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* ISWI Newsletter - Vol. 15 No. 012   15 December 2023 *
* Editor: George Maeda, georgemaeda3[at]gmail.com   *
* Archive of back issues: ISWI Website https://iswi-secretariat.org/
* Archive of all ISWI webinars: *
* https://www.youtube.com/playlist?list=PLaOqa4cngOGF3cKuj6Yz5kqG1BQ-Akkhr
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Dear ISWI Newsletter Subscriber:

This issue is the final one for Year 2023.
One issue was released for each month of this year.

As editor, I wish to thank each person who contributed
material to this newsletter in 2023. Please continue
to send relevant material to me in 2024. The ISWI
community is alive and well !

When you submit material to me for publication, you
can send:
  [1] plain text
  [2] PDF
  [3] a combination of [1] and [2]
Please keep the PDF under 1.0 MB in size.

I have been editor of this newsletter since 2009.
The "ISWI Newsletter" and the "ISWI Website" were both
created as outcomes of the IHY.

This text is from Wikipedia's explanation of IHY:
 <<<...This effort culminates in the "International Heliophysical
   Year" (IHY) in 2007-2008. The IHY concluded in February, 2009,
   but was largely continued via the International Space Weather
   Initiative (ISWI). >>>
https://en.wikipedia.org/wiki/International_Heliophysical_Year

ANNOUNCEMENT:

Starting in January of 2024, the email distribution system
of the ISWI Newsletter will change.

The mailing lists for the ISWI Newsletter and other ISWI announcements
will be managed by Boston College in Boston, Massachusetts,
United States.   Subscribers will receive a welcome email from
"iswi-community@listserv.bc.edu"   with the subject
"Welcome to list iswi-community" stating they have been added
to the new list. No action is needed on the part of the subscriber.

If you wish to send a message to me (ISWI Newsletter Editor),
send email to georgemaeda3[at]gmail.com

Please do not reply to "iswi-community@listserv.bc.edu" which
is just the broadcaster of the newsletter.

Cordially,
George Maeda, Editor of the ISWI Newsletter

CONTENTS OF THIS ISSUE:

[03] "Special Issue 'Ionospheric and Magnetic Signatures
.   of Space Weather Events at Middle and Low Latitudes:
.   Experimental Studies and Modelling (2nd Edition)'   "
.   from Dr. Christine Amory-Mazaudier.

[04] IGRGEA LETTER; No.67, October 2023
.   International Geophysical Research Group /Europe-Africa
.   International Geophysical Research Group /Europe-Asia
.   Editor - Writer : C. Amory-Mazaudier.

[05] "Space Weather Research and Education at
.   The University of Mauritius" ; by D.Sumrah & D. Ramdhanee
.   (students at this university)

[06] African Geophysical Society (AGS), AGS Newsletter, Nov 2023

[07] 4th URSI Atlantic Radio Science Meeting (URSI AT-RASC 2024);
.   Call For Abstracts:
.   "GO6: Modeling and forecasting the ionosphere: new ways to
.   cooperate Complex Systems theory and Machine Learning".

[08] "The Status of Space Weather Infrastructure and Research in Africa"
.   Article in Atmosphere -- December 2023; DOI: 10.3390/atmos14121791

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[01]----------

Message from the Executive Director of ISWI:

Please view this attached PDF:
Dear ISWI colleagues 2023 December 13.pdf
001

[02]----------

Special obiturary for the long-time webmaster of the ISWI website,
Mitko of Bulgaria:

Please view this attached PDF:
Mitko_Danov.pdf
002

[03]----------

Georg
Here it is a paper on Space Weather in Africa,
We succeed to build a scientific community in Africa.
The paper is online at the link below :
https://www.mdpi.com/journal/atmosphere/special_issues/4TP52DMQ2H
Sincerely
Christine

[04]----------

IRGEA Newsletter

Please view this attached PDF:
irgea letter n° 67- October2023.pdf
003

[05]----------

Update from Mauritius

Please view this attached PDF:
report_from_Mauritius_edited_20231210_final.pdf

004

[06]----------

African Geophysical Society (AGS), AGS Newsletter, Nov 2023

Please view this attached PDF:
agsnewsletter1123.pdf
005

[07]----------

Dear George,

I would appreciate if you can include the invitation below
in the next ISWI Newsletter.
Many thanks!

Kind regards,
Yenca
--
Yenca Migoya-Orue'
Researcher, STI Unit
The Abdus Salam International Centre for Theoretical Physics (ICTP)
Strada Costiera 11, 34151 Trieste,Italy; Tel: +39 040 2240338

Dear ISWI community,

Abstracts submission is open for the 4th URSI Atlantic Radio
Science Meeting (URSI AT-RASC 2024) that will be held in
Gran Canaria, Spain during 19 - 24 May, 2024. Please consider
sending an abstract to our session: "GO6: Modeling and forecasting
the ionosphere: new ways to cooperate Complex Systems theory and
Machine Learning". The session description is given below.
The deadline for papers submission is 20 January 2024.

GO6: Modeling and forecasting the ionosphere: new ways to
cooperate Complex Systems theory and Machine Learning

Session Description:

Ionosphere modelling and forecasting are paramount objectives of research in the field. In this framework, several considerable milestones were reached both through Physics-based models and empirical-climatological studies. Our session will bring together novel concepts for modelling and forecasting the ionosphere, both data-driven and physics-based, with underlying machine learning (ML) and or complex dynamical systems methodologies to trigger their fruitful cross-fertilization. The ML approach is recognized to be at the present cutting edge of numerical and big data analysis tools, gleaning a deep understanding of otherwise hidden system behavior from historical records. On the other hand, recognizing the ionosphere as a complex dynamical system structured on many time- and space-scales, intrinsically nonlinear and statistically-treated, paves the way to paradigm changes in its dynamical theory. Both approaches can offer superior forecasting capabilities to explore in cooperation. This session is intended to be open to papers that consider new approaches stemming from the foregoing considerations.

Find more details at https://www.atrasc.com/papersubmission.php.

Conveners:
-Ivan Galkin
-Claudio Cesaroni
-Yenca Migoya-Orue
-Massimo Materassi

[08]----------

The Status of Space Weather Infrastructure and Research in Africa

Article in Atmosphere -- December 2023
DOI: 10.3390/atmos14121791

Abstract:
Space weather science has been a growing field in
Africa since 2007. This growth in infrastructure
and human capital development has been accompanied by
the deployment of ground-based observing infrastructure,
most of which was donated by foreign institutions or
installed and operated by foreign establishments.
However, some of this equipment is no longer operational
due to several factors, which are examined in this paper.
It was observed that there are considerable gaps in groundbased
space-weather-observing infrastructure in many African countries,
a situation that hampers the data acquisition necessary for
space weather research, hence limiting possible development
of space weather products and services that could help address
socio-economic challenges. This paper presents the current
status of space weather science in Africa from the point of view of some
key leaders in this field, focusing on infrastructure, situation,
human capital development, and the research landscape.

Please view this attached PDF:
AFRICA_status-Space-weather.pdf
006

**********[End of this issue of the ISWI Newsletter]**********

001

Dear ISWI colleagues, 2023 December 13

Season's Greetings! This year has been very busy for ISWI with many activities in space weather science and capacity building. This year we lost Mitko Danov, who has been the backbone of ISWI web site for more than a decade. Mitko was a wonderful human being and quietly contributing enormously to the ISWI community including as the technical editor of *Sun and Geosphere.* It is a huge loss to our community.

ISWI Webinar Series:

Graciela Molina and her ISWI Webinar Series committee has been very active, bringing the ISWI community to an online platform every month to listen to and discuss space weather. If you missed any of the webinars, no worries. The webinar recordings are available in the YouTube channel of the United Nations Office for Outer Space Affairs (UNOOSA): https://youtube.com/playlist?list=PLaOqa4cng0GF3cKuj6Yz5kqG1BQ-Akkhr. There are thirteen lectures available as of now. The webinars feature space weather science and instrument experts to enhance the ISWI capacity building activities. Suggestions for speakers and topics are always welcome.

Space Science Schools:

ISWI organized/co-organized three Space Weather School activities.

ICTP-SCOSTEP-ISWI School (https://indico.ictp.it/event/10176/) was jointly organized by ISWI, SCOSTEP, and ICTP hosted by the Abdus Salam International Center for Theoretical Physics in Trieste, Italy on May 29, 2023. This was a 1-day school in preparation for the SCOSTEP/PRESTO workshop that followed (May 30-June 2, 2023). The school provided students and early-career scientists with an introductory review on the topics included in the PRESTO workshop (https://indico.ictp.it/event/10260/). Presentations are available online.

ISWI co-sponsored the second edition of the Iberian Space Science Summer School during 26-30 June 2023 in Coimbra, Portugal (https://www.i4s-iberian-space-science-summer-school.com/), In addition to ISWI, several other organizations provided support to the organization: SCOSTEP, JSPS and ISEE. This school provided high-level professional development for early career, scientists, students, and entrepreneurs in the domain of Space Weather, with an emphasis on the fundamental science of the Sun-Earth system, modeling and forecasting, and its impact on society.

The ISWI Space Weather School in Lusaka, Zambia was held during 26-30 September 2023 at the Grand Palace Hotel (https://iswi-secretariat.org/iswi-space-weather-school-zambia-2023/). This is the first full-fledged ISWI school after the. COVID-19 pandemic. The School targeted MSc and PhD students based primarily in Africa. Lecturers of the also school traveled to high schools in and around Lusaka to talk to the students about the importance of space science as it affects all human beings. The Physics Society of Zambia hosted the school, with sponsors and partners including the African Geophysical Society (AGS), ISWI, University of Zambia, Copperbelt University, Nkrumah University, Mulungushi University, SCOSTEP, the Catholic University of America, NASA, and NSF.

UN Workshop on ISWI:
The ISWI Workshop was hosted by UNOOSA during June 25-30, 2023, at the Vienna International Center, focusing on *the way forward for ISWI*. This is the first time an ISWI workshop was hosted by UNOOSA. Presentations made at the workshop are available at the UNOOSA website: https://www.unoosa.org/oosa/en/ourwork/psa/schedule/2023/2023-iswi-workshop.html. Please visit the site, especially if you were not able to attend the workshop.

Annual Steering Committee Meeting:
The next annual steering committee meeting will be held in hybrid mode. It is scheduled for February 5, 2024, from 14:00 GMT to 13:00 GMT on Tuesday, February 6. Please participate. National and Regional coordinators are encouraged to report their activities with 4 slides or one quad chart. The reports will be coordinated by the regional coordinators (Babatunde Rabiu, Americo Gonzalez Esparza, Daniela Banys, Richard Marshall) and the chair of the membership committee (Christine Amory). A tentative agenda is attached.

ISWI Exhibition at the Vienna International Center:

ISWI is planning to host a poster/ISWI instrument exhibit during the UNCOPUOS/STSC meeting in Vienna along with the ISWI Steering Committee meeting. Each national coordinator has been invited to present a poster on their national space weather activities including but not limited to research activities, instruments, and outreach activities. The posters will be arranged in the Rotunda of the UN building in Vienna during Feb 5-9, 2024. The permanent missions to UN from various countries are expected to view the posters. Posters are also welcome from the regional coordinators. Those national coordinators who cannot attend in person may arrange with their regional coordinator to put the posters up. Poster displays can have maximum dimensions of 150 cm (Height) x 120 cm (Width).

Wish you all the very best for a great 2024!

Nat Gopalswamy

ISWI Steering Committee Annual Meeting

2024 February 5-6

In-Person and Online Meeting

Tentative Agenda

1. Introduction & Report (Chair)

2. Secretariat Update (Nat Gopalswamy, Kathleen Kramer, George Maeda)

3. Steering Committee Update (Nat Gopalswamy)

4. SCOSTEP/PRESTO Report (Kazuo Shiokawa)

5. Reports from ISWI Regional & National Coordinators (lead: Christine Amory)

6. ISWI Instruments Update (Shing Fung and Instrument PIs)

7. ISWI/Iberia School 2023 report (Anna Morozova)

8. ISWI/Zambia School report (Chigo Ngwira)

9 UN/ISWI workshop and UN-ISWI activities (Sharafat Gadimova)

10. Data Subcommittee Report (Shing Fung)

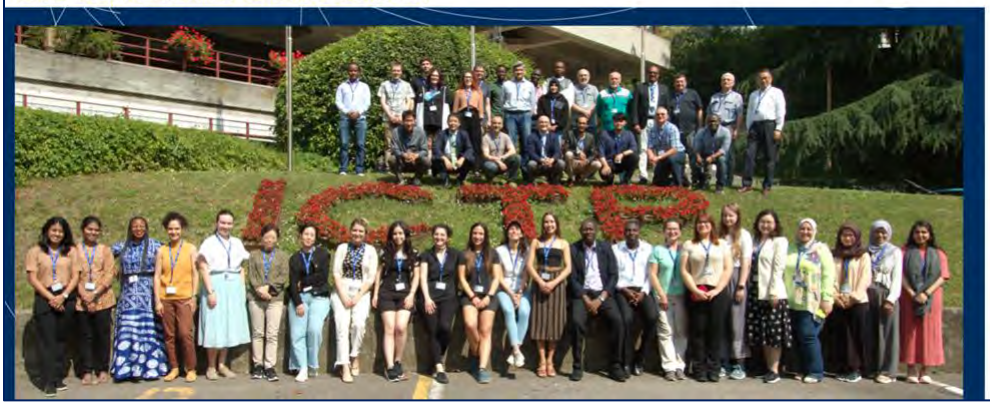
11. ISWI/NASA Report (???)

12. COSPAR Space Weather Roadmap and ISWAT activities (Masha Kuznetsova)

13. Steering committee member presentations

14. Any other business

Season's Greetings & Happy New Year 2024!



ICTP-SCOSTEP-ISWI School
May 29, 2023
Abdus Salam ICTP
Trieste, Italy

Dear ISWI colleagues,

With great grief I have to inform you that our colleague and friend **Mitko (Dimitar) Danov** passed away after a long struggle with cancer.

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Mitko was born in 1951. He received his MSc degree in physics from Sofia University, and was one of the best students in one of the best graduating classes. Mitko joined the Central Laboratory for Space Research (renamed later to Institute for Space Research, Solar-Terrestrial Influences Institute, now Space Research and Technology Institute) in 1981 when the Bulgarian satellite Bulgaria-1300 was launched. Together with his scientific activity, he created a data base of the measurements of all the satellite's instruments which is still actively used.

Mitko's initial scientific interest was in magnetospheric physics which later broadened to include also ionospheric physics, ionospheric precursors of earthquakes, solar-atmospheric influences. He had participated in a number of international space-borne projects like Intercosmos-Bulgaria-1300, APEX, International Space Station, etc., as well as several theoretical international projects.

Mitko was a member of the **ISWI Secretariat**. What he is best known for in the ISWI community is his activity in creating and maintaining web-sites (BBC-network, Sun and Geosphere journal, ISWI, VarSITI program, a number of international conferences). He started doing this as a hobby, without giving up his scientific activity, but very quickly became a real professional. His web-sites are still operational and providing lots of useful information.

Mitko was also a sunny person and with many friends all around the world. We will all be missing him a lot.

He left a daughter Gergana and a son Stoyan who were by his side during all this difficult time.

Katya Georgieva,

Space Research and Technology Institute of the Bulgarian Academy of Sciences

THIS TEXT WAS RECEIVED BY THE ISWI NEWSLETTER OFFICE ON 11 DEC 2023

Continued on the next page

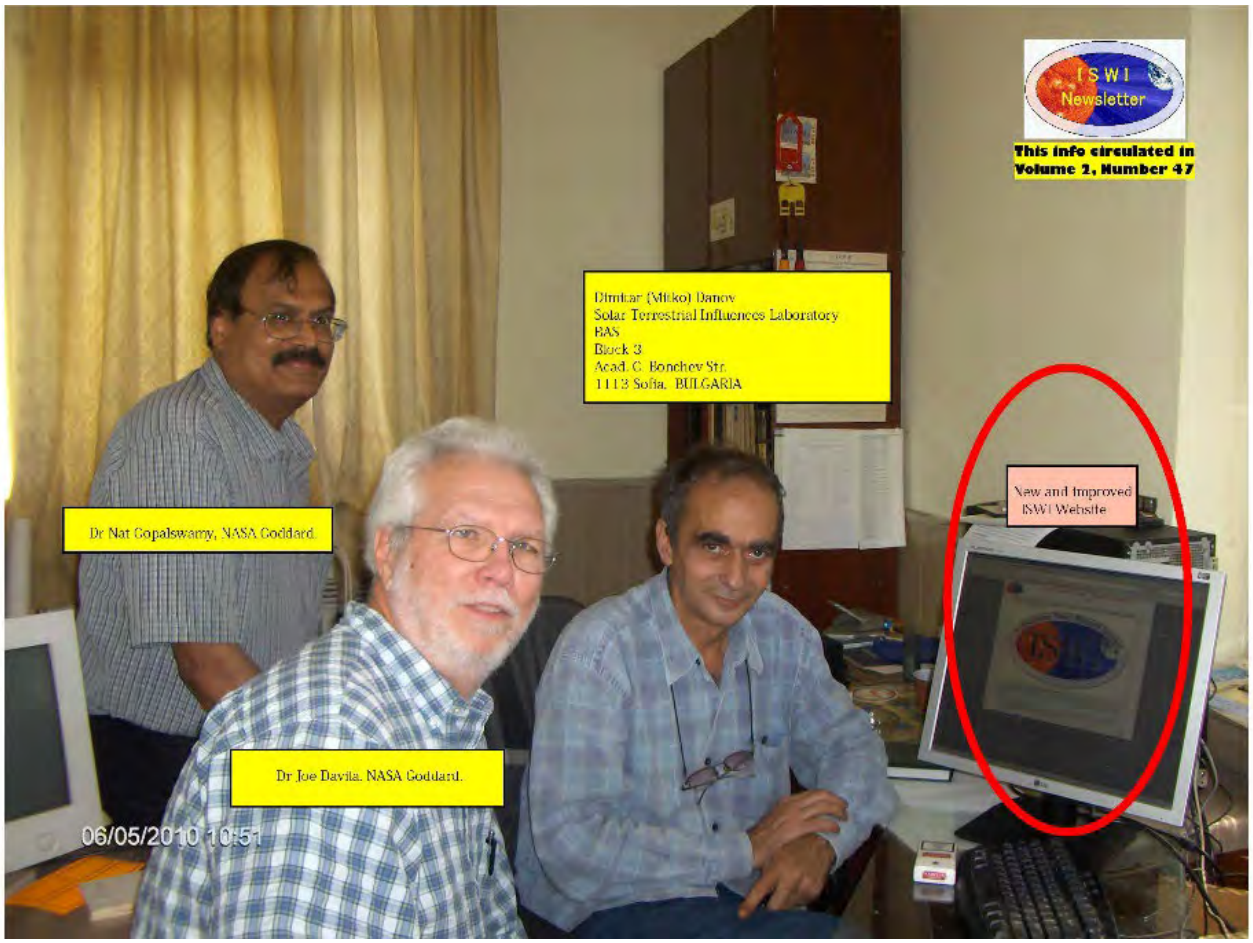
Dear Subscribers of the ISWI Newsletter :

On a personal note, I want to say that Mitko contributed vastly to ISWI since 2009, when he assumed the operations of the ISWI website. Through the years, he and I worked closely. For example, after each issue of the newsletter was sent out by me, he would faithfully archive each issue at his website. We worked well as a team in this manner. He shall be missed by the ISWI community.

Sincerely, George Maeda, Editor of the **ISWI Newsletter**

Fukuoka, Japan, 11-DEC-2023

PS: I found this 2010 photo on my computer drive:



Dr Gopalswamy and Dr Davilia (both with NASA GSFC) visited Mitko in 2010

(in Bulgaria) to work on the website design.

N° 67 OCTOBER 2023

003

IGRGEA LETTER

International Geophysical Research Group /Europe-Africa
International Geophysical Research Group /Europe-Asia

IGRGEA

At the end of the IEEY (International Equatorial Electrojet Year), in 1995, IGRGEA (International Geophysical Research Group Europe Africa) were organized to follow the research work initiated during IEEY, in 1992. Since January 2003 IGRGEA has been established at the Institute of Geophysics in Hanoï, Vietnam.

The last letter, No. 66, dated December 2022

BURKINA FASO

KOALA Somaïla defended his doctorate in Physics on 7 January 2023 at the Nazi BONI University, Bobo-Dioulasso.

Thesis topic: "*From the Sun to the Earth: Dynamics, Structure of the Solar Wind and Geomagnetism during Solar Cycles 23 and 24*"**.**

From left to right in the photo

Christian ZOUNDI, Senior Lecturer, Norbert ZONGO University, Burkina Faso
Saïdou MADOUGOU, Full Professor, Abdou Moumouni University, Niamey, Niger
Jean Louis ZERBO, Senior Lecturer, Nazi BONI University, Burkina Faso
KOALA Somaïla (the student)
Frédéric OUATTARA, Full Professor, Norbert ZONGO University, Burkina Faso (Chairman of the jury)
Emmanuel NANEMA, Research Director, IRSAT/ CNRST, Burkina Faso
Kondia Honoré OUOBA, Senior Lecturer, Nazi BONI University, Burkina Faso
Doua Allain GNABAHOU, Senior Lecturer, Norbert ZONGO University, Burkina Faso

SAWADOGO Yacouba defended his doctorate in Physics on 7 January 2023 at Nazi BONI University, Bobo-Dioulasso.

Thesis topic: *"Coronal mass ejections, fast solar winds and equatorial ionosphere during solar cycles 23 and 24."*

From left to right in the photo

Christian ZOUNDI, Senior Lecturer, Norbert ZONGO University, Burkina Faso
Saïdou MADOUGOU, Full Professor, Abdou Moumouni University, Niamey, Niger
Jean Louis ZERBO, Senior Lecturer, Nazi BONI University, Burkina Faso
SAWADOGO Yacouba (student)
Frédéric OUATTARA, Full Professor, Norbert ZONGO University, Burkina Faso (Chairman of the jury)
Emmanuel NANEMA, Research Director, IRSAT/ CNRST, Burkina Faso
Doua Allain GNABAHOU, Senior Lecturer, Norbert ZONGO University, Burkina Faso
Kondia Honoré OUOBA, Senior Lecturer, Nazi BONI University, Burkina Faso, Université Nazi BONI, Burkina Faso

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Laboratoire de Physiques des Plasmas, Ecole polytechnique Sorbonne Universités, 5 place Jussieu 75005 France
Tél : 33 (1) 45 11 42 37, email : christine.amory@lpp.polytechnique.fr

Ibrahim TRAORE, a doctoral student at the Norbert Zongo University in Koudougou, Burkina Faso, has been working on a research project entitled "The use of the GPS network in Burkina Faso applied to space meteorology. Comparison with space data" since January this year. This thesis is directed by Christian ZOUNDI and co-supervised by Frédéric PITOUT (Irap, Toulouse). Ibrahim, who benefited from a mobility grant from SCOSTEP, will be working in Toulouse in June 2023.

Renovated KOUDOUGOU GPS station, LAREME laboratory directed by **Frédéric OUATTARA**

BURKINA FASO- VIETNAM

Tinlé PAHIMA stayed in Vietnam from 11 to 27 August 2023 at the Geomagnetism Laboratory (LG), at the Institute of Geophysics in Hanoi (Vietnam). During his stay, he learned the techniques for processing GPS data in general and the Koudougou station data in particular: creating daily observation data files, converting observed data to RINEX files, calculating the total electronic content of the TEC ionosphere and the ROTI index. All this was done with Professor Minh LE HUY, director of LG, and in collaboration with the entire team at the laboratory. As a result, he obtained scientific results that were useful for his doctoral thesis

CÔTE D'IVOIRE

Diaby KASSAMBA ABDEL AZIZ is now the National Coordinator of the International Astronomical Union in Côte d'Ivoire. His mission is to promote astronomy among children, pupils, students and the general public .

Nguessan KOUASSI defended his doctorate in physics on 22 December 2022 at the Houphoüet Boigny University Abidjan/Côte d'Ivoire.
The subject of his thesis was:
"Electromagnetic induction associated with eruptive solar events at low latitudes.

From right to left: Moussa GRAFOUTE, Vafi DOUMBIA, Arsène KOBEA, Nguessan KOUASSI, Jean-Pierre ADOHI, Jérémie ZOUEU

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Chairman: M. KOBEA Toka Arsène, Director of Research, Félix Houphouët-Boigny University (Abidjan)
Director: M. DOUMBIA Vafi, Senior Lecturer, Université Félix Houphouët-Boigny (Abidjan)
Rapporteur:
Mr ADOHI Bibi Jean Pierre, Full Professor, Félix Houphouët Boigny University (Abidjan)
Candidate: Nguessan KOUASSI
Rapporteur: M. ZOUEU Thouakesseh Jérémie, Full Professor, Institut National Polytechnic Houphouët- Boigny (Yamoussoukro)
Examiner: Mr GRAFOUTE Moussa, Senior Lecturer, Félix Houphouët Boigny University (Abidjan).

David BARATROUX, Diaby KASSAMBA ABDEL AZIZ and Harris YAO MARC published an article in the journal the conversation entitled 'Côte d'Ivoire launches its first locally-made observation satellite'. https://theconversation.com/la-cote-divoire-lance-son-premier-satellite-dobservation-de-la-terre-fabrique-localement-208318

FRANCE

Announcement by Jean Lilenstein

The aim of the SESAME project (Raising Awareness of Space Weather) is to raise awareness of space weather among the general public in France (mid-2023), then in Europe and French-speaking countries (end-2023), before extending to the rest of the world by 2024. The project has 3 main strands, all of which can be developed in any language:
La Planeterrella: demonstrating the beauty of the polar aurora using a simulator

(https://planeterrella.osug.fr/) that details and explains the interactions between a star and planets. Already reproduced 38 times around the world, it's a great way of popularising the phenomenon.

Space weather bulletins: broadcasting weather forecasts and the physical mechanisms of the Sun's atmosphere on traditional media and/or online platforms. The aim is not to frighten people, but to show the beauty of these phenomena.

The social network: Bringing together people from all walks of life and connecting the general public and scientists through a social network that avoids commercial channels, under the aegis of local scientists, where people express themselves in their own language.
This project is funded by the French CNRS. The first bulletins are broadcast monthly on Radio France International to test their relevance. The first bulletins for the written press should appear in France at the end of the summer, and in the autumn for television bulletins.

By the end of 2023, our ambition is to set up a channel that will enable these bulletins and the network to be shared internationally, and to find funding for Planeterrella. To achieve this, we will be relying on two international networks: E-SWAN (eswan.eu) for Europe, and GIRGEA for Africa. As far as the bulletins are concerned, the process we have devised is as follows: every Monday morning, bulletins (for various media) are prepared in Grenoble by our team of forecasters, assisted by scientists from the French OFRAME group, the CEA and the CNES, who sit on the scientific advisory board. The forecaster from the SIDC in Brussels validated the scientific content. On Monday afternoon, the bulletins are formatted for radio, television and the press. On Tuesday morning, they are sent to our partner countries in English and French. We believe it is essential that a scientific colleague in each country receive them. This colleague will be responsible for translating them into his or her own language (adding local particularities if he or she so wishes) and, on the basis of a contract drawn up between the '*Centre Opérationnel de Météorologie de l'Espace des Alpes (COMEA*)' and a local media outlet (television, radio, newspaper), for broadcasting them on Tuesday evening or Wednesday.

So, almost simultaneously, the information will reach several hundred million people.
SESAME also includes a sociological study. Space weather is a discipline that is still relatively unknown to the general public . With SESAME, it will be accessible to hundreds of millions of people. However, the acceptance and perspective of space are not the same in all regions of the world. That's

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why four other countries have already agreed to help us test the concept while setting up a Sociologist/Space Meteorologist pairing, in a spirit of sharing between researchers on the one hand, and with the general public on the other. The countries involved are Côte d'Ivoire, Algeria, Greece and Kazakhstan.

--

Jean Lilensten
jean.lilensten@univ-grenoble-alpes.fr
IPAG :http://ipag.osug.fr/
JSWSC: http://www.swsc-journal.org/
Planeterrella : http://planeterrella.osug.fr/

Announcement by Frédéric Pitout

After many years of being organised in Belgium, the European Space Weather Week is now travelling. After Belgrade in 2022, Toulouse will host the 2023 event, from 20 to 24 November. Unlike the usual scientific congresses, the European Space Weather Week is also aimed at private players in the sector, as well as users. So it's a large community that's coming together. The congress will be punctuated by a number of different events : the traditional plenary and parallel sessions, as well as more informal discussion groups and poster sessions. All the information you need about the event, including paper submissions and registration, can be found on the dedicated website: esww2023.org.
To attract students and young researchers to the congress, the organizing committee and the European Space Weather Association (E-SWAN) are organizing a 3-day training course on the weekend before the congress. Other satellite events during the European Space Weather Week are also on offer. For more information: esww2023.org.

Frédéric Pitout: frederic.pitout@irap.omp.eu

The article on GIRGEA's last school, to be held in Côte d'Ivoire in 2022, which appeared in the journal La Météorologie, is now available online: issue 121

https://lameteorologie.fr/issues/2023/121

GUINEA

The next GIRGEA IMAOC6 school will be held in Guinea in autumn 2024. The national coordinator of this school is **René Tato LOUA**, Director of Meteorology in Guinea. **Olivier Le CONTEL** (LPP) and René Tato LOUA's request for financial support for the School, submitted under the CNRS/Africa call for proposals (https://international.cnrs.fr/actualite/le-cnrs-lance-trois-campagnes-pour-renforcer-sa-cooperation-scientifique-avec-lafrique/) has been accepted and will cover all student travel costs. The institutions of each speaker at the School will be officially informed by the CNRS of this support.

SPACE WEATHER SUMMER SCHOOL
Physics and use of tools
October 14-25 2024
Conakry, Guinea
2024

Organized by
National Meteorological Agency
Directorate General for Innovation

With the support
International Space Weather Initiative (ISWI)

and
ICG (International Commission of GNSS)

Under the High Patronage of the Minister of Transport of the Guinea Republic
Mr Félix LAMAH

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NIGERIA

From 4 to 8 September, an ICELLI workshop on equatorial and low latitude ionosphere was held at the University of Ilorin in Nigeria.

University of Ilorin

The first IPS-42 ionosonde was installed in 1989 at the University of Ilorin. Below are photos of the laboratory and antennas

The scientist in charge are :
Professor **Olushola A. OLADIPO**
ooladipo@ilorin.edu.ng
Professor **Adeniji O. OLAWEPO**
Olawepson@unilorin.edu.ng

Bowen University

At Bowen University, an HF radar is currently being installed.

The scientists in charge are:
Professor O. S. BOLAJI
olorieimpjch2002@yahoo.co.uk
Professor Babatunde RABIU
Tunderabiu2@gmail.com

Laboratory « Space Research Environment » at Abuja https://arcsstee.org.ng
"United Nations African Regional Centre for Space Science and Technology Education –English/Nigeria"

Instruments
GNSS receivers, Full sky camera
Scintillator
Fabry Perot interferometer
HF Radar, GNSS receivers
Space Meteorology Laboratory
The MAGDAS and AMBER magnetometers are no longer working, but the data are available.

Contacts
Babatunde Rabiu: tunderabiu2@gmail.com
Daniel Okoh : okodan2003@gmail.com

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PAKISTAN

Waqar YOUNAS defended his thesis in Physics on 31 May at Quaid-I-Azam University.
Thesis topic:
"*Ionospheric and magnetic changes induced by space weather at low-and-mid-latitudes."*

From left to right :

Waqar YOUNAS (Candidate), **Dr Muhammad KAMRAN** (Examiner 2), **Dr Majid KHAN** (Thesis Director), **Dr Aman UR REHMAN** (Examiner 1) **Dr Kashif SABEEH** (Chairman, Department of Physics QAU),

External Rapporteurs
Art RICHMOND, Michel BLANC
Co-Directors:
Christine AMORY-MAZAUDIER, Rolland FLEURY

DRC

The members of the Supervisory Committee for the doctoral thesis of the Head of Works **NDIADIA KANDOLO** Emmanuel/ University of Kinshasa (DR Congo), meeting on Saturday 13.05.2023, having heard the main results of this thesis, have declared it admissible.

Head of work NDIADA KANDOLO Emmanuel is preparing his presentation to the jury.

Thesis topic: "*Contribution to the study of monthly, seasonal and inter annual variability of lightning activity in Equatorial Africa*".

The University of Kinshasa has donated space within the University for the construction of a new Geophysical Research Centre (CRG). The centre is currently under construction.

Professor **Keto TONDOZI**, pictured below, has been appointed Director of the CRG.

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SENEGAL

Idrissa GAYE, from the University of Thiès, has been promoted to Senior Lecturer.

Idrissa GAYE is currently on an immersion stay at the University Technologic of Troyes as part of the Erasmus+/KA171 Key 171 action, from 1 October to 1 November. This action concerns mobility projects for students and higher education staff between *member countries of the Erasmus + program and non-associated third countries.

TUNISIA

Ahmed AMMAR has been recruited as a permanent lecturer at the ESPRIT engineering school (*École Supérieure PRivée d'Ingénierie et de Technologies*) in Tunis, which is one of the institutions affiliated to Honoris United Universities.
He would like to create a research unit on weather and space technologies.

UNITED NATIONS WORKSHOP

From 26 to 30 June, the United Nations Workshop on the International Space Weather Initiative: the Way Forward was held in Vienna. There were two presentations from GIRGEA (Côte d'Ivoire and Burkina Faso)
Diaby KASSAMBA ABDEL AZIZ (Côte d'Ivoire) and **Inza GNAMOU** (Burkina Faso) presented their work.

Communication of Diaby KASSAMBA ABDEL AZIZ:
« Estimating the daytime vertical ExB drift velocities in the F region equatorial ionosphere using IEEF and AMBER magnetic data in West Africa."
Communication of Inza GNAMOU:
« *Effect of turbulence high speed solar winds upstream of the Earth's magnetosphere, cases of the outer minima of solar cycles 20, 21, 22, 23 and 24."*

CHINA - ICMP 2023

An international workshop/Yanqi Youth Forum and the first ICMP Space Weather School were held in Beijing from 14 to 23 September.
Christine AMORY-MAZAUDIER presented:
Space Weather activities within the GIRGEAA Europe-Africa-Asia
Michel BLANC presented:
Progress report and way forward on the Europe-Africa-Pacific second Meridian Circle
There was only one participant from Africa:
Diaby KASSAMBA ABDEL AZIZ

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SITE INTERNET

At www.girgea.org, you will find all the GIRGEA letters sent since May 1992.
You can also download all Rolland FLEURY's softwares for processing GPS data and some ionosonde data.
To download the softwares you need a password, which Rolland will provide.
Mails from Rolland :
rolland.fleury@telecom-bretagne-eu
rolland.fleury@imt-atlantique.fr

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004

Submitted to the ISWI Newsletter
on
10 Dec. 2023

Space Weather Research and Education at The University of Mauritius

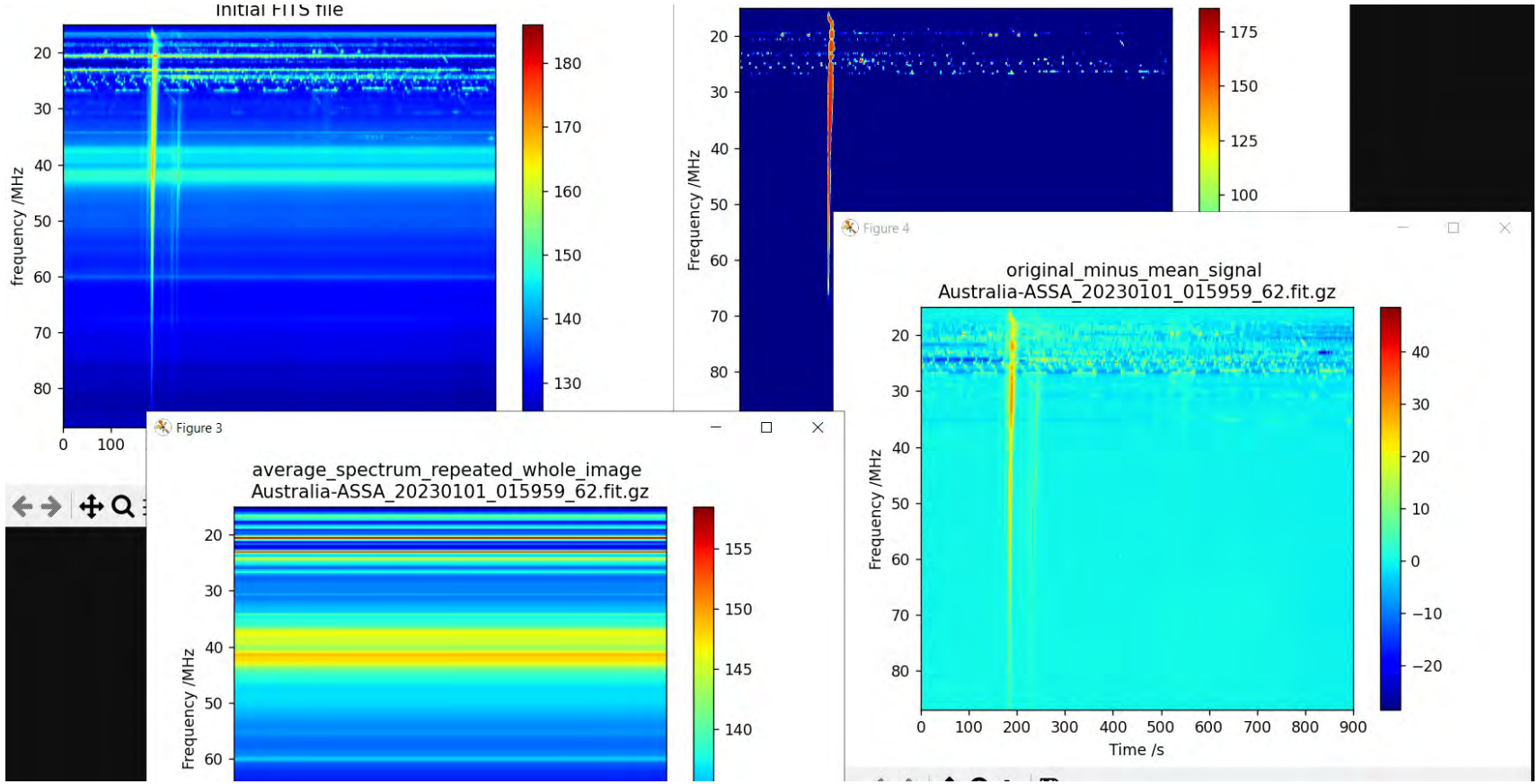
UNIVERSITY OF MAURITIUS

D.Sumrah & D. Ramdhanee,
10 Dec 2023

Undergraduate students Debaashish Ramdhanee [left] (enrolled in BSc (Hons) Physics with Computing) and Digeesh Sumrah [right] (enrolled in BSc (Hons) Physics (Minor: Chemistry)) teamed up to investigate the Solar Radio Bursts (SRBs) for their summer internship programme at the University of Mauritius.

Under the supervision of Associate Professor Girish Kumar Beeharry [centre], the students have attempted to automatically detect SRBs in the e-CALLISTO archived observation data. Transferable skills such as data visualisation and image processing were at the core of this internship project.

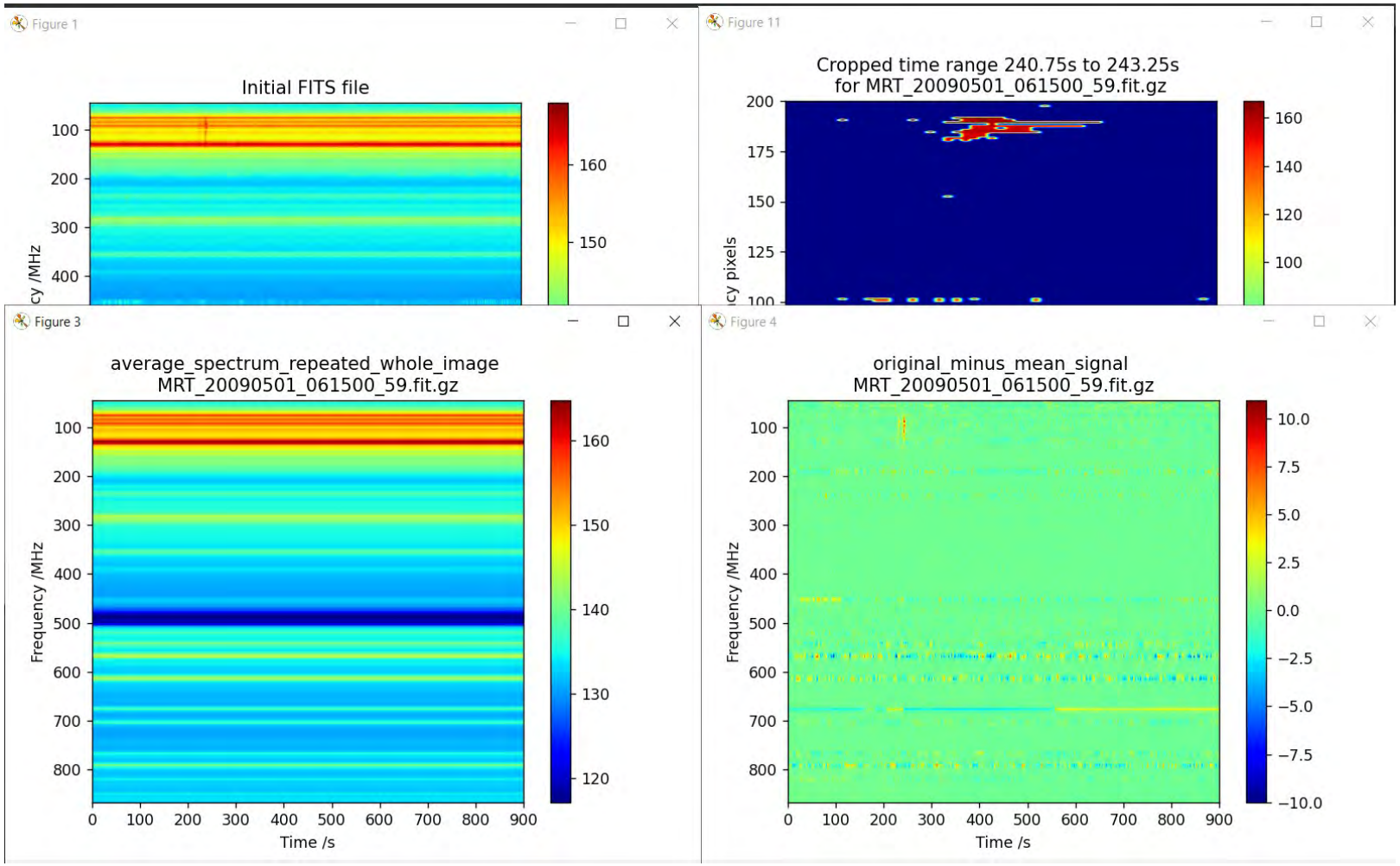
The study of SRBs helps to probe certain solar processes remotely. Disturbances in the solar plasma can be associated with solar flares and Coronal Mass Ejections (CMEs). High-resolution dynamic spectra can be scrutinised by experts to identify main features; the underlying fine structure of SRBs can be used to place them in sub-categories.



Anticlockwise, starting from top left: The raw dynamic spectrum, mean spectrum, the mean-subtracted spectrum, and the SRB visible after thresholding (Australia-ASSA station for the 1 January 2023, 02 00 -02 15 Universal Time).

The iterative powers of computers can be harnessed to automate this sometimes tedious task, given the volume of data generated daily worldwide by stations scattered across the globe. Mainly, the interns focused on the detection of Type III SRBs; practical problems involved the identification of Radio Frequency Interference (RFI). The main goal for the algorithm was to achieve the same (or better) performance when compared to what a human can identify.

In brief, freely available data from the e-Callisto network (https://www.e-callisto.org/) was obtained in the form of Flexible Image Transport System (FITS) files. The data for the dynamic spectra were extracted and processed in order to flag the detection of shapes which could be potential SRBs. The code was implemented with the Python Programming language.



Anticlockwise, starting from top left: The raw dynamic spectrum, mean spectrum, the mean-subtracted spectrum, and the zoomed-in brighter SRB after thresholding (Mauritius Radio Telescope (MRT) station for 1 May 2009, 06 15 - 06 30 Universal Time).

The development of the filtering and detection algorithms were the outcome of daily discussions; these often required the intervention of the supervisor who made evident the real-life difficulty of dealing with noisy spectra. Mean-spectrum subtraction and the Hough transform were used to remove noise and detect lines to a satisfactory level.

The trainees are grateful for this internship programme which greatly enhanced their professional aspect. Problem-solving skills and teamwork were uplifted as solutions were continuously being found, tested, and implemented on the problem which was broken up into several degrees of complexity. SRB detection can sometimes prove to be tricky and hence requires mental flexibility. The students likewise extend their gratitude to their supervisor who gave them the opportunity to work on SRBs. His guidance and words of encouragement were invaluable during this training period.

The End

AFRICAN GEOPHYSICAL SOCIETY

NOVEMBER 2023, VOL. 6. NO 11

AGS Newsletter 005

Welcome to AGS Newsletter

by EDITOR : ADERONKE OBAFAYE

Are you looking for a platform to share your news? AGS Newsletter is your best choice. We encourage you to announce your meeting reports, conferences, workshops, job openings, scholarships, and news related to Astronomy, Earth and Space Science.

Let me thank all our subscribers and wish everyone who celebrates a Happy Thanksgiving. We are grateful for your continued support..

1. Apply for the 2024 SCOSTEP Visiting Scholar (SVS) scholarship

The SVS program is a capacity building activity of the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP), which will complement its new scientific program (PRESTO) and public outreach activities. Interested candidates should contact one of the SVS program hosts; develop a project and work out the details of the visit. Once the applicant and host agree on a visit, the applicant needs to prepare an application package including:
1) a 2-page proposal of the work to be performed as an SVS awardee
2) applicant's curriculum vitae
3) dates of the proposed visit
4) letter of recommendation from the applicant's supervisor - with verification on the applicant's eligibility
5) letter from the host scientist/institution indicating that the work will be mutually beneficial
Send a single pdf file with all of the above to one of the secretaries of the SCOSTEP President, Ms. Miho Sugiyama (sugiyama.miho@isee.nagoya-u.ac.jp). Deadline for applications is February 15, 2024.

Please note that with continued travel limitations, the 2024 SVS awardees will have until June 30, 2025, to complete their training program. Click to following link for all the relevant information and a list of SVS host institutions: https://scostep.org/svs/

2. Applications for the 2024 UN/Japan Kyutech PNST (scholarship program) is now open.

Dear Colleagues, With great pleasure I announce that PNST (Postgraduate study on Nano-Satellite Technologies) 2024 is now open for applications. If you are interested in applying for PNST, please visit this website : https://www.unoosa.org/oosa/en/ourwork/access2space4all/PNST/PNST_Index.html
The deadline for application is 23:59 on 5 January 2024 [Japan Standard Time]. Late applications will not be accepted. Please note that the age limit (born on or after 2 April 1989) still exists. Therefore, the applicants born before this date are not eligible for PNST.
Sincerely,
Prof Mengu Cho Director of SEIC/PNST at Kyutech Inquiry for PNST https://forms.office.com/r/YfEm1isdwQ

3. SCOSTEP/PRESTO Announcement of Opportunity - Grants for campaigns, meetings, and databases (deadline: December 22, 2023)

by KAZUO SHIOKAWA
SCOSTEP PRESIDENT

Dear AGS members, please click on the link below to find Announcement of Opportunities for the campaigns, meetings, and development of databases relevant to the PRESTO topics in 2024 which is the last year of the 5-year PRESTO program. PRESTO website : https://scostep.org/presto/
Guidelines for these grants are detailed in the link above. Please contact relevant PRESTO Pillar co-leaders on your proposal and ex-

plain the relevance of your proposal to the PRESTO activity. Proposals for markedly interdisciplinary activities can be explained directly to PRESTO chair/co-chairs. The deadline is December 22, 2023.
With best regards,

4. ITS4.15/BG1.20 African led Geosciences and climate research on the African continent: prospects and challenges

by Convener : Robyn Pickering Co-conveners : Daniel Boateng, Temitope Samuel Egbebiyi, Samuel Ogunjo

The African continent has long been the subject of geoscience investigation, but much of this research has been led by the global North. Despite this, African-born and -based geoscience on the continent is evolving exponentially, with an increasing number of researchers working within the geosciences from solid earth to planetary science, groundwater to climate, minerals to sustainability. Geosciences, as a broad discipline, have a rich role to play in fulfilling the African Union Agenda 2063 agenda of inclusive and sustainable development, a pan-African drive for unity, self-determination, freedom, progress and collective prosperity. The aim of this session is to provide a platform for African led geoscience research at the EGU, and we welcome submissions from participants based on the continent and within the diaspora. Our goal is to consolidate geoscience research on the continent to raise awareness of work already being done, foster collaboration and to build an African-led geoscience network. This session will cover all aspects of African geology, climate and energy research. In addition, we call for submissions dealing with the issues faced by African geoscientists: parachute science, poaching of African scientists, publication bias, funding issues, mobility and visa issues and politics, as well as strategies to overcome these. We want to build "an integrated, prosperous and peaceful Africa, driven by its own citizens, representing a dynamic force in the international arena" by connecting research and researchers within the geosciences. https://meetingorganizer.copernicus.org/EGU24/session/50376

Poem of the month : Treasures

by Patricia L. Cisco September 8, 2017

Treasures come in so many ways: the sun that lights the cloudy days, a rainbow from a summer shower, a rose that blooms within an hour. Yes, treasures come in so many ways.

A baby's staring, wandering gaze, a dolphin's dance on ocean waves. Yes, treasures come in so many ways.

The heart beats of two souls in love, a beautiful white and peaceful dove. Yes, treasures come in so many ways.

A sky full of snowflakes of rarest form, a cup of cocoa to keep us warm. Yes, treasures come in so many ways.

A house full of family on holidays. For these treasures we should give God praise! Yes, treasures come in so many ways.

I could keep on counting for days and days!

https://www.familyfriendpoems.com/poem/treasures

The Status of Space Weather Infrastructure and Research in Africa

Article *in* Atmosphere · December 2023

DOI: 10.3390/atmos14121791

27 authors, including:

Paul Baki
Technical University of Kenya
11 PUBLICATIONS **20** CITATIONS
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A. Babatunde Rabiu
National Space Research and Development Agency
179 PUBLICATIONS **1,707** CITATIONS
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Christine Amory-Mazaudier
Sorbonne Universités LPP Polytechnique
247 PUBLICATIONS **3,308** CITATIONS
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Pierre J. Cilliers
The South African National Space Agency
129 PUBLICATIONS **1,822** CITATIONS
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Review

The Status of Space Weather Infrastructure and Research in Africa

Paul Baki [1,*], Babatunde Rabiu [2], Christine Amory-Mazaudier [3], Rolland Fleury [4], Pierre J. Cilliers [5], Joseph Adechinan [6], Anas Emran [7], Aziza Bounhir [8,9], Claudio Cesaroni [10], J. Bienvenue Dinga [11], Patricia Doherty [12,†], Idrissa Gaye [13], Hassen Ghalila [14], Franck Grodji [15], John-Bosco Habarulema [5], Bruno Kahindo [16], Ayman Mahrous [17], Honoré Messanga [18], Patrick Mungufeni [19], Bruno Nava [20], Melessew Nigussie [21], Joseph Olwendo [22], Patrick Sibanda [23], René Tato Loua [24], Jean Uwamahoro [25], Naima Zaourar [26] and Jean-Louis Zerbo [27]

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† Dr. Doherty made valuable contributions to previous versions of this paper but died on 14 July 2022.

Citation: Baki, P.; Rabiu, B.; Amory-Mazaudier, C.; Fleury, R.; Cilliers, P.J.; Adechinan, J.; Emran, A.; Bounhir, A.; Cesaroni, C.; Dinga, J.B.; et al. The Status of Space Weather Infrastructure and Research in Africa. *Atmosphere* **2023**, *14*, 1791. https://doi.org/10.3390/atmos14121791

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Abstract: Space weather science has been a growing field in Africa since 2007. This growth in infrastructure and human capital development has been accompanied by the deployment of ground-based observing infrastructure, most of which was donated by foreign institutions or installed and operated by foreign establishments. However, some of this equipment is no longer operational due to several factors, which are examined in this paper. It was observed that there are considerable gaps in ground-based space-weather-observing infrastructure in many African countries, a situation that hampers the data acquisition necessary for space weather research, hence limiting possible development of space weather products and services that could help address socio-economic challenges. This paper presents the current status of space weather science in Africa from the point of view of some key leaders in this field, focusing on infrastructure, situation, human capital development, and the research landscape.

Keywords: space weather infrastructure; space weather capacity building in Africa

1. Introduction

1.1. What Is Space Weather?

Space weather refers to the highly variable conditions in the geospace environment, including those on the sun, the interplanetary medium, and the magnetosphere-ionosphere-thermosphere system.

Space weather can have serious adverse effects on the advanced technology that our society depends on, such as satellite communications, Global Navigation Satellite Systems (GNSS) positioning, navigation and timing (PNT) services, and power grids, among others. The primary sources of space weather are solar flares and coronal mass ejections (CMEs), both initiated by the Sun. Solar flares produce sudden bursts of radiation, while CMEs are associated with bursts of plasma, embedded with magnetic field structures, that travel in the solar wind before interacting with the Earth's magnetosphere [1]. Energy and radiation from these events can harm astronauts, damage electronics on spacecraft, and impact GNSS precision, tracking, and acquisition. The geospace response to these changes includes impacts on the radiation belts, multiple large-scale and small-scale changes in the ionosphere, and the production of intense geomagnetically induced currents. To better mitigate space weather impacts on humanity and technological systems, there is a recognized need for improved forecasts, better environmental specifications, and more durable infrastructure. Improved monitoring and modelling of space weather has been identified as critical for the better protection of infrastructure and national economies during periods of large space weather events.

Understanding space weather is of great importance for awareness and avoidance of the consequences attached to space weather events either by system design or by efficient warning and prediction systems. Providing timely and accurate *space weather* information, nowcasts and forecasts are possible only if sufficient *observation* data are continuously available. Based on a thorough analysis of current conditions, comparing these conditions to past situations, and using numerical models similar to terrestrial weather models, forecasters can predict space weather on time scales of hours to weeks.

1.2. The African Context

The African Union (AU) has identified space science and technology as a key enabler of Africa's Agenda 2063 and created an African Space Agency (AfSA). The long-term goal of the agency is to enable Africa to leverage technologies developed in the space sector to address societal challenges, in addition to opening up new frontiers of space applications that could be a basis for the establishment of industries that would provide job opportunities for the many unemployed youths in Africa.

Space weather science, in particular, is one of the areas under active consideration by the AU partly due to growing interest in the acquisition and deployment of satellites in

space and also the requirement by the International Civil Aviation Organization (ICAO) for the provision of space weather services to the aviation industry across the world [2]. Space weather science has been a growing field in Africa since 2007, the year of the International Heliophysical Year (IHY 2007), during which time deployment in Africa of most ground-based observing infrastructure commenced. The deployment of ground-based observing infrastructure was rolled out through collaborations between African universities and their counterparts, mostly American institutions (such as Boston College, United States Airforce Research Laboratories (AFRL), Stanford University), and Kyushu University (Japan), among others. The deployments have often been accompanied by workshops aimed at African university lecturers and their students, with a focus on data acquisition, data processing, and interpretation. The training workshops, which continue to be held at least once a year, are run jointly through partnerships of the Abdus Salam International Centre for Theoretical Physics (ICTP) and Boston College. Supplementing these efforts is the training provided by the Scientific Committee on Solar-Terrestrial Physics (SCOSTEP).

However, despite these efforts, there are still considerable gaps in ground-based space-weather-observing infrastructure in African regions/countries. This hampers the data acquisition necessary for space weather research, hence limiting the provision of products and services that could help address socio-economic challenges. Due to the growing investment in space activities in Africa, including the building of nano-satellites/cubesats and the purchase and deployment of off-the-shelf satellites, there is a growing need for Africa to develop a critical mass of expertise to help mitigate space weather effects on critical space-based and ground-based technological infrastructure. Space weather effects could be felt in the aviation industry, power grid, land/sea and air navigation, and high-frequency communications, among other technological systems. Evidence of space weather's impact in Africa includes South Africa's space-weather-induced loss of its homemade SumbadilaSat satellite in September 2011 and of several high-voltage power transformers following the impacts of the Halloween storm of October 2003 on power systems through geomagnetically induced currents [3]. These events created awareness in Africa about the realities of space weather's impact on investments in the space sector and power sector, and they also brought to the fore the need for thorough space weather modelling and forecasting to prepare Africa to mitigate the consequences of space weather impacts on technologies.

Space weather preparedness is important not only for Africa but indeed the rest of the world. Space weather preparedness is underpinned by three elements: designing mitigation into infrastructure where possible; developing the ability to provide alerts and warnings of space weather and its potential impacts; and having in place plans to respond to severe events. This kind of preparedness calls for high-level research and national and international coordination.

This paper provides information on space weather infrastructure, human capital development, research achievements, ongoing and upcoming projects, international collaborations, funding sources, gaps in infrastructure, and human resources, as well as suggestions on what needs to be done going into the future.

This paper is organized as follows: In Section 2, we present the distribution of space weather infrastructure in Africa and discuss data accessibility and reliability; Section 3 deals with human capital development (HCD), completed and on-going postgraduate research, and various HCD initiatives; Section 4 gives insight into gaps in infrastructure and current and planned space weather projects; and in Section 5, we give the conclusion and way forward.

2. Distribution of Space Weather Infrastructure in Africa

The information captured in this paper was obtained using desktop research; information from individual and institutional equipment hosts in various countries who also participated in authoring this paper; internet sources; reports; and other publications that are publicly available.

2.1. Space Weather Monitoring

In monitoring space weather, ground-based instruments and satellites are used to monitor the Sun for any changes and issue warnings and alerts for hazardous space weather events.

Solar activities, such as solar flares, coronal mass ejection, and moon shadow of an eclipse, induce the rapid change of ionosphere morphology, so-called ionospheric weather, which significantly impacts radio communication and navigation systems. Ground-based GNSS receivers can measure the ionospheric total electron content (TEC) and the ionospheric electron density (through ionospheric tomography). This tool allows continuous monitoring of ionospheric weather and modelling of ionospheric climate. Magnetometers make it possible to follow the regular variations of electric currents in the ionosphere and magnetosphere caused by solar wind dynamics. During magnetic storms, the magnetic variations are affected by the disturbance of ionospheric and magnetospheric currents generated by solar events. Thus, GNSS receivers and magnetometers are very useful in monitoring the impact of solar disturbances on the Earth's environment and in the development of space weather science in Africa.

Many other instruments are used for space weather monitoring, including very-high-frequency (VHF) and very-low-frequency (VLF) receivers, ionosondes, incoherent scatter radar, all-sky cameras, and Fabret–Perot interferometers, among others. Some of these are discussed below.

2.1.1. Global Navigation Satellite Systems Receivers

GNSS has been used in all forms of transportation: space stations, aviation, maritime, rail, road, and mass transit. PNT plays a critical role in telecommunications, land surveying, law enforcement, emergency response, precision agriculture, mining, finance, scientific research, and so on. Space weather is one of the major limiting factors for the precision and reliability of PNT services from GNSS. Geomagnetic storms and substorms, solar flares, and ionospheric irregularities can result in PNT deterioration.

Since the ionosphere is a very dynamic medium and due to its dispersive nature, dual-frequency GNSS measurements may effectively be used to derive robust and accurate information about the ionospheric state under quiet and perturbed space weather conditions. Ground-based measurements enable mapping of the total ionization of the ionosphere (i.e., TEC). The hosts of most of the equipment installed for space weather research have a free data policy for research purposes, so the accessibility of data via the internet is not a challenge.

(a) GNSS Receivers for Ionospheric Scintillation Monitoring

Most of the dedicated high-rate GNSS receivers required for GNSS ionospheric scintillation and TEC monitoring (GISTM) were donated by US Air Force Research Laboratories (AFRL) and Boston College [4]. The deployments took place mostly between the years 2007 and 2014.

These instruments are primarily used for L-band monitoring of scintillations on GNSS signals traversing through the ionosphere. Figure 1 and Table 1 below show the distribution of GNSS ionospheric scintillation receivers across the continent. The map in Figure 1 shows a limited number of GISTMs in North and Southern Africa, which are mid-latitude regions with a low incidence of ionospheric scintillation. East Africa stands out as the area with the largest number of instruments for GISTM, followed by West Africa [5–14]. The line running from the geographic longitude 10° to the east in Figure 1, Figure 3, Figure 4 and Figure 5, is the geomagnetic meridian.

The USA equipment donors (SCINDA) and their collaborators deployed most of the instruments in Central Africa, which is the region with the highest incidence of ionospheric scintillation. Due to problems with maintenance, power, security, and internet access, there is a considerable gap in the currently operating ionospheric scintillation monitoring

infrastructure in large parts of Africa. The GISTM stations and their host countries are listed in Table 1.

Other than the above-listed stations, the South African National Space Agency (SANSA) also operates Novatel GSV4004B scintillation receivers at several other locations in South Africa and on nearby islands, namely at Louisvale (28.49° S, 21.23° E), Grahamstown (33.32° S, 26.5° E), Gough Island, (40.34° S, 9.88° W), and Marion Island (46.87° S, 37.85° E). Since 2017, SANSA has installed Novatel GPStation6 and Septentrio PolaRx5S multi-constellation GNSS scintillation receivers for real-time data streaming from each of the following locations in Africa: Kilifi (Kenya, 3.62° S, 39.84° E) [15], Kabwe (Zambia, 28.46° N, 14.44° E), Lagos (Nigeria, 6.52° N, 3.38° E), and Busitema (Uganda 0.75° N, 34.04° E). SANSA is currently working on the deployment of a few more such receivers in Central and East Africa (Gaborone in Botswana, Tororo in Uganda, and Bahir Dar in Ethiopia) to provide essential real-time data to the Regional Space Weather Warning Centre of the International Space Environment Service (ISES) at the South African National Space Agency in Hermanus.

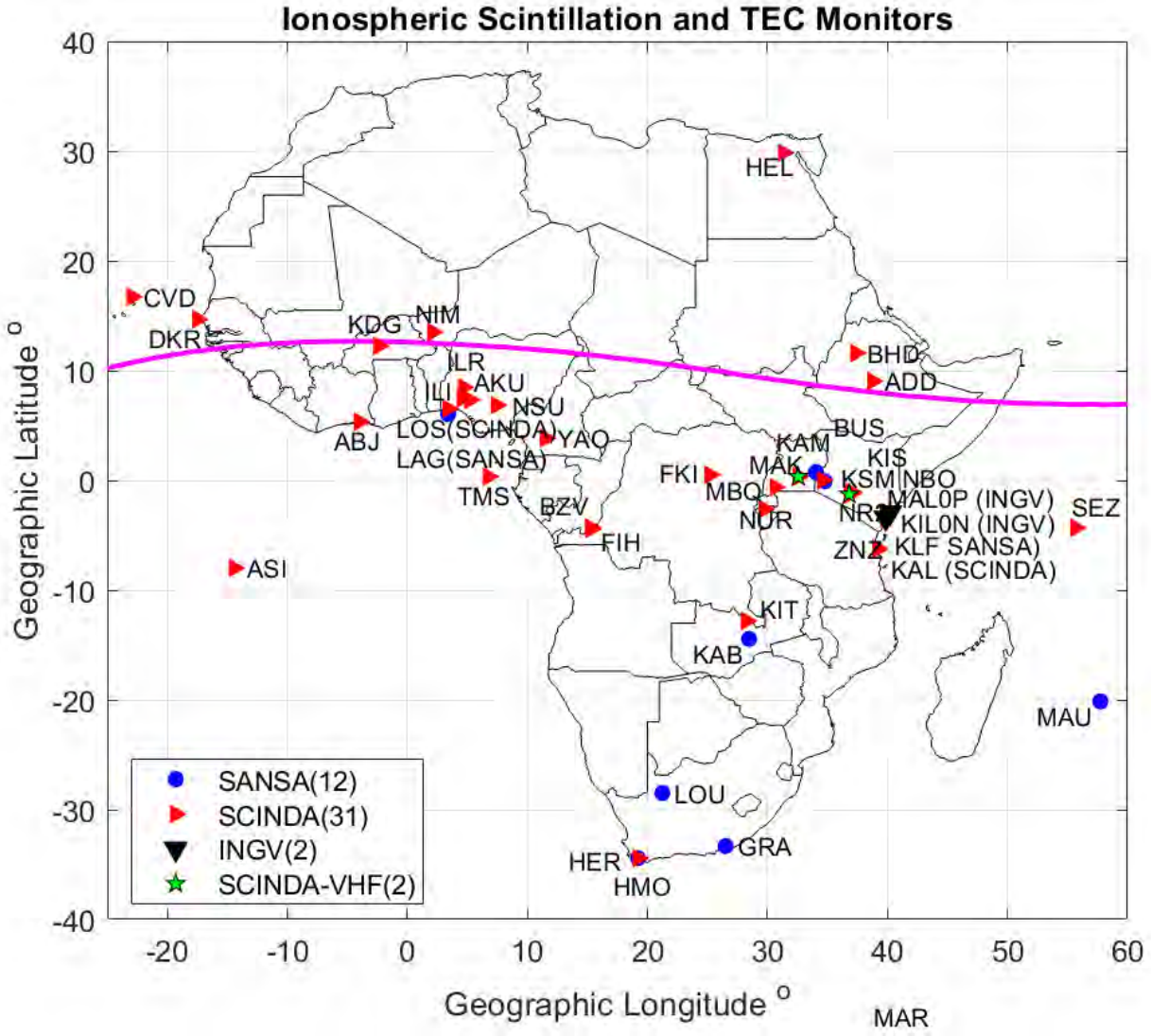

Figure 1. Distribution of GPS ionospheric scintillation and TEC monitors (GISTM) deployed by Boston College (USA) and US Air Force Research Laboratories in Africa (SCINDA 2007–2014) and by the South African National Space Agency (SANSA). The line running from the geographic longitude 10° is the geomagnetic meridian.

Table 1. GPS ionospheric scintillation and TEC monitors in Africa.

Locations	Host Nation	Station Code	Network	Latitude	Longitude
Abidjan	Ivory Coast	ABJ	SCINDA	5.34	5.36
Addis Abeba	Ethiopia	ADD	SCINDA	9.33	38.75
Ascension Island	Atlantic Ocean	ASI	SCINDA	−7.98	−14.41
Bahir Dar	Ethiopia	BHD	SCINDA	11.57	37.39

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Ascension Island	Atlantic Ocean	ASI	SCINDA	−7.98	−14.41
Bahir-Dar	Ethiopia	BHD	SCINDA	11.57	37.39
Brazzaville	Congo	BZV	SCINDA	−4.28	15.25
Busitema	Uganda	BUS	SANSA	0.75	34.04
Butare	Rwanda	NUR	SCINDA	−2.61	29.74
Cape Verde	Atlantic Ocean	CVD	SCINDA	16.73	−22.94
Dakar	Senegal	DKR	SCINDA	14.68	−17.46
Helwan	Egypt	HEL	SCINDA	29.87	31.32
Hermanus	South Africa	HMO	SCINDA	−34.42	19.22
Ilorin	Nigeria	ILR	SCINDA	8.48	4.67
Kabwe	Zambia	KAB	SANSA	−14.44	28.46
Kampala	Uganda	KAM	SCINDA	0.37	32.56
Kampala	Uganda	KMP	SCINDA-VHF	0.37	32.56
Kilifi	Kenya	KIL0N	INGV	−3.62	39.84
Kilifi	Kenya	KAL	SANSA	−3.62	39.84
Kinshasa	Congo	FIH	SCINDA	−4.42	15.31
Kisangani	Congo	FKI	SCINDA	0.51	25.21
Kitwe	Zambia	KIT	SCINDA	−12.80	28.24
Koudougou	Burkina Faso	KDG	SCINDA	12.24	−2.40
Lagos	Nigeria	LOS	SCINDA	6.52	3.39
Lagos	Nigeria	LAG	SANSA	6.52	3.39
Malindi	Kenya	MAL0P	INGV	−2.93	40.21
Maseno	Kenya	KIS	SCINDA	0	34.6
Mbarara	Uganda	MBQ	SCINDA	−0.62	30.65
Nairobi (J K U)	Kenya	NBO	SCINDA	−1.09	37.02
Nairobi (U of Nairobi)	Kenya	NR2	SCINDA	−1.27	36.81
Nairobi (U of Nairobi)	Kenya	NAI	SCINDA-VHF	−1.27	36.81
Niamey	Niger	NIM	SCINDA	13.50	2.10
Nsukka	Nigeria	NSU	SCINDA	6.86	7.41
Sao Tome and Principe	Atlantic Ocean	TMS	SCINDA	0.34	6.74
Seychelles	Indian Ocean	SEZ	SCINDA	−4.32	55.69
Yaounde	Cameroon	YAO	SCINDA	3.90	11.50
Zanzibar	Tanzania	ZNZ	SCINDA	−6.23	39.21

In 2019, the Istituto Nazionale di Geofisica e Vulcanologia (INGV) started the installation of new GNSS receivers for scintillation monitoring covering both East and West Africa. At present, three receivers in Kilifi (Kenya, 3.62° S, 39.84° E), Malindi (Kenya, 2.93° S, 40.21° E), and Abuja (9.07° N, 7.49° E) are operational, making their data available in real-time.

Almost 50% of installed SCINDA GISTMs in Africa are non-operational. This state of affairs is not suitable for space weather research in Africa. The reasons for this are damage, intermittent electricity supply, and poor internet connectivity, thus prohibiting data transfer to the central server in Boston College; missing equipment parts; equipment reaching the end of its useful operational lifetime; and system configuration problems (see Figure 2). This means mitigating space weather effects is not possible in large swathes of Africa due to the infrastructure gaps and the non-operational status of most receivers. Consequently, space weather advisories to various sectors would only be possible in certain parts of Africa but not in others. This is particularly bad for the aviation industry since the International Civil Aviation Organization (ICAO) now requires all airports to integrate space weather information in their aeronautical information services [16]. This state of the GISTMs in Africa hampers space weather research in the continent and jeopardizes networking and collaborations. In addition, it highlights the lack of goodwill by the hosts to avail funds

avail funds to replace damaged equipment or even add more to the network to enable research work to continue.

Figure 2 clearly shows that most of the GPS receiver stations are unable to transmit data to external collaborators because of poor internet connectivity, followed by unreliable electricity supply, and lack of technical expertise to configure the receiver systems properly. These equipment hosts often need thorough training to be able to run and maintain the equipment, but usually, this is at the cost of the external collaborator. For operational stations, not all operate optimally (i.e., some GPS receiver stations operate intermittently, a few are fully operational, and the vast majority are non-operational).

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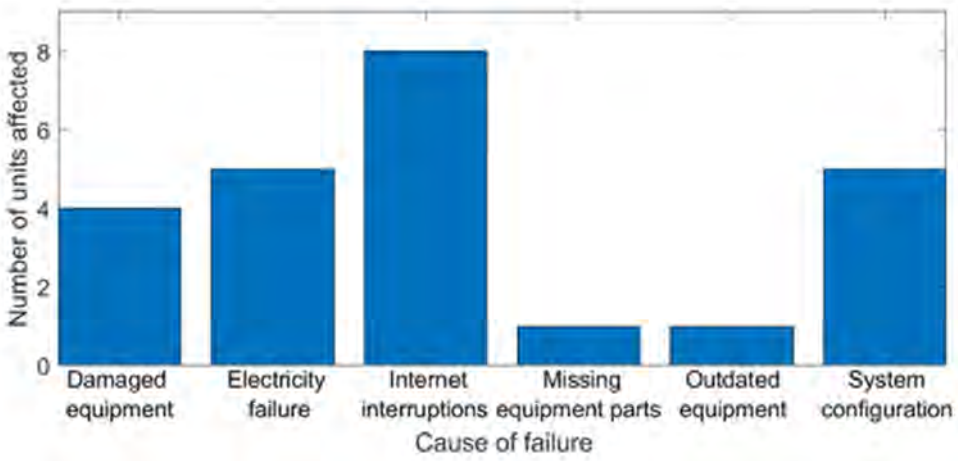

Figure 2. The causes of the non-operational status of SCINDA GISTM stations and the number of stations affected by each of these causes.

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(b) Geodetic GNSS Receivers and GNSS reference receivers for surveying and mapping.

GNSS receivers have been deployed by several external parties (NASA, NOAA, ESA, BKG, and others) for geodetic studies of the African continent. Besides the GNSS receivers deployed by external parties, national mapping agencies in many African countries have installed GNSS reference receivers to support mapping and surveying work. Figure 3 shows the distribution of GNSS geodetic and reference receivers in and around Africa.

(b) Geodetic GNSS Receivers and GNSS reference receivers for surveying and mapping.

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(b1) International Global Navigation Satellite Systems Service (IGS).

The IGS is a voluntary federation of many worldwide agencies (350) that pool resources and data from permanent GNSS stations (512 in 2023) to generate precise GNSS products. The International GNSS Service provides, on an openly available basis, the highest-quality GNSS data, products, and services in support of the terrestrial reference frame; Earth observation and research; PNT; and other applications that benefit science and society [17].

Out of a total of 118 countries around the world, only 22 countries in Africa participate in this network. The list of the 30 operational stations in 2023 is given in Table 2.

Table 2. IGS GNSS stations operating in 2023.

Marker	Country	Latitude	Longitude
ABPO	Madagascar	−19.018	47.229
ACRG	Ghana	5.641	−0.207
ADIS	Ethiopia	9.035	38.766
ASCG	Ascension Is.	−7.916	−14.333
CPVG	Cape Verde	−16.732	−22.935
DJIG	Djibouti	11.526	42.847
FUNC	Portugal	32.648	−16.908
HARB	South Africa	−25.887	27.707
HNUS	South Africa	−34.425	19.223

Table 2. *Cont.*

Marker	Country	Latitude	Longitude
JCTW	South Africa	−33.951	18.469
LLAG	Canary Is.	28.482	−16.321
LPAL	Canary Is.	28.764	−17.894
MAL2	Kenya	−2.996	40.194
MAS1	Canary Is.	27.764	−15.633
MAYG	Mayotte	−12.782	45.258
MBAR	Uganda	−0.601	30.738
MELI	Spain	35.281	−2.952
MFKG	South Africa	−25.805	25.540
NKLG	Gabon	0.354	9.672
PRE3	South Africa	−25.746	28.224
RABT	Morocco	33.998	−6.854
REUN	La Reunion	−21.208	55.572
SEYG	Seychelles Is.	−4.679	55.531
STHL	Sainte Helene	−15.943	−5.667
SUTH	South Africa	−32.380	20.810
TDOU	South Africa	−23.080	30.384
ULDI	South Africa	−28.293	31.421
VACS	Mauritius	−20.297	57.497
VOIM	Madagascar	−21.906	46.793
WIND	Namibia	−22.575	17.089
YKRO	Ivory Coast	6.871	−5.240
ZAMB	Zambia	−15.426	28.311

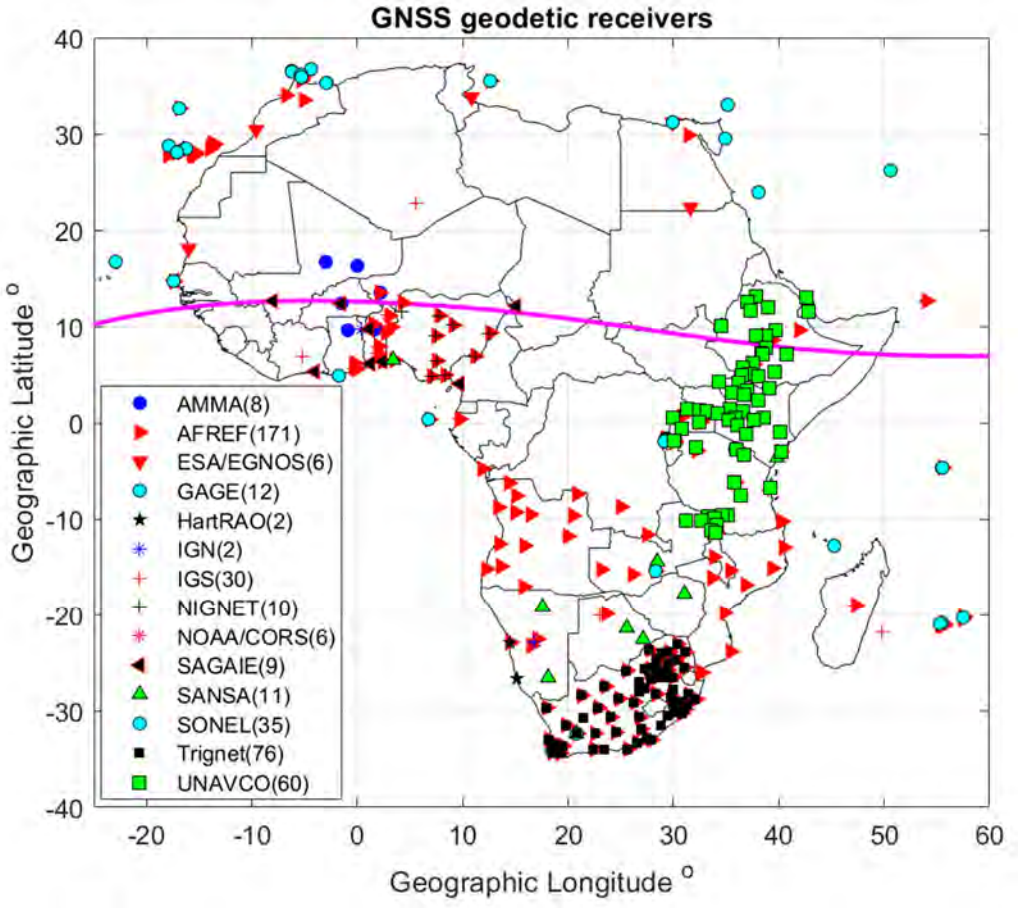

Figure 3. GNSS geodetic and reference receiver distribution. The purple line shows the location of the geomagnetic equator.

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The measurements from 1994 are available on two websites in the United States, NASA's CDDIS and SOPAC [2,18], and on regional sites (IGN in France [19] and BKG in Germany [20]).

(c) GAGE/UNAVCO Network

The Geodetic Facility for the Advancement of Geoscience (GAGE, formerly UNAVCO, ***University NAVSTAR Consortium***) is a non-profit university-governed consortium funded by the National Science Foundation (NSF) and The National Aeronautics and Space Administration (NASA). It provides technical support to scientists for geodesy, tectonic, and geophysical events and education. It is responsible for archiving and disseminating measurements in RINEX format. The main projects are for North America and the poles. However, for more than 20 years, UNAVCO has supported a project covering the African continent ('AfricaArray'), with the installation of many GNSS receivers mainly around the East African Rift for a few months up to several years, which can be used for space weather research (Figure 4). The files are available on their site via ftp or web GUI [21].

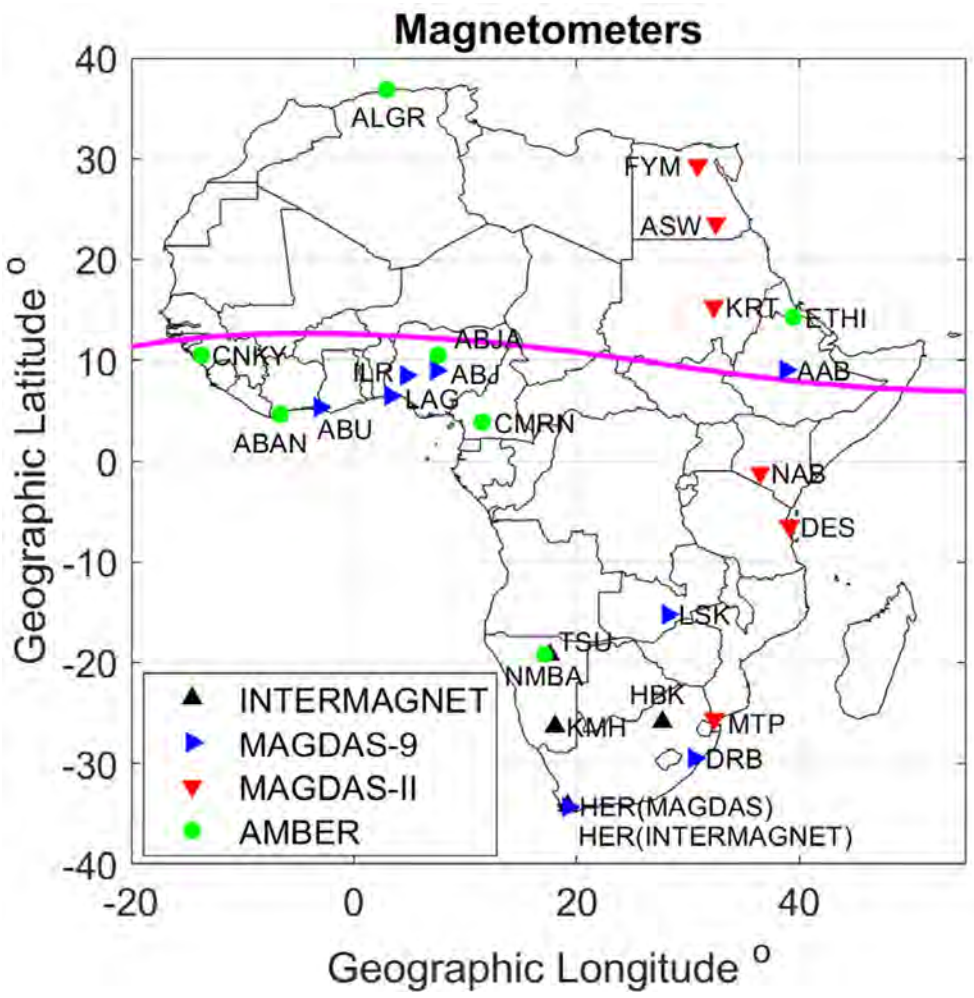

Figure 4. Locations of magnetometers of various networks in Africa. The purple line shows the location of the geomagnetic equator.

(d) The African Geodetic Reference Frame (AFREF)

The African Geodetic Reference Frame (AFREF) was conceived as a unified geodetic reference frame for Africa and as the fundamental basis for national and regional three-dimensional reference networks that are entirely consistent and homogeneous with the International Terrestrial Reference Frame (ITRF). Continuously Operating Reference Stations (CORS) or GNSS base stations were established to achieve this. The AFREF operational data center collects data daily. The data from all the stations of the IGS and GAGE networks are freely available on this website [22].

(e) The TRIGNET Network

tional data center collects data daily. The data from all the stations of the IGS and GAGE networks are freely available on this website [22].

(e) The TRIGNET Network

The geodetic GNSS reference receivers of the TRIGNET network in South Africa are deployed and maintained by the South African Chief Directorate: National Geospatial Information (CD:NGI). This network of more than 60 GNSS receivers has provided South Africa with better GNSS infrastructure than the rest of the African countries. Data from the TRIGNET network is available via the web link of the Chief Directorate: National Geospatial Information (CD:NGI) [23].

SANSA (South African National Space Agency) recently deployed multi-constellation geodetic GNSS receivers for real-time ionospheric monitoring in South Africa (SUTG, 32.37° S, 20.81° E), in Southern Botswana (PALP, 22.60° S, 27.13° E; and LETL, 21.42° S, 25.57° E), in Zimbabwe (HARG, 17.78° S, 31.05° E), in Namibia (KMHG, 26.53° S, 18.1° E) and in Lagos, Nigeria (TSUG, 19.20° S,17.58° E).

(f) African Monsoon Multidisciplinary Analysis (AMMA) GPS Network [24]

The AMMA GNSS receivers were installed in Djougou (Benin), Niamey (Niger), Gao (Mali), Tamale (Ghana), Ouagadougou (Burkina-Faso), and Tombouctou (Mali) during the period 2006–2009. Although the data can be used across disciplines, these GNSS stations were established for meteorological applications, but the data can also be used for space weather studies and can be downloaded from the AFREF website.

(g) The CNES/SAGAIE network

CNES (France) began the implementation of the SAGAIE (Stations ASECNA GNSS pour l'Analyse de la Ionosphère Equatoriale) network in 2013 for the real-time correction of an extension of SBAS/EGNOS to Africa. The current network includes nine stations (Table 3), all installed at major airports, often with one geodesy receiver and one scintillator receiver at each station. Operational monitoring is carried out by ASECNA (**Agence pour la Sécurité de la Navigation aérienne en Afrique et à Madagascar**). Unfortunately, these data are not yet freely accessible [25].

Table 3. CNES/SAGAIE stations operating in 2023.

Marker	Country	Latitude	Longitude
ABI1	Ivory Coast	5.32	−4.03
CTO1	Benin	6.37	2.39
DAK2	Senegal	14.76	−17.38
NIA1	Togo	9.74	1.12
LOM2	Togo	6.14	1.24
NDJA	Chad	12.12	15.06
OUAG	Burkina Faso	12.36	−1.53
DOUA	Cameroon	4.05	9.71
BAM1	Mali	12.65	−8.00

(h) The SONEL network

SONEL (Système d'observation du Niveau des eaux Littorales) produces accurate sea level measurements from tide gauges and geodetic receivers. There are more than 1000 GNSS stations near the coasts around the world, but only a few dozen around the African continent. The measurements are available on their website [26].

(i) CORS and Private Networks

There are many CORS networks in several African countries. Unfortunately, their advertising is limited, so it is very difficult to establish a list of operational stations in each. Those responsible do not offer web links, and the measurements taken are unfortunately inaccessible. Two exceptions can be cited:

The NOAA/CORS network in Benin included 7 stations (BJKA, BJNA, BJNI, BJPA, BJSA, BJAB, BJCO). The network was shut down in January 2020.

The NIGNET network (Nigerian GNSS Reference Network) in Nigeria. It included up to 14 stations distributed in each region (BKFP, HUKP, MDGR, RECT, FPNO, ABUZ, CGGT, FUTY, OSGF, ULAG, UNEC, RUST, CLBR, GEMB). The measurements were used for geodesy, troposphere, and ionosphere. The network was shut down in 2017. The data of these two networks are available on the AFREF website.

(j) OMNISTAR Differential GNSS

OmniSTAR provides GNSS receivers for their space-based GNSS correction services that can improve the accuracy of precise positioning applications. The OMNISTAR (Trimble Private Network) GPS receivers are mainly deployed along the African coast to improve the accuracy of GPS positioning for ocean navigation, but they are still useful for space weather studies. OMNISTAR is a private commercial network of satellite-based augmentation services. The data from this network are not freely available [27].

2.1.2. Magnetometers in Africa

Magnetometers are ground-based infrastructure used in space weather monitoring for monitoring the impact of geomagnetic storms. Figure 4 and Tables 4–7 provide the locations and other details of the magnetometers in Africa.

Table 4. AMBER magnetometer stations in Africa.

Station and Host Country	Code	Geo Lat/ Geo Lon	Mag Lat/ Mag Lon	L-Shell Value
Medea Station Algeria	ALGR	36.85 2.93	27.98 77.67	1.30
Yaounde Station Cameroon	CMRN	3.87 11.52	−5.30 83.12	1.00
Abidjan Station Côte d'Ivoire	ABAN	4.60 −6.60	−6.00 65.80	1.00
Adigrat Station Ethiopia	ETHI	14.28 39.46	5.90 111.06	1.00
Conakry Station Guinea	CNKY	10.50 −13.70	−0.50 60.40	1.00
Windhoek Station Namibia	NMBA	−19.20 17.09	−33.15 84.65	1.40
Abuja Station Nigeria	ABJA	10.50 7.55	0.55 79.63	1.00

Table 5. AMBER network host institutions and contact persons.

Name	Organization	Email Address
Fatma Anad	Centre de Recherche en Astronomie Astrophysique et Géophysique (CRAAG), Algeria	f_anad@yahoo.fr
Cesar Biouele PhD.	University of Yaounde I, Cameroon	cesar.mbane@yahoo.fr
Amoré Nel, PhD	South African National Space Agency (SANSA), Hermanus, South Africa	anel@sansa.org.za
Alem Mebrahtu PhD.	Adigrat University, Ethiopia	alemmeb@yahoo.com
Rabiu Babatunde, PhD.	Centre for Atmospheric Science, National Space Research and Development, Nigeria	tunderabiu@yahoo.com

Table 6. Magnetometers installed in Africa by Kyushu University, Japan. The geomagnetic dipole coordinates are determined using model calculations provided by the British Geological Survey—Geomagnetism (https://www.bgs.ac.uk/?s=coordinate+calculator, accessed on 26 November 2023) The geomagnetic coordinates and the dip latitude were calculated using the BGS online IGRF model (https://geomag.bgs.ac.uk/data_service/models_compass/igrf_calc.html, accessed on 26 November 2023).

Abbrev.	Station Name	Nation	GG Lat.	GG Lon.	GM Lat.	GM Lon.	L-Shell	Dip Lat.	Installed	Type
FYM	Fayum	Egypt	29.30	30.88	26.76	103.64	1.15	43.68	08/01/14	MAGDAS-II
ASW	Aswan	Egypt	23.59	32.51	20.88	108.75	1.07	33.98	08/12/23	MAGDAS-II
KRT	Khartoum	Sudan	15.33	32.32	12.76	107.18	1.01	16.30	08/09/23	MAGDAS-II
AAB	Addis Ababa	Ethiopia	9.04	38.77	5.56	112.51	1.00	3.39	06/08/19	MAGDAS-9
ILR	Ilorin	Nigeria	8.50	4.68	10.42	78.83	1.00	−8.44	06/08/24	MAGDAS-9
ABU	Abuja	Nigeria	8.99	7.39	10.48	81.60	1.00	−6.75	10/08/15	MAGDAS-9
LAG	Lagos	Nigeria	6.48	3.27	8.65	77.11	1.00	−13.91	08/09/04	MAGDAS-9
ABJ	Abidjan	Ivory Coast	5.35	−3.08	8.52	70.62	1.00	−17.41	06/09/01	MAGDAS−9
NAB	Nairobi	Kenya	−1.16	36.48	−4.18	108.73	1.09	−22.36	08/09/16	MAGDAS-II
DES	Dar Es Salaam	Tanzania	−6.47	39.12	−9.83	110.54	1.09	−33.10	08/09/10	MAGDAS-II
LSK	Lusaka	Zambia	−15.23	28.20	−16.78	98.25	1.24	−52.48	08/09/25	MAGDAS-9
MPT	Maputo	Mozambique	−25.57	32.36	−27.63	100.52	1.53	−60.40	08/09/15	MAGDAS-II
DRB	Durban	South Africa	−29.49	30.56	−31.20	97.92	1.67	−62.05	08/09/08	MAGDAS-9
HER	Hermanus	South Africa	−34.34	19.24	−34.14	85.64	1.83	−64.74	07/09/14	MAGDAS-9

Table 7. MAGDAS magnetometer station host countries and their universities.

Station Code	Station Name	Country	Institution
ABJ	Abidjan	Ivory Coast	University of Cocody
LAG	Lagos	Nigeria	Redeemer's University
ILR	Ilorin	Nigeria	University of Ilorin
ABU	Abuja	Nigeria	National Space Research and Development Agency
AAB	Addis Ababa	Ethiopia	Addis Ababa University
HER	Hermanus	South Africa	SANSA Space Science
DRB	Durban	South Africa	University of KwaZulu Natal
MTP	Maputo	Mozambique	Eduardo Mondlane University
LSK	Lusaka	Zambia	University of Zambia
DES	Dar es Salaam	Tanzania	University of Dar es Salaam
NAB	Nairobi	Kenya	University of Nairobi
KRT	Khartoum	Sudan	University of Khartoum
ASW	Aswan	Egypt	Helwan University
FYM	Fayum	Egypt	Helwan University

(a) AMBER Magnetometers [28–31]

The African Meridian B-field Education and Research (AMBER) magnetometer network is operated by Boston College and funded by NASA and the Air Force Office of Scientific Research (AFOSR). The principal investigators are Endawoke Yizengaw, PhD. (Ethiopia), Boston College, USA and Mark Moldwin, PhD, University of Michigan, USA (http://magnetometers.bc.edu/index.php/amber2, accessed on 26 November 2023). The

AMBER stations in Africa are Adigrat (Ethiopia), Medea (Algeria), Yaounde (Cameroon), Tsumeb (Namibia), Abuja (Nigeria), Conakry (Guinea), and Abidjan (Ivory Coast).

(b) Magnetic Data Acquisition System (MAGDAS) stations in Africa [32–38]

The principal investigator (PI) of the project which installed these magnetometers was Prof. Kiyohumi Yumoto (deceased) of the International Center for Space Weather Science and Education (ICSWSE), Kyushu University, Japan. ICSWSE, Kyushu University, is one of the few research institutes/universities conducting research and education in space weather in the world. The MAGDAS network has over seventy fluxgate magnetometers distributed across the world, with 14 of them installed in Africa. The MADGAS data have been used by several researchers in Africa for space weather research, but quite a number of these magnetometers are no longer operational.

The African countries and their respective universities hosting the magnetometers are listed in Table 7.

Most of these facilities are hosted by departments of physics and a few by the electrical engineering departments in the respective universities. Ensuring the continuity of operations of the magnetometers has been a challenge since the funding stream from Japan dried up after the demise of the PI.

(c) INTERMAGNET

INTERMAGNET is a global network of observatories dedicated to monitoring geomagnetic field variations across the world. There are INTERMAGNET magnetometers in five countries in Africa, namely Ethiopia, Madagascar, South Africa, Algeria, and Senegal. Details of the four INTERMAGNET observatories and other magnetometers in Southern Africa can be found in [16,39–42]. At each of the four INTERMAGNET observatories in Southern Africa, there are several types of magnetometers, including Overhauser Scalar Magnetometer GSM-90, 3-axis Fluxgate Magnetometers DMI FGE, and 3-axis Fluxgate Magnetometers LEMI025.

2.1.3. Other Ground-Based Facilities

Several other ground-based facilities that can be used for space weather monitoring have been deployed in Africa. Figure 5 depicts the distribution of most of the other space weather equipment in Africa.

(a) Incoherent Scatter Radars

The incoherent scatter radar (ISR) is one of the most powerful sounding methods developed to estimate certain properties of the ionosphere. This radar system determines the plasma parameters by sending powerful electromagnetic pulses to the ionosphere and analyzing the received backscatter. This analysis provides information about parameters such as electron and ion temperatures, electron densities, ion composition, and ion drift velocities. Nevertheless, in some cases, ISR analysis has ambiguities in the determination of plasma characteristics. They are in Ethiopia and Nigeria. There is also one under construction in Kenya.

(b) Ionosondes

The ionosondes are used to generate ionograms and assist in determining the state of the ionosphere and selecting the optimum frequencies for HF radio communication.

The ionosondes are installed in South Africa (four), Kenya (one), Ethiopia (one), and Nigeria (one). The stations in Kenya, Ethiopia, and Nigeria are non-operational. In the Ethiopian case, the electric power supply is unreliable and unstable, and in the Kenyan case, there are issues with system configuration as well as storage of data. Only two of the ionosondes in South Africa are currently operational (HR, GR), while the two others are being refurbished after vandalism and theft.

A new ionosonde was installed in July 2023 in Malindi, Kenya, at the Broglio Space Center (BSC) managed by the Italian Space Agency and it is the only one operational, at present, outside South Africa.

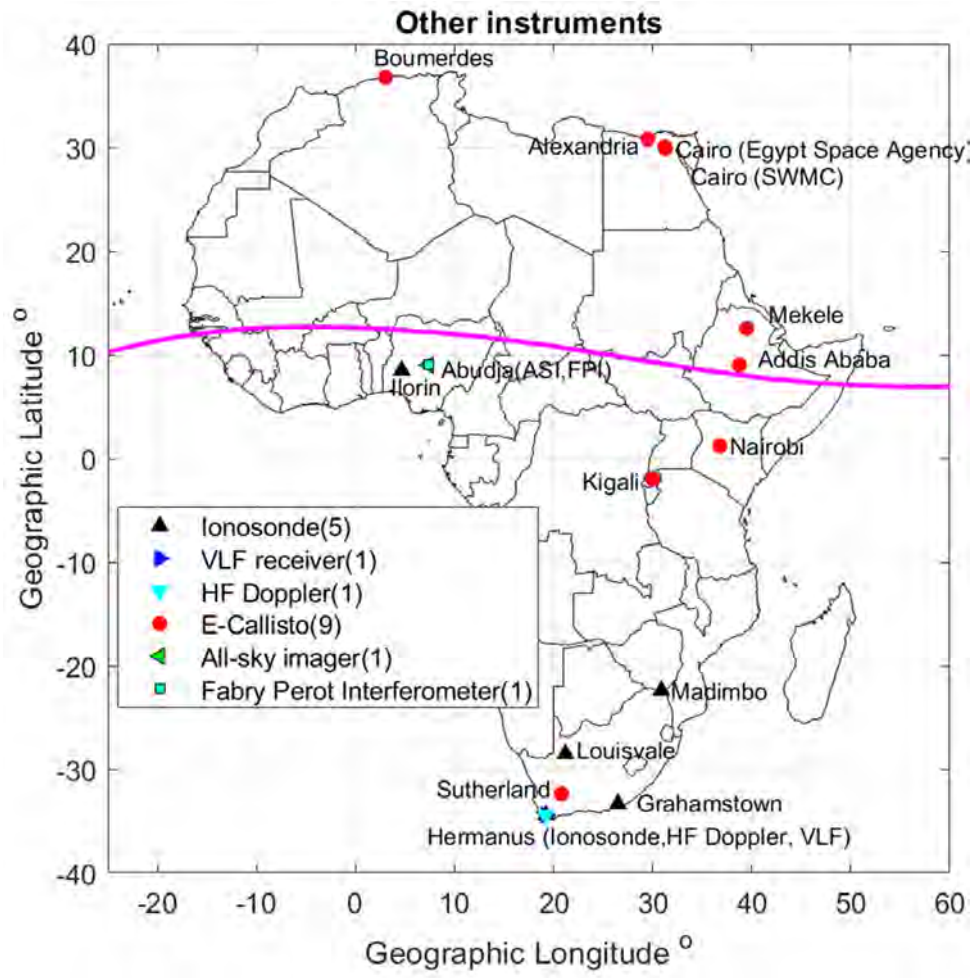

Figure 5. Distribution of other infrastructure dedicated to space weather monitoring in Africa.

(c) Very-Low-Frequency (VLF) and Very-High-Frequency (VHF) receivers

Several VLF devices have been distributed by Stanford University (USA) and installed in several African countries (See Table 8) to monitor the lower layer of the ionosphere (D layer). They are divided into two groups: those related to the AWESOME (Atmospheric Weather Education System for Observation and Modeling of Effects) network and those related to the SID (Sudden Ionospheric Disturbance Monitor) and super-SID receivers. Besides these, we also the Compact Astronomical Low-Cost Low-Frequency Instrument for Spectroscopy and Transportable Observatory (*CALLISTO*) *spectrometer* [43,44], which operates between 45 to 870 MHz. The monitors are installed in Kenya, Ethiopia, Uganda, Egypt, Algeria, and South Africa. The principal investigator of CALLISTO is Christian Monstein of the Radio Astronomy Group (IRAG) at ETH Zurich Switzerland. SANSA operates an e-Callisto Solar Radio Spectrometer (http://e-callisto.org/) at Sutherland in South Africa (Lat 32:38° S, Lon 20:81° E). Table 8 gives some details of the VLF and VHF receivers installed in Africa.

Table 8. The number of VLF and VHF receivers installed.

Countries	AWESOME	VHF	SID
Algeria	1	0	2
Burkina Faso	0	0	1
Congo Brazzaville	0	0	6
Ivory Coast	0	2	2
Egypt	1	2	14
Ethiopia	1	2	14
Kenya	1	2	3
Libya	2	0	1
Morocco	1	0	0
Namibia	0	0	1
Nigeria	0	2	38
Senegal	0	0	1
South Africa	0	2	13
Tunisia	1	0	9
Uganda	0	2	4
Zambia	0	0	2

Some VHF monitors [11] were installed across the continent by AFRL. The host countries are Congo (Brazzaville), Egypt, Ethiopia, Kenya, Nigeria, South Africa, and Uganda.

Most of North Africa and parts of Central Africa have substantial infrastructure gaps. Several countries in these regions are politically unstable, thus making the installation of ground-based space weather equipment rather difficult. These gaps will need to be filled so that there will be sufficient data to enable adequate coverage of Africa in terms of space weather research.

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Ivory Coast	0	2	2
Egypt	1	2	14
Ethiopia	1	2	14
Kenya	0	2	3
Libya	2	0	1
Morocco	1	0	0
Namibia	0	0	1
Nigeria	0	2	38
Senegal	0	0	1
South Africa	0	2	13
Tunisia	1	0	9
Uganda	0	2	4
Zambia	0	0	2

2.2. Data Access and Reliability

Most of the data generated by the observing equipment have a free access policy, except for those owned by national mapping agencies in various countries. However, different data providers have imposed conditions to be met before granting access to the data. In most cases, if the data is purely for research, and not for commercial use, then free access is always granted, but some acknowledgement of the data source is required whenever a publication is produced with them. The SANDIMS data portal at SANSA [45] provides free access, via a data request for research applications, to all geomagnetic, ionospheric, and magnetospheric data gathered from SANSA Space Science's instrumentation network. The eSWua web portal of Istituto Nazionale di Geofisica e Vulcanologia (INGV) in Italy [46] provides free access to visualization and downloads of the data from instruments managed by INGV. The users can access data from a GUI or a service from which massive data downloading can be performed automatically.

This open data policy has enabled many African researchers to benefit from space weather data generated by equipment hosted in the continent and beyond. In effect, this has contributed immensely to human capital development in space weather science in many countries in Africa. However, a major setback is the non-operational status of most of the equipment due to several factors such as non-stable electric power supply, poor internet connectivity, poor system configuration, poor maintenance, and equipment operating beyond its useful lifetime. Replacement of ageing equipment and maintenance issues are made worse by the fact that some African equipment hosts do not actually use the data for any training or research and hence have no interest in maintaining or replacing the equipment. Although some of the factors limiting successful equipment functioning could be addressed by the hosts (e.g., unreliable electric power by investing in solar power), most of the equipment hosts do not have funding for this, and most of the host institutions do not provide support towards that end.

The lack of a good network of space weather monitors in Africa is limiting the modelling of the African sector of the near-earth space environment and thus the development of space weather products and services. For example, it is known that scintillation threatens the performances of GNSS-reliant services requiring high-precision positioning, but forecasting scintillation is still a challenge. The development of ionospheric climatology over various geographic regions of Africa would be a useful step in providing space weather information. Climatology is only possible with a proper network of space weather monitors that continuously provide data over an extended period.

2.3. Space Weather Products and Services

There is a need to develop thresholds of space weather threats on a variety of technological systems in Africa. This includes the aviation industry since ICAO now recommends the provision of space weather alerts as part of regulations and standards for enhanced safety in civil aviation. Except for SANSA Space Science in South Africa, the rest of Africa has not developed space weather products and services for the aviation industry and other industrial sectors. Commercialization of space weather research findings will help mitigate economic losses brought about by space weather events, and it could also possibly provide funding streams to support space weather research. At the moment, there is a huge disconnect between industry and academia in Africa.

3. Human Capital Development

The training and research in space weather in various African countries are at different levels. We provide a detailed summary of the human resource situation in selected countries below.

3.1. Capacity Building

Activities geared towards human capital development are given in Table 9. These include training workshops and doctoral studies in some countries in Africa as of the end of 2022. Table 9 also gives a list of the universities involved.

Efforts by the United Nations Basic Space Science Initiative (UNBSSI) since the year 1991 have led to an increase in space weather capacity building. For example, there were 10 PhD theses defended during the first decade (1991–2001), while 84 PhD theses were defended during the period 2001–2023. Presently, there are 68 PhD theses in progress.

3.2. International Achievements [47,48]

Since 2014, many African space weather researchers have obtained international awards for exemplary research in space weather (Table 10).

Thus, capacity building in this field is growing, and the quality of African space weather researchers is comparable to the rest of the world. This is exemplified by the number of recipients of international awards coming from Africa, and also by the sheer number of those graduating with PhDs or with PhDs in progress.

3.3. Initiatives by Professional Societies/International Organizations

Some selected initiatives in support of space weather research in Africa are mentioned here.

(a) African Geophysical Society

The African Geophysical Society (AGS) is a dynamic, innovative, and interdisciplinary scientific association committed to the pursuit of understanding Earth and space for the benefit of mankind. The objectives of the AGS are to expand and strengthen the study in the African continent of the Earth and other planets, including their environments. The main goals are to facilitate cooperation among scientists; create national, regional, and international scientific organizations involved in geophysical and other related research and intiating new research and training programs; and popularize various geophysical research and training programs via scientific conferences, publications, and training in both the short and long terms.

The AGS has brought together African researchers and created platforms for collaborative research, co-supervision of students, and external examination of theses/dissertations. This has greatly improved the space weather research landscape in Africa.

Table 9. Capacity building by African scientists.

Country	School/Workshop	PhD	Universities/Institutions
Algeria	ISWI Maghreb Algerian (ISWI Maghreb) School organized in 2013 at Algiers University—6–16 May 2013	PhDs defended: 4; in progress: 3	USTHB, CTC Arzew, CRAAG
Benin	No school but the participation of students in l ISWI school, Maghreb, West Africa	PhDs defended: 1; in progress:1	University of Abomey-Calavi
Burkina Faso	No schools/workshops but the participation of students in the ISWI School, Maghreb West Africa	PhDs defended: 16; in progress: 16	University Nobert ZONGO University Joseph Ki-ZERBO University Nazi BONI (Bobo Dioulasso) IRSAT/National Center for Scientific Research and Technology
Cameroon	No school, but the participation of students in the ISWI, school, Maghreb, West Africa	PhD defended: 1	Higher Technical Teacher Training College/Department of Geomatics, University of Ebolowa, Cameroon
Ivory Coast	International school in Abidjan (15–25 October 1995), Ivory Coast 3rd edition of the ISWI-Magreb-West Africa Space Weather School (IMAO), UFHB, Bingerville (16–28 October 2017), Ivory Coast	PhDs defended: 15; in progress: 4	University Félix Houphouët Boigny, Cocody, Abidjan University of Man University Pelefero gon Coulibaly, Korhogo
Democratic Republic of Congo	School ISWI in Kinshasa, 11–24 September 2011	PhDs defended: 5; in progress: 1	University of Kinshasa
Egypt	International Space Weather Initiative (ISWI) UN/NASA/JAXA Workshop 6–10 November 2010 Helwan, Egypt International Workshop on Space Weather and Space Navigation, 3–4 October 2017, Beni-Suef University, Egypt African Geophysical Society Conference on Space Weather, 25–28 March 2019, Cairo, Egypt	PhDs defended: 5; in progress: 3	Space Environment Research Lab at Egypt, Japan University of Science Technology (E-JUST) Space Weather Monitoring Center at Helwan University Faculty of Navigation Science and Space Technology-Beni Suef University Department of Astronomy and Meteorology, Faculty of Sciences, Cairo University National Research Institute of Astronomy and Geophysics (NRIAG) National Authority for Remote Sensing & Space Sciences Egyptian Space Agency
Ethiopia	IHY—Africa Space Weather Science and Education workshop, 12–16 November 2007, Addis Ababa, Ethiopia AGU-Chapman conference, Addis Ababa, 12–16 November 2012 First ISWI Space Science School in Bahir Dar University, November 2010 in Ethiopia. 14th International Symposium on Equatorial Aeronomy, 19–23 October 2015, Bahir Dar, Ethiopia	PhD defended: 10 in progress: 6	Physics Department Science College, Bahir Dar University, Washera Geospace and Radar Science Research Laboratory at Bahir Dar University Department of Physics, Addis Ababa University Institute of Geophysics, Space Science and Astronomy (IGSSA), Addis Ababa University, Entoto Observatory and Research Center, Ethiopia
Guinea	No school, but participation of students in the ISWI Maghreb West Africa school	PhD defended: 1	
Kenya	African Geophysical Society Conference on Space Weather, Nairobi, 21–25 September 2015 The Eastern Africa GNSS and Space Weather Capacity Building Workshop, 13–17 May 2019 The second edition of the Eastern Africa GNSS and Space Weather Capacity Building Workshop, 21–25 June 2021 East, Central, and Southern Africa GNSS and Space Weather Workshop, 9–23 July 2010, Nairobi, Kenya. ISWI/SCOSTEP Space Science School, October 21– 1 November 2013, Kenya Institute of Education, Nairobi, Kenya	PhDs defended: 3; in progress: 1	Pwani University Technical University of Kenya Maseno University Jomo Kenyatta University of Science and Technology University of Nairobi Masinde Muliro University of Science and Technology
Morocco	Workshop on Space Weather and Instruments with the Illinois Space Weather team, the Moroccan team, and master's and PhD students for the installation of the RENOIR (Remote Equatorial Night-time Observatory of Ionospheric Regions), 4–11 November 2013 ISWI school (Space Weather) organized in 2014 at Cady Ayyad University, 5–10 May 2014	PhDs defended: 3; in progress: 3	University Cady Ayyad at Marrakech

Table 9. *Cont.*

Country	School/Workshop	PhD	Universities/Institutions
Morocco	ISWI School of Space Weather and GNSS, 16–21 February 2015 African Workshop on GNSS and Space Weather, 5–6 October 2020 ICTP activity co-organized by CRASTE-LF UNOOSA–ICG and Boston College scheduled in Rabat and held online because of COVID-19		African Regional Centre for Space Science and Technology Education in French Language (CRASTE-LF)
Nigeria	Third United Nations/European Space Agency Workshop on Basic Space Science, 18–22 October 1993, Lagos First Annual National Workshop of the International Heliophysical Year (IHY), Nigeria, 27 October 2005, Federal University of Technology, Akure, Nigeria African Regional International Heliophysical Year School (AFRIS), 9–22 November 2008, Enugu, Nigeria Nigerian National Meeting on GNSS Science and Application: National Augmentation System For GPS (application to geodesy, air, ground and water navigation systems), 16–19 November 2009, Virtual Library Hall, National Universities Commission (NUC), Abuja, Nigeria 2009 African Regional Conference of the International Academy of Astronautics; 24–26 November 2009, Abuja, Nigeria ISWI/MAGDAS School on Litho-Space Weather, 15–21 August 2011, Redeemer's University, Mowe, Nigeria UN/Nigeria Workshop on International Space Weather Initiative ISWI, 17–21 October 2011, Abuja, Nigeria 2nd African Regional Centre for Space Science Technology Education—English (ARCSSTEE) regional conference, 22–24 August 2012, Obafemi Awolowo University, Ile-Ife, Nigeria National Conference on Space Weather and Space-Based Technologies, 2–9 February 2013, Bells University of Technology, Ota, Nigeria 2nd Cyril Onwumechili School on Physics of Upper Atmosphere, 23–27 June 2013, Centre for Atmospheric Research, Anyigba, Nigeria International Space Weather School, 20–25 January 2014, Bells University of Technology, Ota, Nigeria Centre for Satellite Technology Development (CSTD) Space Week 2014, 3–5 June 2014, Abuja, Nigeria. African Geophysical Society Conference 2–6 June 2014, Abuja, Nigeria 2nd Annual Nigerian Geophysical Society Conference, 17–20 March 2015, Covenant University, Canaanland, Ota, Nigeria International School on Equatorial and Low-Latitude Ionosphere (ISELLI), 14–18 September 2015 Centre for Atmospheric Research, National Space Research and Development Agency (NASRDA), Abuja, Nigeria Radicella 80th Birthday Symposium, University of Lagos, Akoka, Nigeria, UNILAG, 8th May 2017 Nigerian Geophysical Society 4th International Conference, Bayero University, Kano, Nigeria, 9–12 May 2017 5th Nigerian Geophysical Society Annual International Conference, Federal University, Dutse, Jigawa, Nigeria, 19th and 22nd June 2018. Superdarn radar workshop, Bowen University, Iwo, Nigeria, June 3–7 June 2019 International Colloquium on Equatorial and Low-Latitude Ionosphere (ICELLI, UNILAG), 9–13 September 2019 2nd International Colloquium on Equatorial and Low-Latitude Ionosphere (ICELLI), online, 15–17 September 2020 International Colloquium on Equatorial and Low-Latitude Ionosphere (ICELLI), Bowen University, Iwo, Nigeria, September 13–18, 2021,	PhDs defended: 20; in progress: 15	More than 20 Nigerian Universities are offering graduate programs in space-weather-related fields Centre for Atmospheric Research, National Space Research and Development Agency, Anyigba, Nigeria African Regional Centre for Space Science and Technology Education in English Language (ARCSSTE-E)

Table 9. *Cont.*

Country	School/Workshop	PhD	Universities/Institutions
Rwanda	School for describing and analyzing solar data for a better prediction of space weather: postponed in July-August 2022	PhDs in progress: 2	University of Rwanda—College of Science and Technology University of Rwanda—College of Education
Republic of Congo	School IHY in RC, 2–9 December 2009	PhD defended: 1; in progress: 2	University Marien Ngouabi
Senegal	ISWI, Maghreb, West Africa school organized in 2019 at Thiès University—15 to 25 October 2019	PhDs defended: 2; in progress: 3	University Iba Der Thiam of Thiès
South Africa	International Reference Ionosphere Workshop hosted by SANSA: 10–14 October 2011 African Workshop on Space Science Research held at SANSA, Hermanus, South Africa: 04–08 May 2015 South African National Space Agency (SANSA) and European Space Agency (ESA) The Path to South Africa—European Space Innovation Partnerships Workshop Program, Hermanus, 31 January 2019–2 February 2019 Joint IAPSO-IAMAS-IAGA Assembly, Cape Town, South Africa, 26 Aug–01 Sept, 2017 The 17th European Incoherent Scatter Scientific Association (EISCAT) Symposium and 42nd Annual European Meeting on Atmospheric Studies by Optical Methods (42AM), Hosted by SANSA during 14–18 September 2015 SANSA also participates in the International Space Weather Camp (ISWC), which brings together students from South Africa, the USA, and Germany to learn about space physics topics, including space weather. This is an annual event, with the three countries alternating in hosting.	At least 15 students supervised by SANSA staff (in various universities) have graduated with MSc and PhD degrees in the past 4–5 years	South African National Space Agency, Hermanus, South Africa
Tunisia	The First IHY International Workshop on Advancing VLF Science Through the Global AWESOME Network, 30 May–01 June 2009, Tunis	PhD defended: 1	Faculty of Sciences of Tunis
Uganda	No international school or conference has been organized in Uganda. The plan to host ISWI in Uganda in 2020 failed due to the COVID-19 pandemic	PhDs defended: 2; in progress: 3	Physics Department, Muni University, Arua City, Uganda Physics department, Mbarara University of Science and Technology, Mbararara City Physics Department, Busitema University
Zambia	No space-weather-related international school or conference has been organized in Zambia. Zambia is strengthening its collaboration with South Africa. A workshop to sensitize government officials in space science is planned for June 2022. This has been organized specifically because the government is developing a space policy and strategy, and a need has arisen to educate the decision makers on the key benefits of space science	1 PhD in progress	Department of Physics of Natural Sciences, University of Zambia, Lusaka Department of Physical Sciences, School of Natural Sciences, Kwame Nkrumah University

Table 10. Awards.

Name	Country	Year of Award	Award
John Bosco Habarulema	Uganda	2014	Basu Early Career Award in Sun-Earth System Science.
John Bosco Habarulema	Uganda	2016	AGU Africa Award for Research Excellence in Space Science
Joseph Olwendo	Kenya	2016	Basu Early Career Award in Sun-Earth System Science.
Melessew Nigusie	Ethiopia	2017	AGU Africa Award for Research Excellence in Space Science
Frédéric Ouattara	Burkina Faso	2018	AGU Africa Award for Research Excellence in Space Science
Zama T. Katamzi-Joseph	South Africa	2018	Basu Early Career Award in Sun-Earth System Science.
Andrew Akala	Nigeria	2019	AGU Africa Award for Research Excellence in Space Science
Olawale S. Bolaji	Nigeria	2020	AGU Africa Award for Research Excellence in Space Science

(b) URSI Commission G Working group: "Capacity building and training"

During the International Radio Science Union (URSI) General Assembly 2021, held in Rome from 28 August to 4 September, a new working group (WG) in the framework of Commission G (Ionospheric Radio and Propagation) has been established. This WG, named "Capacity Building and Training," is chaired by C. Cesaroni (INGV, Italy) and co-chaired by J. Olwendo (PU, Kenya), B. Nava (ICTP, Italy), and P. Doherty (now deceased; BC, USA). The "Capacity Building and Training" working group deals with activities related to the training of students and young scientists mainly from developing countries. The main objectives of the working group are: to rganize international workshops, especially for young scientists from developing countries; to facilitate visits/exchanges for young scientists by putting in place actions for fundraising; and to organize periodical webinars for sharing new research among the commission G community members. This group is championing the aspirations of the African space weather research community.

(c) Scientific Committee on Solar-Terrestrial Physics (SCOSTEP)

Many African master's and doctoral researchers have benefited from the SCOSTEP visiting scholar program, whereby a scholar is sponsored to undertake his/her study in another institute to access facilities and expertise that are not available at their home institute. This has provided excellent opportunities for networking and co-authorship of research articles.

(d) The Abdus Salam International Centre for Theoretical Physics/Boston College/INGV

Every year since 2009, the ICTP and Boston College have been organizing training workshops on GNSS and space weather for developing countries. Recently, INGV has been contributing by organizing additional workshops in collaboration with the aforementioned institutions. Many African lecturers and students have been trained in space weather monitoring equipment installation and maintenance and data acquisition, reduction, and interpretation. Some of these works have been organized in Africa and have greatly impacted space weather research capacity in Africa.

(e) Groupe de Recherche en Géophysique Europe Afrique (GIRGEA) network [49–53]

In the framework of the UNBSSI program, the GIRGEA network organized has schools on space weather since 1995. Since 2013, the GIRGEA scientific network has been organizing regional schools every two years.

3.4. International Collaborations

Space weather training in Africa has been built on two models, namely:

(a) Training of trainers and their students: The first cohort of African lecturers who were converted from their fields of research to space weather research were made hosts of space weather equipment. The equipment hosts were then trained to archive

and use the data produced for research. The pioneering students who used the data for their postgraduate research were jointly supervised by their home-based academic staff and equipment donors. This model has enabled Africans to do research at their home institutions where they were/are registered as students while also building international networks and collaborations. The model forestalled potential brain drain.

(b) Intra-Africa co-supervision of postgraduate research: Many African students are given research topics by their African senior researchers who co-supervise them and also host them for research visits whenever possible.

The weak link in these two models is the lack of investment by the researchers' home institutions in space weather infrastructure development.

3.5. Funding Sources

Space weather research in Africa has been supported through a variety of funding streams. These include:

(a) External financing: Most of the space weather capacity building has been supported through external funding, especially for the acquisition and installation of research equipment, but local African universities have often provided their students with the necessary facilitation to enable them to undertake their research work. More often than not, the facilitation has been in terms of tuition fee waivers and in-kind support.

(b) Government: Some national space agencies and research councils/agencies are now funding space weather research and training workshops to build a critical mass of expertise within the shortest time possible.

(c) Industry: A few industry stakeholders, like the aviation industry and electric power distribution companies, in some few African countries have also come on board to support space weather research, although their involvement is still at a very low level. The challenge here has been that the industry players are not aware of the relevance of space weather research to their businesses. This calls for more awareness campaigns to enlighten the industry, and thus possibly attract more funding from the sector.

4. Gaps in Infrastructure and Human Resources

Gaps

There are many countries in Africa where space weather research is non-existent or infrastructure for space weather monitoring is lacking. In some cases, institutions in some African countries may be hosting facilities whose data they do not use at all, and hence they take little interest in ensuring the functionality of the facilities. This situation is equivalent to cases where there are no facilities installed at all because the result is the same, namely, there is no data to facilitate research.

Gaps in infrastructure are evident in regions like Chad, Central African Republic, Somalia, Eritrea, and South Sudan. Incidentally, these countries lie on or very close to the geomagnetic equator, where ionospheric conditions are very dynamic and have potentially adverse consequences for the technological systems in use. This lack of ground-based observing facilities makes the understanding of space weather dynamics over Africa difficult. Non-deployment of space weather monitors may have been occasioned by political instability in those countries. In some other countries, the infrastructure exists but is not operating optimally due to erratic electric power supply, low internet bandwidths, poor maintenance, or lack of funds to replace ageing or obsolete monitors. Another aspect of the gaps observed is the non-uniform spread of different types of monitors across the continent. The reason for this is partly because collaborators would normally deploy their facilities where they already have points of contact or in a region of interest depending on the relevant space weather campaign at that time. This aspect informs the observed trends in the distribution of equipment across Africa.

The gaps in infrastructure also go hand in hand with the lack of or inadequate human resources in many countries. Many countries do not have well-established departments of

physics where space weather research could thrive. This badly limits postgraduate research in space weather. However, despite the gaps in the deployment of monitors, some current and upcoming projects will help improve the situation (see Table 11). This table may not be exhaustive, but it indicates that more facilities are coming to Africa.

Table 11. Completed, current, and upcoming projects in space science/space weather in Africa.

Country	Projects	Contacts
Algeria	- March 2022: installation of the Algerian GNSS network across the national territory with 109 stations by the INCT (National Institute of Cartography and Teledetection)	Naima ZAOURAR USTHB naimaboulasba@gmail.com
Benin	- Organization of a conference on the importance of space weather in the development of countries	Adébiyi Joseph ADECHINAN Physics Department University of Abomey-Calavi adechinanjoseph@yahoo.fr
Burkina Faso	- Developing SIG and drones for expert surveyor training - Burkina Sat1 project of nanosatellite launching (for agriculture, land management, Earth atmosphere study, and so on) - Acquisition of scintillator (Septentrio) for ionospheric investigation - Planetarium for presenting educational shows about astronomy -Meteorological station - Understanding the effect of geomagnetic activity on ionospheric dynamics	Jean-Louis ZERBO University Nazi BONI (Bobo Dioulasso) JeanLouis.zerbo@gmail.com
Cameroon	- African Meridian B-field Education and Research (AMBER) magnetometer Array Project since 2008 - SCINDA-GPS installation in 2009	Honoré MESSANGA Higher Technical Teacher Training College/Department of Geomatics, University of Ebolowa, Cameroon messanga.honore@gmail.com
Ivory Coast	- Organization of IMAO5 (ISWI Maghreb West Africa, School) 2022 in Abidjan, 17–28 October - Study of the influence of solar events on GNSS positioning	Franck GRODJI University Félix Houphouët Boigny, Cocody, Abidjan franckgrodji@yahoo.fr
Democratic Republic of Congo	- The current situation is not known but some university lecturers have been attending GNSS workshops organized by ICTP and Boston College and the MAGDAS group. The lectures facilitated the deployment of a SCINDA GPS scintillation and TEC monitor in 2011.	Bruno KAHINDO University of Kinshasa bkahindo@gmail.com
Egypt	- Space weather forecasting and warning using artificial Intelligence - Installation of new equipment: Fluxgate Magnetometer and Telluric System CALLISTO Solar Radio Spectrometer GNSS TEC/Scintillation Monitoring Unit	Ayman MAHROUS Space Environment Research Lab at Egypt-Japan University of science technology(E-JUST) ayman.mahrous@ejust.edu.eg
Ethiopia	- Developing the state-of-the-art ionospheric TEC model for improved accuracy of positioning (applicable finally for agriculture, land management, and so on) - Understanding the triggering mechanism of the East African equatorial ionospheric post-sunset irregularities - Understanding the effect of geomagnetic storm time-driven ionospheric currents on low-latitude power grids	Melessew NIGUSSIE Washera Geospace and Radar Science Research Laboratory at Bahir Dar University melessewnigussie@yahoo.com

Table 11. *Cont.*

Country	Projects	Contacts
Guinea	No new initiatives	Rene TATO LOUA Direction Nationale de la Météorologie de Guinée lrenetatometeo@gmail.com
Kenya	- The 2022 event was planned and carried out at the ICTP in Italy during the first two weeks of October. The subsequent events in the years 2023 and 2024 are planned to be conducted at ICTP, Italy, and in Malindi, Kenya, respectively. These two workshops are planned in the framework of the NORISK project with the collaboration of the Italian Space Agency and the Kenyan Space Agency (ASI). - NORISK will install an ionosonde, a GNSS scintillation receiver, and ICT infrastructure for space weather data and product management in Malindi, and it will develop a nowcasting and forecasting model for TEC in the Eastern Africa region. - The Kenya Space Agency in the year 2020 disbursed about USD 30,000 to two universities for the installation of space weather monitors, and the work is still in progress. - Study of solar flares and geo-effectiveness and potential impact on GNSS systems.	Claudio CESARONI Istituto Nazionale di Geofisica e Vulcanologia claudio.cesaroni@ingv.it Local contact Joseph OLWENDO Pwani University j.olwendo@pu.ac.ke Director General, KSA Paul BAKI Technical University of Kenya
Morocco	- Measurements of thermospheric winds with Fabry–Perrot interferometer - Ionospheric irregularities analysis with an all-sky camera (PICASSO) - Analysis of GPS data from five GPS stations installed in Morocco - Analysis of satellite data (SWARM) - Use of simulation resources	Aziza BOUNHIR University Mohammed V of Rabat (and University Cady Ayyad of Marrakech) a.bounhir@uca.ma
Nigeria	- Studies on equatorial electrojet - Measurements of thermospheric winds with Fabry–Perrot interferometer - Measurements of thermospheric winds with Fabry–Perrot interferometer - Equatorial plasma bubbles with an all-sky camera - Analysis of GPS data during various scenarios such as geomagnetic storms, stratospheric warming, solar flares, etc. - Use of ground and satellite data for ionospheric studies - Complexities of the ionosphere using non-linear methods - Ionospheric irregularities studies	Scientists in various universities and research institutions including national space agencies tunderabiu@yahoo.com
Rwanda	-Space weather study through an analysis of solar radio bursts. -Kinematics of CMEs trough solar type II radio bursts and subsequent geo effectiveness -Empirical modelling of storms-time ionospheric TEC and other parameters.	Jean UWAMAHORO University of Rwanda—College of Science and Technology mahorojpacis@gmail.com
Republic Congo	- April 2022, National Week of Science: space technologies for sustainable development in Africa. - Contribution of solar wind parameters to the variation of ionospheric activity in the African equatorial zone	Bienvenue DINGA University Marien Ngouabi bvs_dinga@yahoo.fr

Table 11. *Cont.*

Country	Projects	Contacts
Senegal	- November 2017, installation of a GNSS station at the GLOSS tide gauge in Dakar - Installation of CORS (Continuously Operating Reference Stations) network in 2022, which will cover the country. This CORS network will define the Senegalese Datum - Project to launch a nanosatellite in 2023	Idrissa GAYE University Iba Der Thiam of Thiès idrissagaye3@hotmail.com
South Africa	- Space Weather Project in preparation for providing ICAO advisories for the aviation industry. We are currently developing products such as real-time TEC maps, scintillation products, and 3-dimensional electron density reconstruction maps. - Coupled with the one above, there has been a focus on the installation of GNSS receivers outside South Africa, such as in Kenya and Zambia. All of these are aimed at improving the accuracy of our space weather products. - The National Astrophysics and Space Science Program (http://www.nassp.uct.ac.za/) trains postgraduate students in Astrophysics and Space Science. Students who choose the Space Science stream conduct various projects in space physics, including space weather. This program has three nodes at the University of Cape Town, North West University, and the University of KwaZulu Natal	John Bosco HABARULEMA South African National Space Agency, Hermanus, South Africa jhabarulema@sansa.org.za
Tunisia	- 2006, installation of an AWESOME station at the Faculty of Sciences of Tunis - 2007, installation of the first SID station at the Faculty of Sciences of Tunis - Since 2009, several super-SID stations have been installed - Tunisia launched its first nanosatellite on Mars in 2021	Hassen GHALILA Faculty of Sciences of Tunis, University Tunis El Manar Hassen.ghalila@gmail.com
Uganda	- Developing an institute for space weather research at Busitema University	Patrick MUNGUFENI Physics Department, Muni University, Arua City, Uganda pmungufeni@gmail.com
Zambia	- Installation of Space Weather instrumentation - GNSS, total electron content (TEC), and scintillation monitor at Kwame Nkrumah University in Kabwe, Zambia, in March 2020 - Two (2) space-based augmentation (SBAS) reference receivers in the Northwestern District of Chavurah at the border with Angola and another in Kabwe at Kwame Nkrumah University in March 2020	Patrick SIBANDA Department of Physical Sciences, School of Natural Sciences, Kwame Nkrumah University sibandapatrick.ps@gmail.com

5. Conclusions and the Way Forward

In conclusion, we have gathered that:

(a) There is a huge infrastructure gap, so more instruments need to be deployed for space weather monitoring in Africa to fill in the gaps. This should not be left entirely to outsiders. There is a need for more African institutions/governments to invest in space weather research. To a small extent, this already happening, especially as an initiative by some space agencies in Africa, and perhaps the newly established African Space Agency should play a more proactive role in this.

(b) The community of space weather researchers in Africa is growing in number and competence, and this should encourage collaborations with other researchers from

outside the continent. African and other researchers should team up and run more joint research projects, write proposals for funding, and carry out joint supervision of students.

(c) There is a need to develop thresholds of space weather threats on a variety of technological systems in Africa to inform space weather services in Africa.

(d) There is a need to create more awareness among the potential commercial stakeholders whose infrastructures and businesses could be impacted by space weather so that they put in place measures to mitigate space weather impacts. This could be one avenue for attracting the funding needed for research and development.

(e) We recommend that the African Space Agency (AfSA), when it becomes operational, takes up the challenge of improving space weather research infrastructure in the continent.

(f) Finally, it is well known that space weather prediction can only be possible by fully understanding the complex interactions and coupling occurring between the upper and the lower atmosphere, including the troposphere level. In this regard, the African continent offers a unique opportunity to have a global view as it is mostly composed of land areas spanning the northern mid-latitudes to the southern mid-latitudes. For this reason, the installation of different pieces of space-weather-monitoring equipment in Africa will have important and priceless benefits for the space weather field as a whole.

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