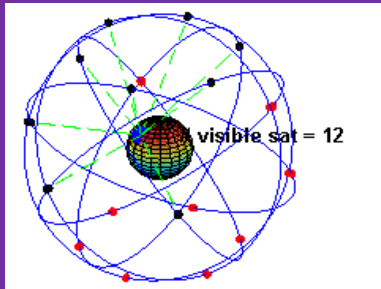


1. Distribution of scientific tools
2. Training schools / GNSS and Physics of the Sun Earth's System
3. PhD => position in the country
4. Curricula in Universities

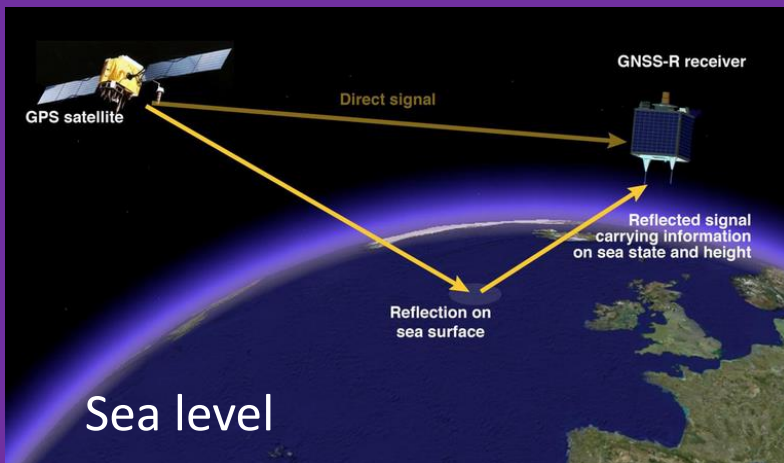
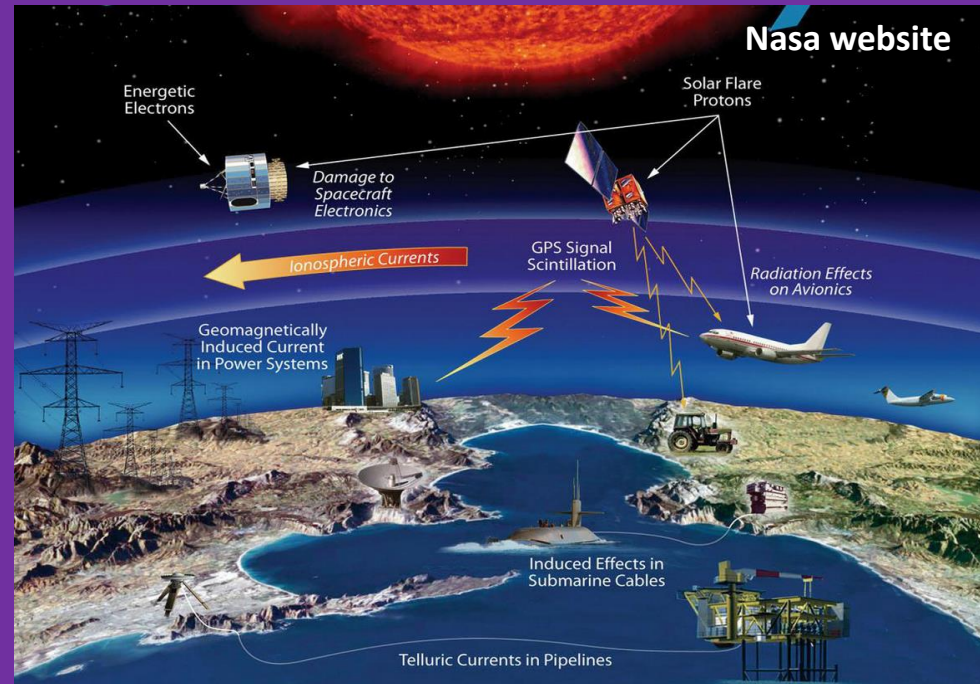
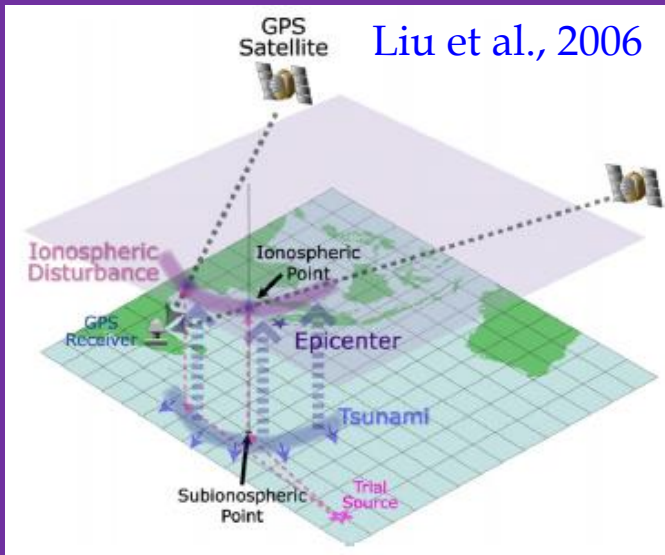


# Science and GNSS

# Use of GNSS for research



The ionosphere is the largest source of perturbations for GNSS signals



GNSS is a research tool for many scientific disciplines. GNSS receivers are cheaper than radar, lidar and other scientific instruments and can be easily installed on the ground. GNSS receivers are the most common instruments on the globe some tens of thousands.



# Science and GNSS : Tectonic plates

## GPS and plate tectonics

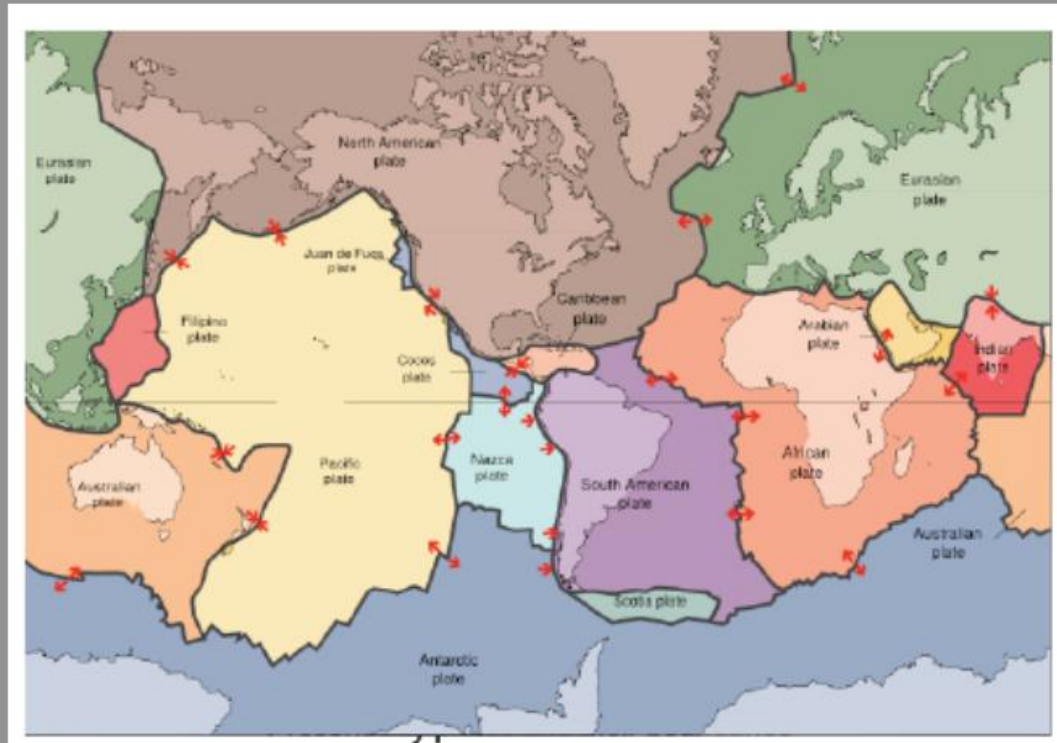


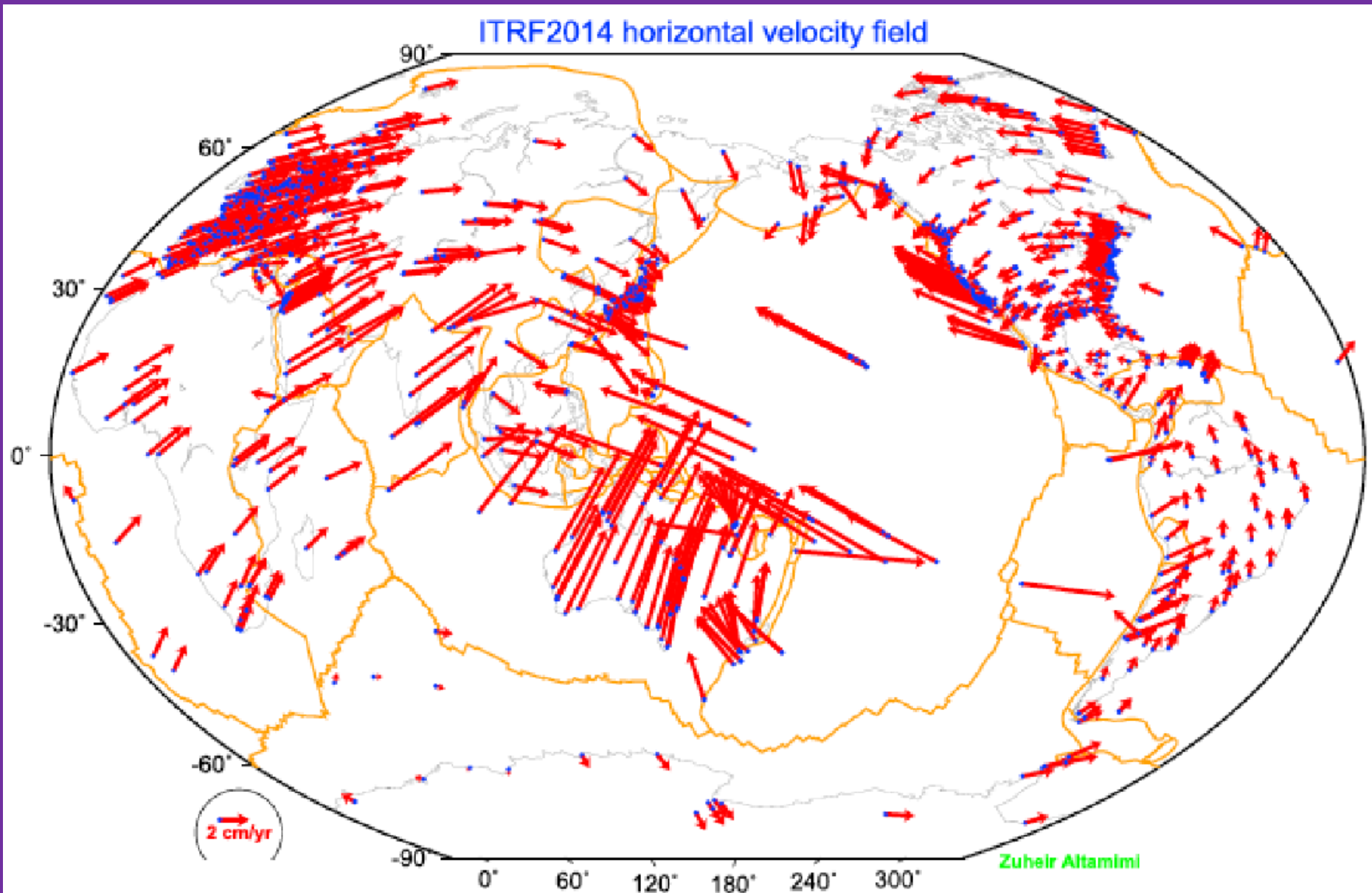
Plate tectonics =

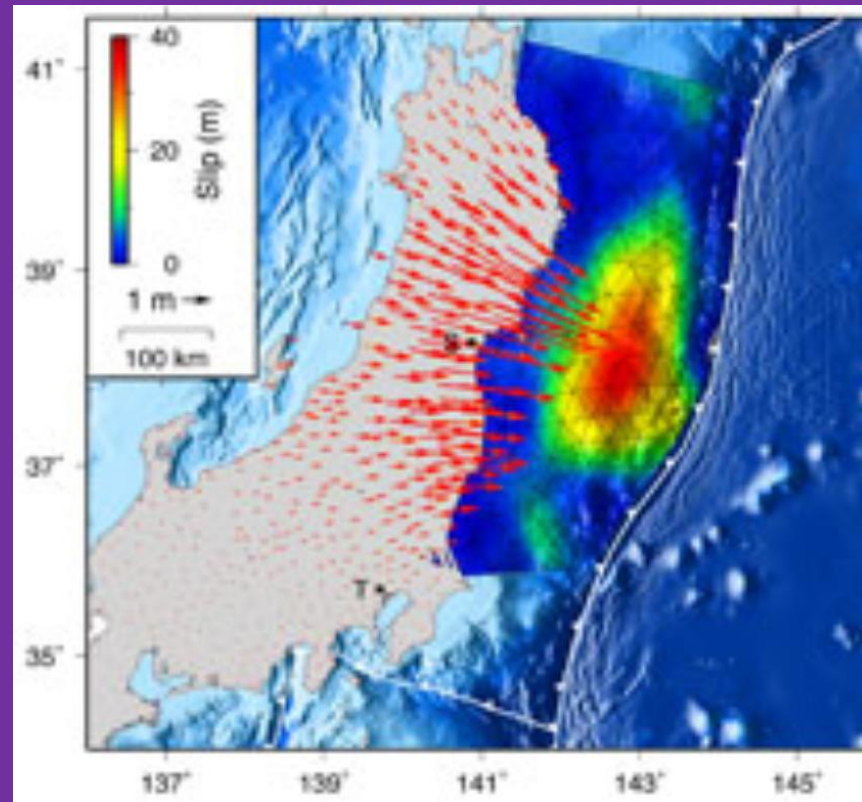
*The Earth is a set of large and rigid plates moving at the surface*

The GPS system :

- Allow to measure the movements
- Check the rigidity

# Model ITRF 2014 based on GPS data



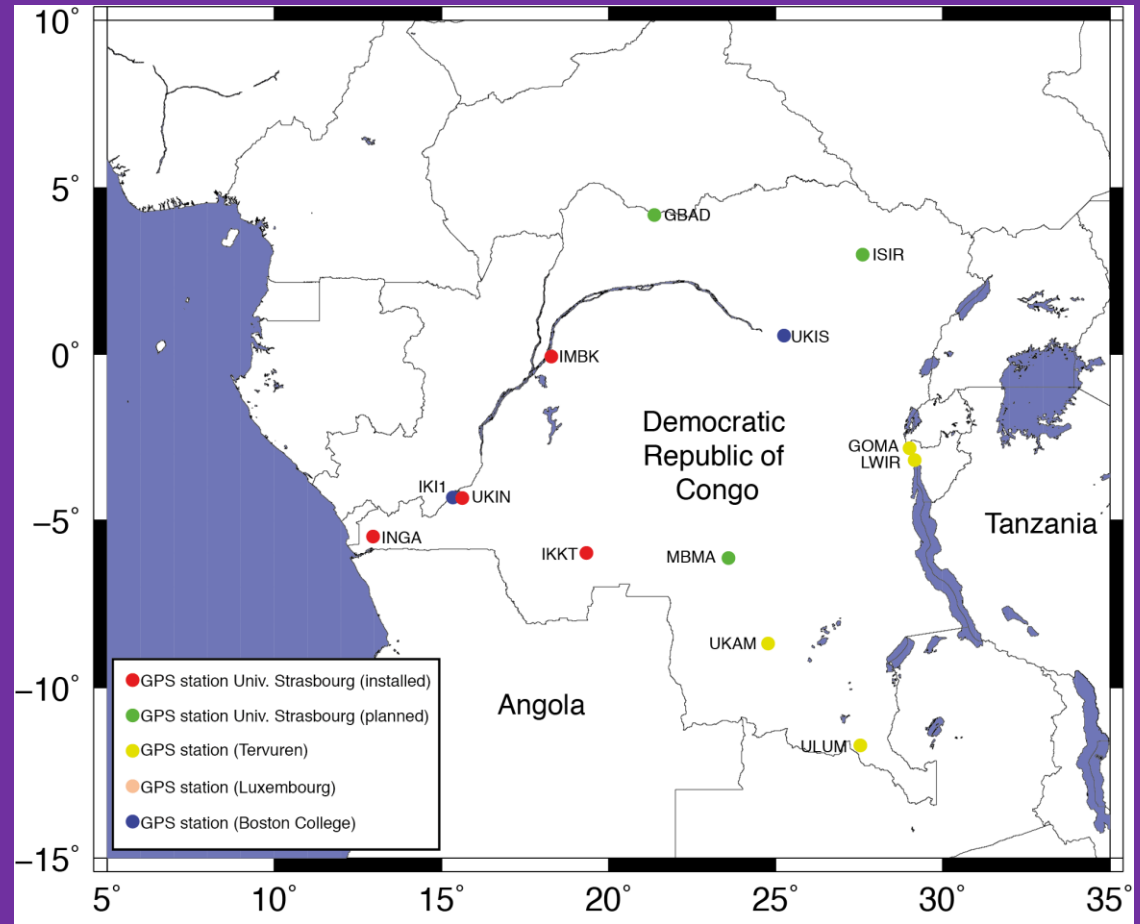


Sumatra earthquake : we observe the cosmic displacement of several meters and we can make models of sliding of the fault.

Scientific project in DRC : GNSS data analysis of the African continent from 1994 to 2017 characterization of active movement and deformation. (Phd Student Raphaël Mukandila, Director Frédéric Masson)

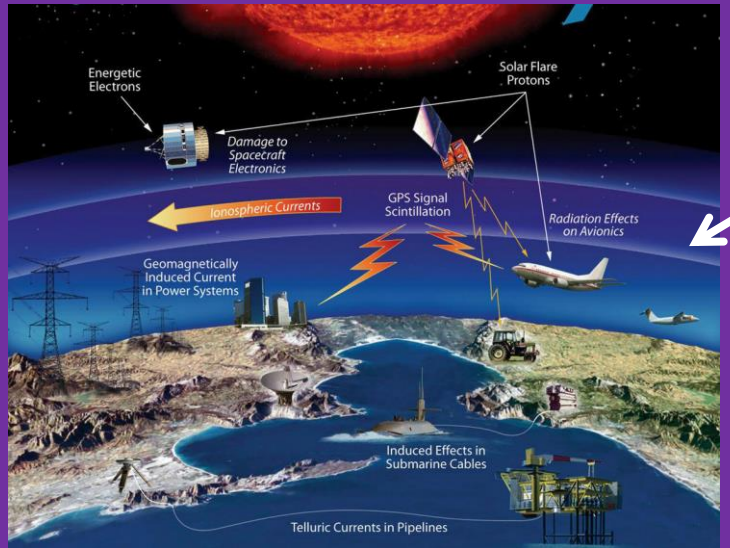


Raphaël MUKANDILA  
PhD - 4th year  
*Université de Kinshasa*



GNSS network in DRC. Stations UKAM, ULUB, UKI1 and UKIS are currently stopped. The status of GOMA and LWIR is not known. IKKT, IMBA, INGA and UKIN have been installed recently. ISIR, GBAD and MBMA should coming soon. UKAM and ULUB are available on UNAVCO web site.

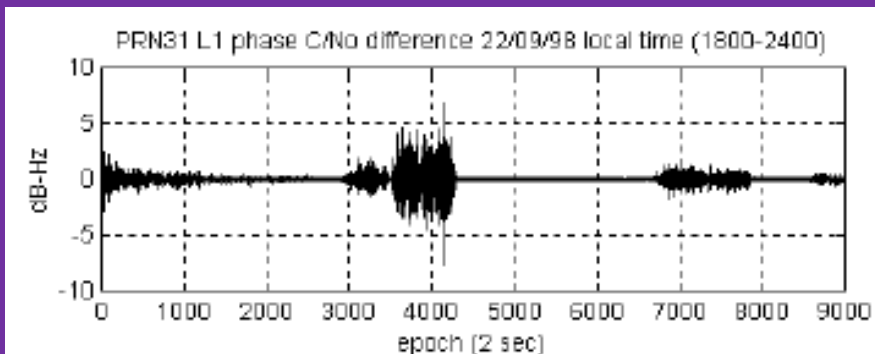
# Science and GNSS : Ionosphere - Space Weather



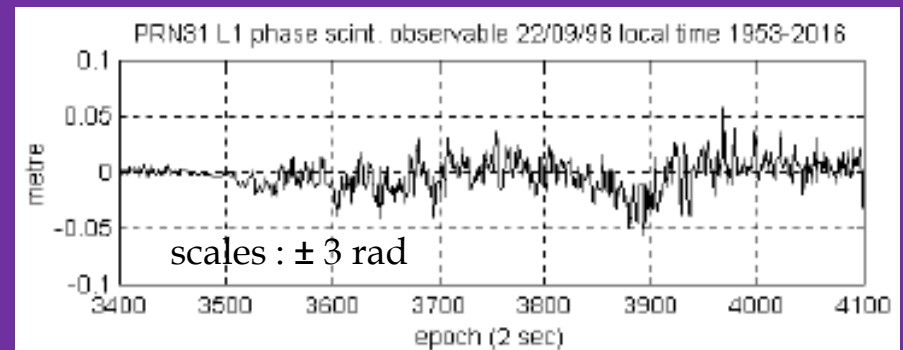
Between the Sun and the Earth : the ionosphere is a ionized layer around the Earth (from  $\sim 50$  km up to 800 km). The ionosphere is the largest source of perturbations for GNSS signals

## Scintillations

fluctuations of the GNSS signal due to inhomogeneities of the medium



Scintillations of amplitude



Scintillations of phase

## Effects of the ionosphere on propagation (TEC)

–Reduction of the phase path length  
(with respect to propagation in vacuum)

$$\Delta P_{\varphi} = P_{\varphi} - L = \int_L (n - 1) ds$$

$$n = 1 - a \frac{N_e}{f^2}$$

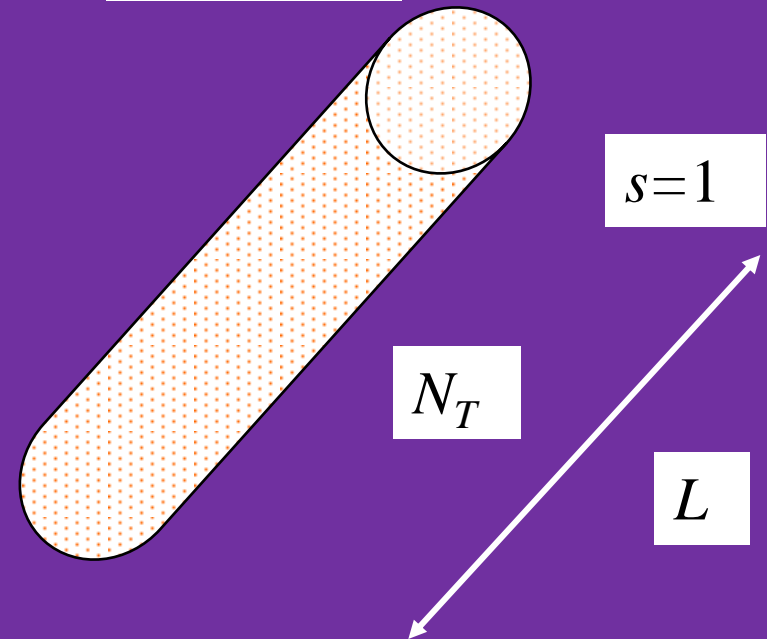
$$\Delta P_{\varphi} = -\frac{a}{f^2} \int_L N_e ds$$

$$\Delta P_{\varphi} = -a \frac{N_T}{f^2}$$

Phase path length : Distance that a wave needs to propagate in a vacuum to have the same total phase shift ( $\varphi$ )

– Total Electron Content (TEC)

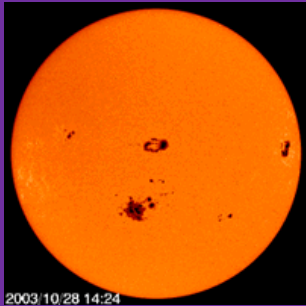
$$N_T = \int_L N_e dl$$



$$1 \text{ TECU} = 10^{16} \text{ electron/m}^2$$

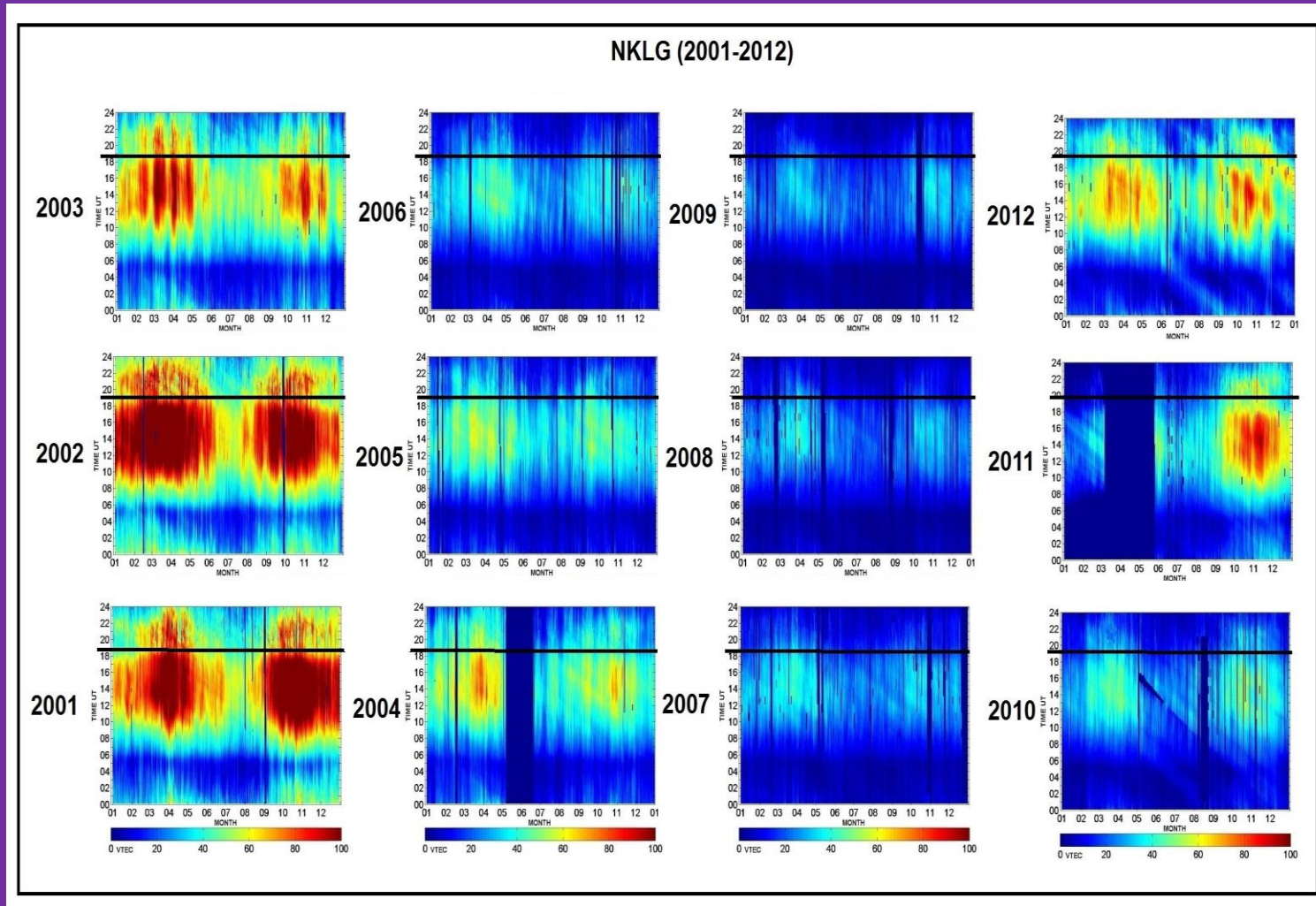


# The study of the VTEC makes it possible to characterize the ionosphere, its day-to-day seasonal and solar cycle variations



sunspots

Amira Shimeis  
PhD in Physics 2015  
Egypt



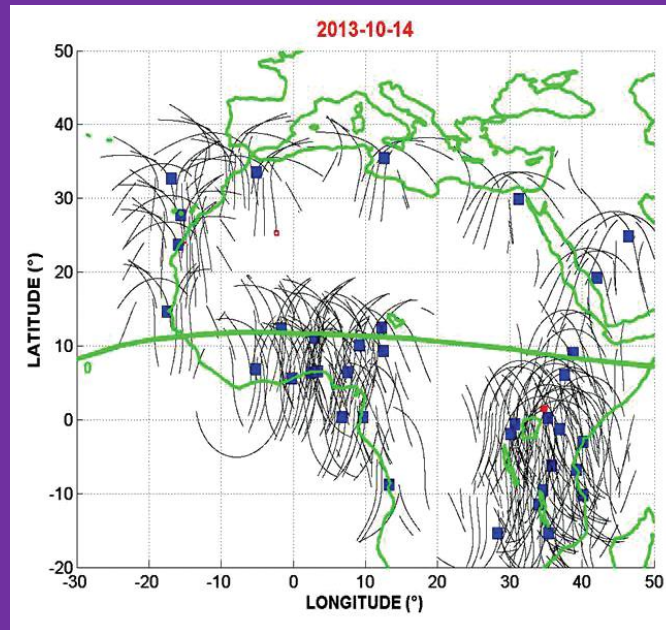
# SCINTILLATIONS : ROTI index

The ROTI index is important as it gives information on the scintillation phenomena. The ROTI index is calculated according to the development of Pi et al. (1977). From the 30s Rinex files, we calculate the gradient of STEC (ROT for Rate of TEC) in unit of tecu/mn

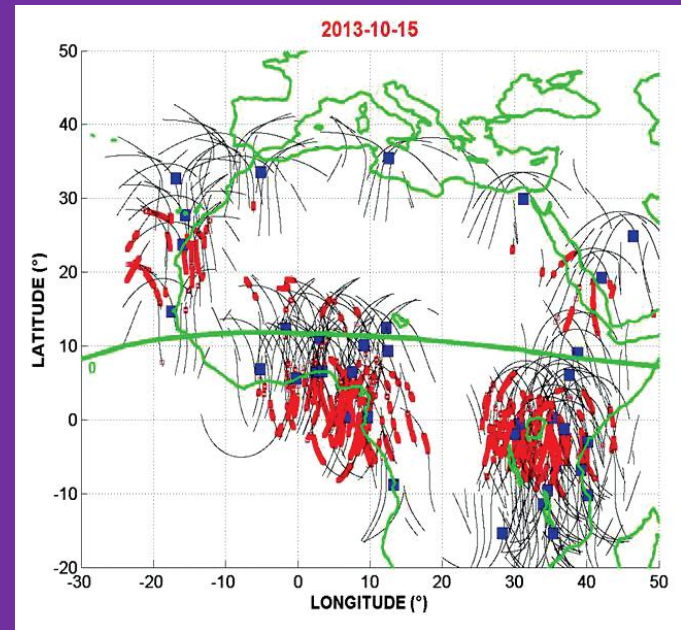
$$\text{rot} = \frac{STEC_{k+1} - STEC_k}{time_{k+1} - time_k} * 60$$



Ilyasse Azzouzi  
PhD physics 2016  
Morocco



ROTI index on October 14, 2013



ROTI index on October 15, 2013

# SCINTILLATIONS

S4 -> fluctuations of the GPS power signal (small scale)



Lan TRAN THI  
PhD in 2014  
Vietnam

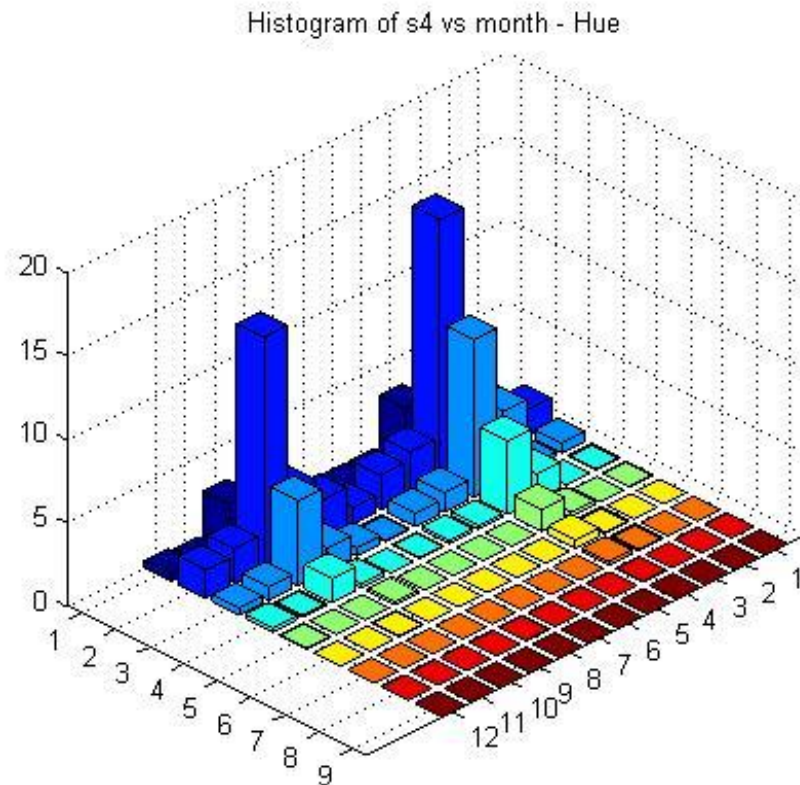


Figure from Bourdillon

Scintillation index S4 observed at Hue (Vietnam)  
during the period 2006-2008

$$I = \frac{A^2}{2}$$

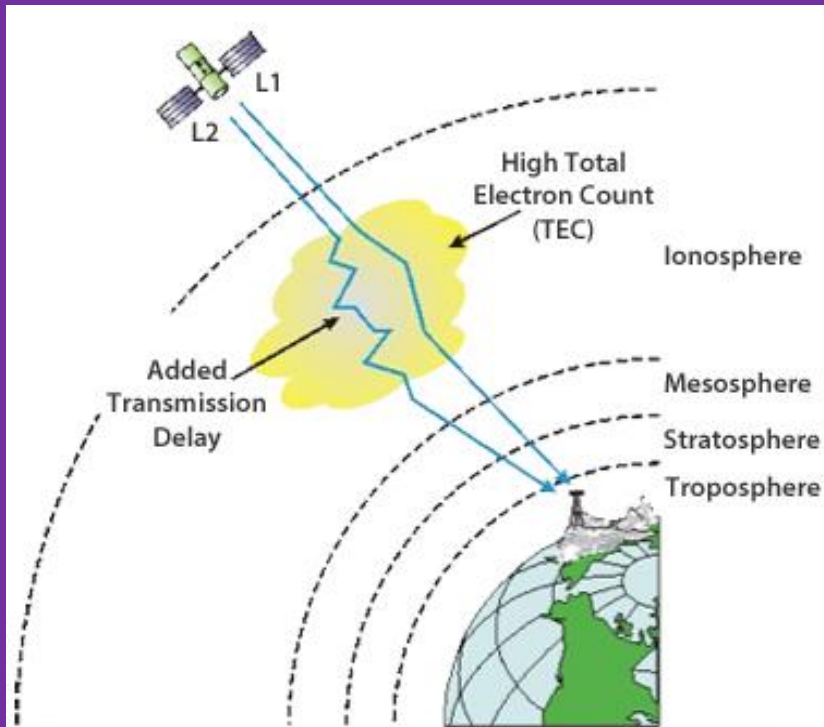
I : intensity of the signal

$$s4 = \sqrt{\frac{\langle I^2 \rangle - \langle I \rangle^2}{\langle I \rangle^2}}$$

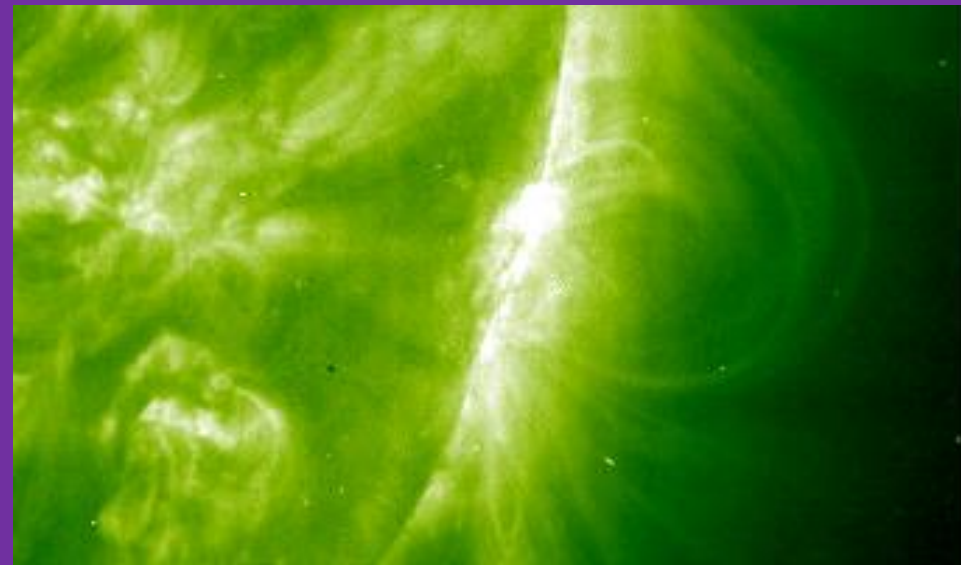
# Science and GNSS : Space Weather

The effect of the solar flare reaches the Earth in 8' and disturbed the VTEC

The extra X-rays emitted by the solar Flare directly ionize the atmosphere and thus increase the electron density and the TEC.



Big solar flare of November 2003



SOHO data

# Capacity building : Working method

- 1. Schools in an African country**
- 2. Scientific project with this country including the training of PhD students and installation of scientific instruments**
- 3. Position for the students**
- 4. Courses in the universities of the country organized by the new doctors**



Rolland Fleury

# Training on GNSS in France 2010,2012, 2013,2014, 2016, 2017

The National Telecommunications School 'IMT Atlantique' organized a training (addressing a small number of participants) for the use of GPS networks in Africa for the development of studies of the Ionosphere. This training was provided by Patrick Lassudrie-Duchesne and Roland Fleury. The National School has taken care of the costs of the training, the accommodation and food for the participants.

**[IMT Permanent school in AFRICA-2020]**



- Countries
- Algeria
  - Burkina Faso
  - Côte d'Ivoire
  - Egypt
  - Morocco
  - Senegal
  - RC
  - RDC

# In cooperation with the CRASTE-LF/ in Morocco 2011, 2015, 2017



In the framework of the GNSS master

# Sustainability : IMAO school each 2 years

## IMAO : ISWI Maghreb West Africa



Next IMAO schools  
Senegal:2019  
Tunisia : 2021



# Training on GNSS in schools on Space Weather



RC : 2009

French : 100%



DRC : 2011

French : 80%

English : 20%



English : 100%

Egypt : 2010



French : 100%

Morocco 2014

All information is available online

Courses on GPS are available on the website:

<http://www.unoosa.org/oosa/en/ourwork/icg/activities/2017/icg2017-event.html>

Amory-Mazaudier, C., R. Fleury, S. Gadimova, A. Touzani (February 2017), Space Weather, from the Sun to the Earth, the key role of Global Navigation Satellite Systems , Part I. From the Sun to the Earth Space Weather and its effects, Coordinates a monthly magazine on positioning, navigation and beyond, <http://www.mycoordinates.org>. invited paper.

Amory-Mazaudier, C., R. Fleury, S. Gadimova, A. Touzani (March 2017), Space Weather from the sun to the Earth, the key role of Global Navigation Satellite Systems- Part II: training on daily global positioning system GPS, Coordinates a monthly magazine on positioning, navigation and beyond, <http://www.mycoordinates.org>, invited paper.

Amory-Mazaudier, C. , Menvielle, M. Curto, J-J., Le Huy, M. Recent Advances in Atmospheric, Solar-Terrestrial Physics and Space Weather from a North-South network of scientists [2006-2016]", PART A: TUTORIAL, in Sun and Geosphere, supplement 2017, pp1,26.

Amory-Mazaudier, C., M., Fleury, R., Petitdidier, M., Soula, S, Masson, J-F., GIRGEA team\*, Davila, J., Doherty, P., Elias, A., Gadimova, A., Makela, J., Nava, B., Radicella, S., Richardson, J., Touzani, A. Recent Advances in Atmospheric, Solar-Terrestrial Physics and Space Weather from a North-South network of scientists [2006-2016]", PART B : RESULTS AND CAPACITY BUILDING, Sun and Geosphere, supplement 2017, pp 21,69. [ 50 authors/ 18 countries] 26

Senegal -2009



Côte d'Ivoire -2016



8 PhD => 1993-2000  
10 PhD => 2001-2010  
25 PhD => 2011-2018

Côte d'Ivoire 2007



Burkina Faso-2012



Morocco-2016

Tunisia-2017



Cameroon-2018



Algeria -2017

DRC-2016



43 PhD ⇔ 41 students ⇔ 38 positions (2 students left their country)  
[~18 PhD in progress], 1 defended on 02/03/2018

## PhD Defended

Algeria :	3
Benin :	1
Burkina Faso :	6
Cameroon :	1
Côte d'Ivoire :	10
Egypt :	3
Spain:	1
France :	3
Inde :	1
Morocco :	1
RC :	1
DRC :	3
Senegal :	2
Tunisia :	1
Vietnam :	6

**43**

## PhD defended GNSS

2 (2009 ,2014)

1 (2015)

1 (2016)

1 (2014)

**5**

## PhD in progress GNSS

1

1

1

2

1

2

1

**9**

# GNSS and SPACE WEATHER : new teams in North AFRICA

## Professors and PhD students

Professor Naima ZAOURAR /Algeria  
organized a school in 2013/ Alger



Ali Omar HAMMOU



+ 2 master students

Professor Aziza BOUNHIR/Morocco  
organized a school in 2014/ Marrakech



Khaoula  
EL BOUYAHYAOU



Loufti AMAL



Scientific Conferences - Teen Ager => application GNSS

Isah memorial Islamic Academy Anyigba Nigeria 2014

CMML secondary school Anyigba (Nigeria 2014)

Royal success Academy Anyigba (Nigeria 2014)



School Mt Amba /RDC -2014

School St Marie /Côte d'Ivoire 2013 during the MAGDAS School



# Conclusion

# Success

43 PhD – 235 publications

- All students have position
- They do not have to emigrate to have a thesis
- Courses develop in African Universities
- School in Africa each 2 years with a team of African professors
- Creation of doctoral schools
- South-South cooperation greatly facilitated
- Publications in very good journals with an African author first author



# Problem to solve

- We need more tools
- We need Post doc
- We need the development of sharing practices for GNSS data (ESA, CNES)
- Sustainability of GNSS tools
- Some networks are no more available on the web

Nigeria: no more measures available for more than 1 year, there was a network of about ten stations that provided measurements for about 6 years.

Angola: only 1 ZAMB station but a network of 20 stations existed (REPANGOL) and measures were available over 3 years. why this brutal stop (as in Nigeria)?