The Abdus Salam International Centre for Theoretical Physics

The Storm-Time Assessment of GNSS-SBAS Performance within African Equatorial and Low Latitude Region

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Training on EGNOS-GNSS in Africa (TREGA)

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Outline

- Introduction
- Data Analysis
- Results and Discussion
- Summary
- Acknowledgements

Introduction

- Storm-time refers to the period of increased geomagnetic activity that influences the space environment.

- it is an interaction of the sun's magnetic field (solar wind), interplanetary magnetic field and Earth's magnetic field (magnetosphere).

- This affects the ionospheric-thermospheric system and influence the performance and reliability of space-based and ground-based technological systems as well endanger human life.

The specific condition of African Equatorial and Low Latitude Region

From ICAO: IONOSPHERIC EFFECT ON GNSS AVIATION OPERATIONS, First Meeting of Ionospheric Studies Task Force, Tokyo, February 2012

"For APV [Approach Procedures with Vertical Guidance] operations, ionospheric delay corrections and associated integrity bounds must be obtained from a SBAS. SBAS is capable of broadcasting ionospheric integrity bounds that are sufficiently small to ensure a high availability of APV service in mid- and high-latitude regions However, the availability of APV service may be reduced or even severely limited in relatively rare occasions (roughly 1% of the time) due to disturbances caused by a severe ionospheric storm. APV service is also conceptually possible in low-latitude regions; however, the variability and unique phenomena of the equatorial ionosphere present a very difficult challenge to ensuring the integrity of the ionospheric corrections without causing frequent interruptions of APV service (i.e., frequent, and perhaps even daily, interruptions of service in the local evening hours during years near the peak of the solar cycle)".

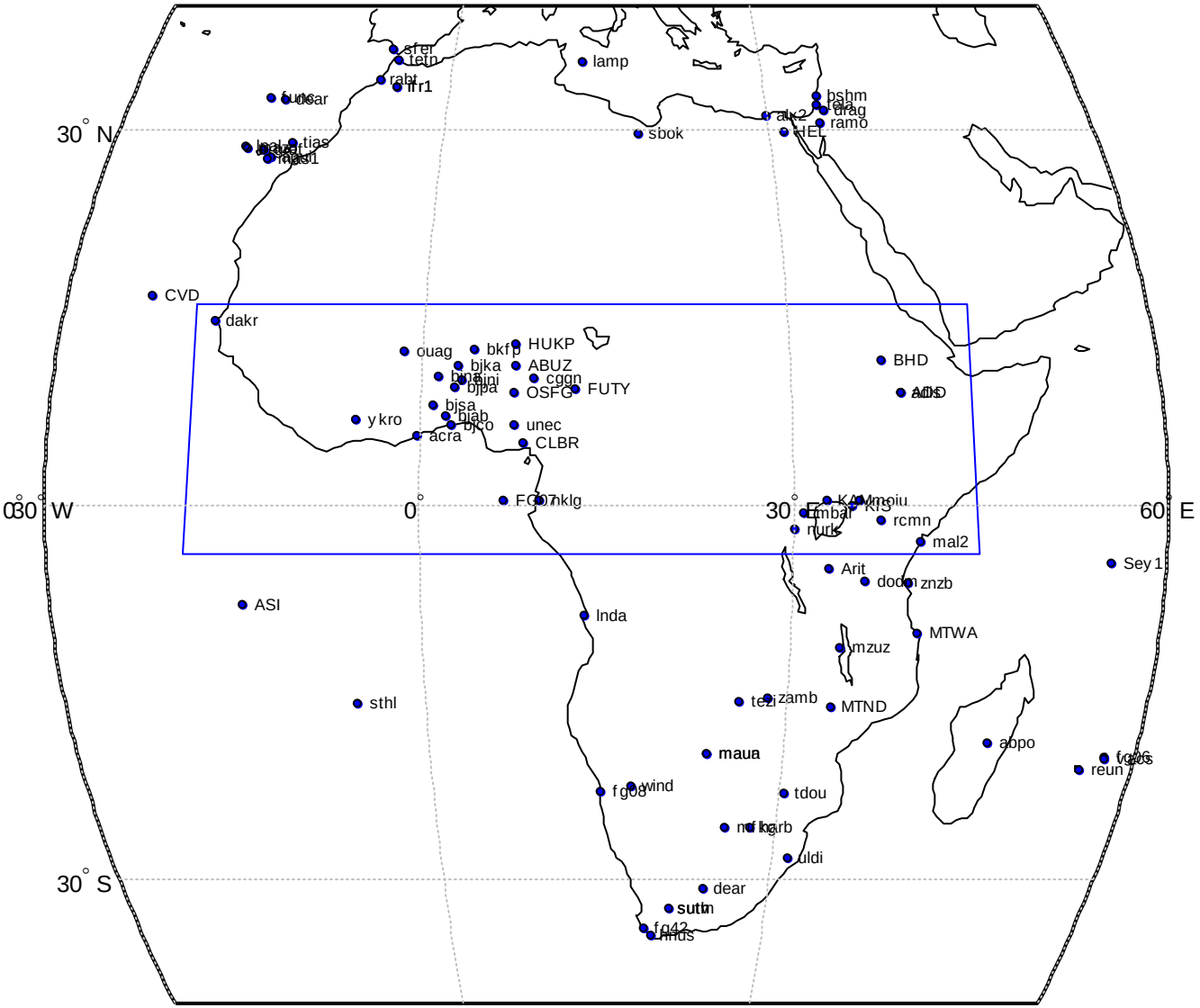
Characteristics of Ionosphere over Low Latitudes

- Low latitudes is considered here within the range of ± 25^{o} magnetic latitudes or modip.
- It shows two peaks of electron density and total electron content around ± 20^{o} and a trough along the geomagnetic equator.
- It is more complex to model than mid-latitude ionosphere.
- Highly variable with time.
- It causes more delay on L band frequency because of the high values of TEC.
- It becomes highly irregular after sunset.
- The irregularities produce large fluctuations in L band signals.

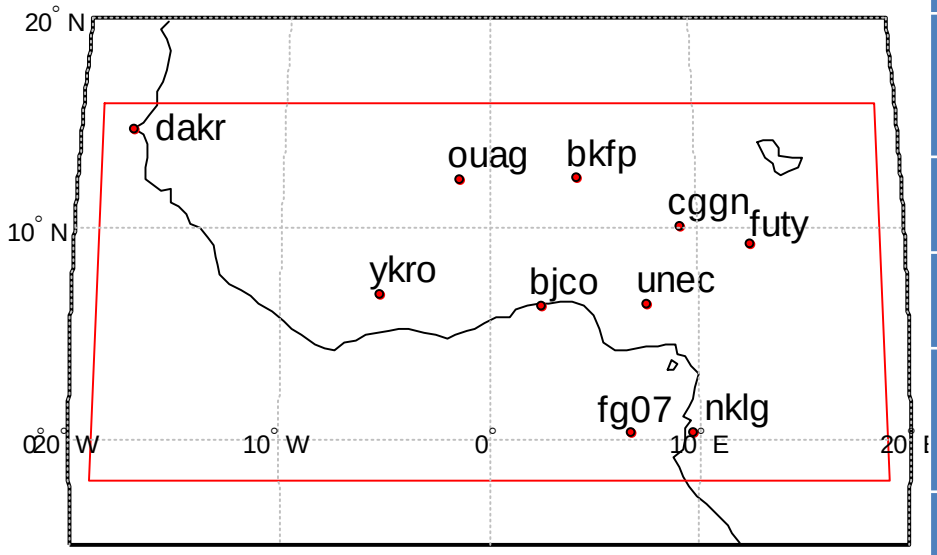
Data Analysis

- The data used were obtained from openly-available GNSS receiver stations within the Northern and Southern crest of the African Equatorial Ionization Anomaly (EIA) region, for the month of July and October 2013.
- The stations were divided into two groups based on their local time.
- SBAS APV-1 availability maps were obtained using a SBAS emulator (magicSBAS platform) with a specific low-latitude algorithm developed by GMV and acquired by ICTP for TREGA project.

Overview of GNSS stations in Africa



TREGA scenario



ID	Location	Geo. Lat (ºN)	Geo. Lon (ºE)	Modip (º)	Groups
cggn	Toro (Nigeria)	10.12	9.12	-1.96	B
ouag	Ouagadougou (Burkina Faso)	12.35	-1.51	2.86	A
futy	Yola (Nigeria)	9.35	12.50	-3.34	B
bkfp	Kebbi (Nigeria)	12.47	4.23	3.50	B
ykro	Yamoussoukro (Cote d'Ivorie)	6.87	-5.24	-10.63	A
unec	Enugu (Nigeria)	6.42	7.51	-10.89	B
bjco	Cotonou (Benin)	6.23	2.27	-11.83	B
dakr	Dakar (Senegal)	14.75	-17.49	11.86	A
nklg	Libreville (Gabon)	0.35	9.67	-23.90	B
fg07	Sao-Tome (Soa-Tome)	0.34	6.73	-24.60	A

Main drivers:

- **Spatial** gaps
- **Temporal** gaps

ROTI and DvTEC Estimation

- *Rate of change of TEC (ROT) is defined as:*

$$ROT = \frac{TEC_k^i - TEC_{k-1}^i}{t_k - t_{k-1}}$$

it is computed: along the line of sight from satellite to receiver; and for each 1 min interval

ROTI is defined as the standard deviation of ROT for 5 min interval:

$$ROTI = \sqrt{< ROT^2 > - < ROT >^2}$$

where *i* is the visible satellite and *k* is the time of epoch, TEC is the total electron content, ROT is the rate of change of TEC and ROTI is the change of change of TEC index

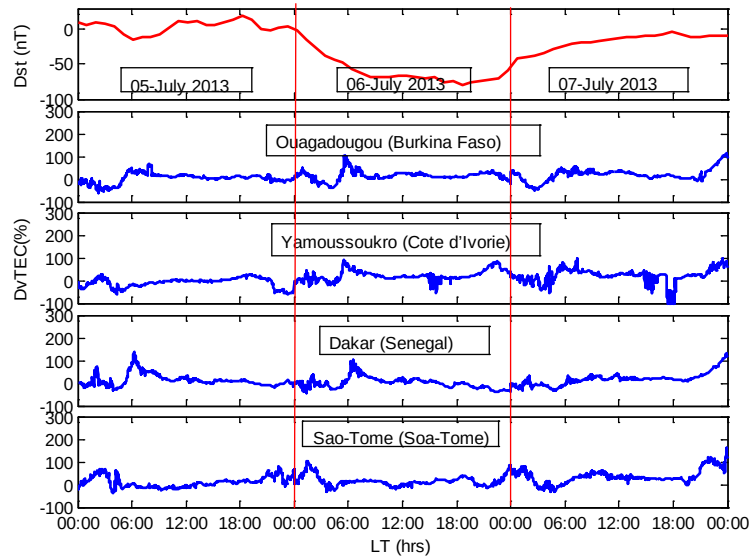
- *Percentage of the relative deviation of the vertical TEC (DvTEC) from the quiet reference level for each station was calculated*

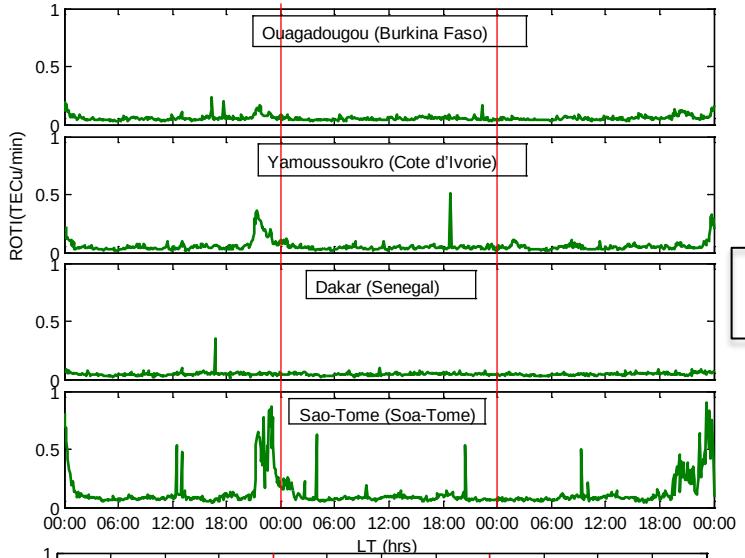
$$DvTEC = \frac{vTEC_d - vTEC_q}{vTEC_q} \times 100$$

where DvTEC is the relative percentage deviation of vertical TEC from the reference level, $vTEC_q$ is the reference level (monthly mean of vTEC for the most 10 quietest days of the month of the storm), $vTEC_d$ is the vTEC of the disturbed day.

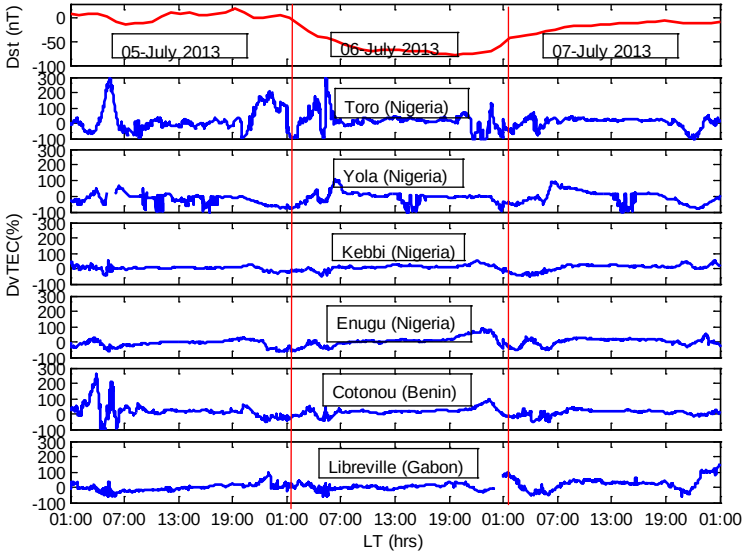
Results and Discussion

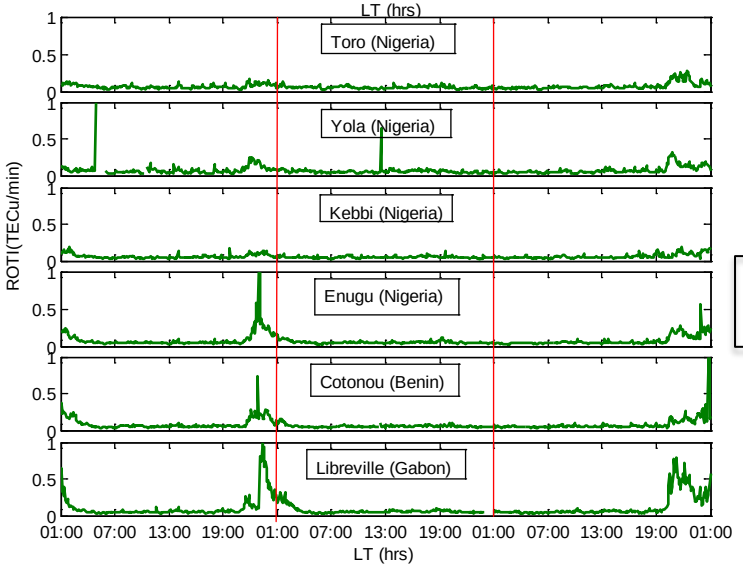
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating Ionospheric irregularities inhibition for 6th July 2013





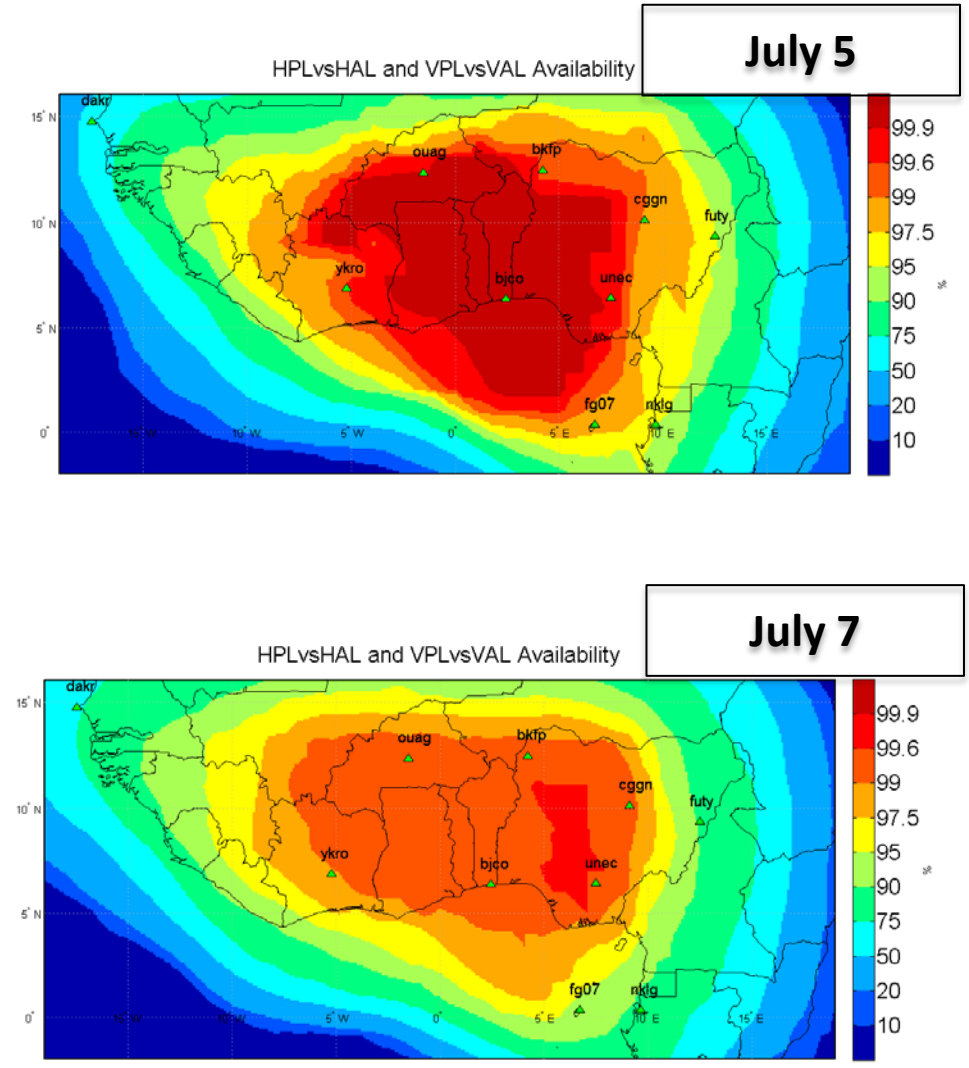
Group A

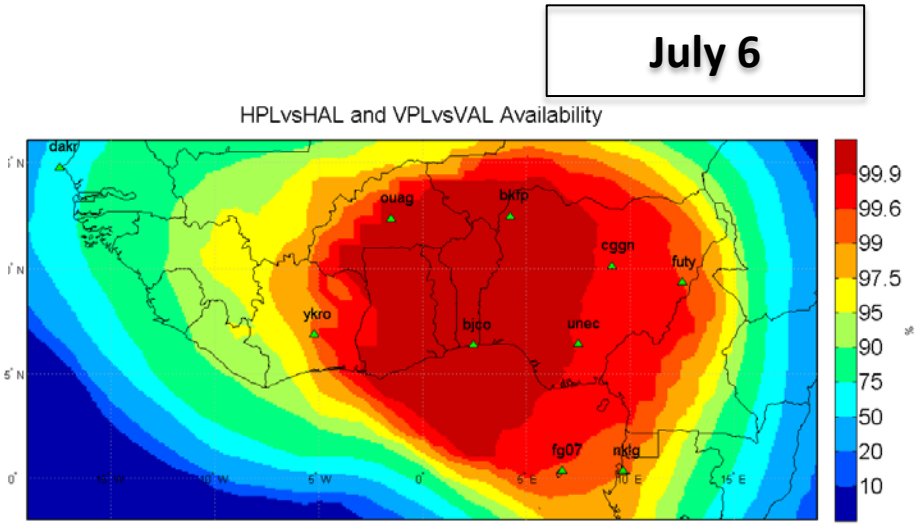




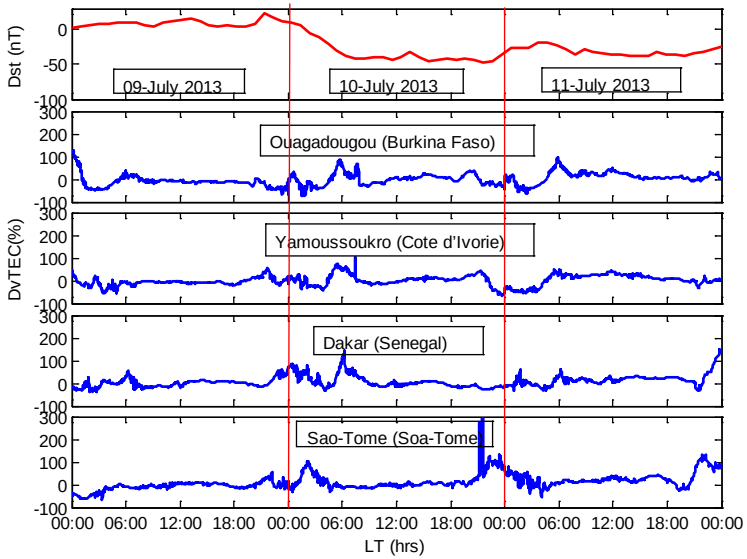
Group B

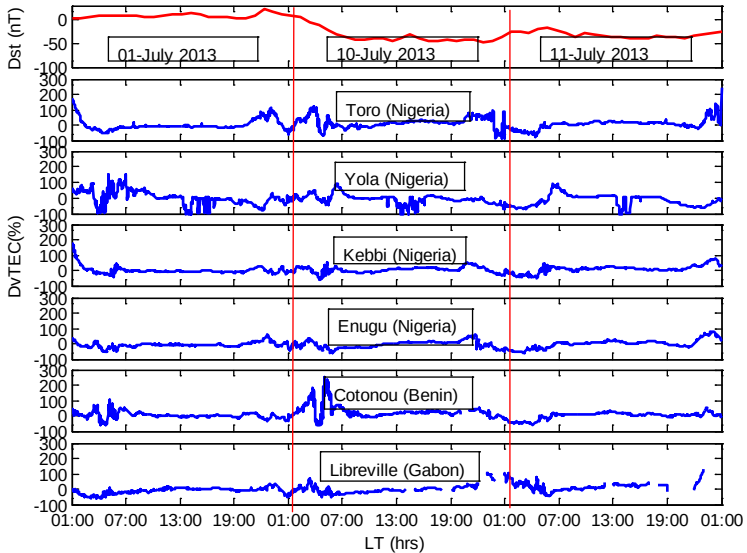
SBAS APV-1 availability maps indicating enhancements in SBAS performance for July 6th

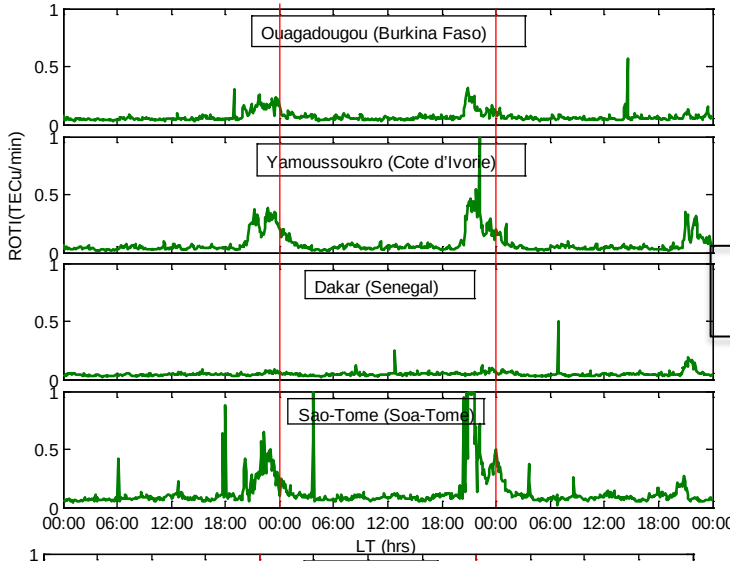




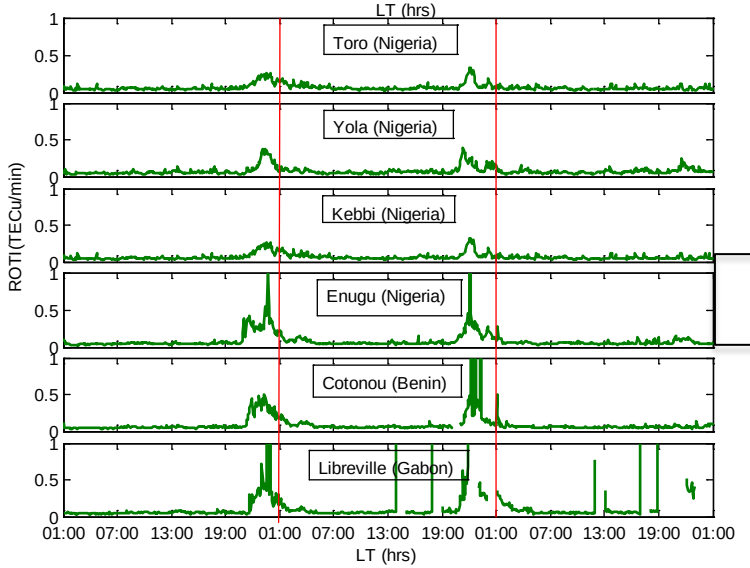
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating Ionospheric irregularities enhancements for 10th July 2013







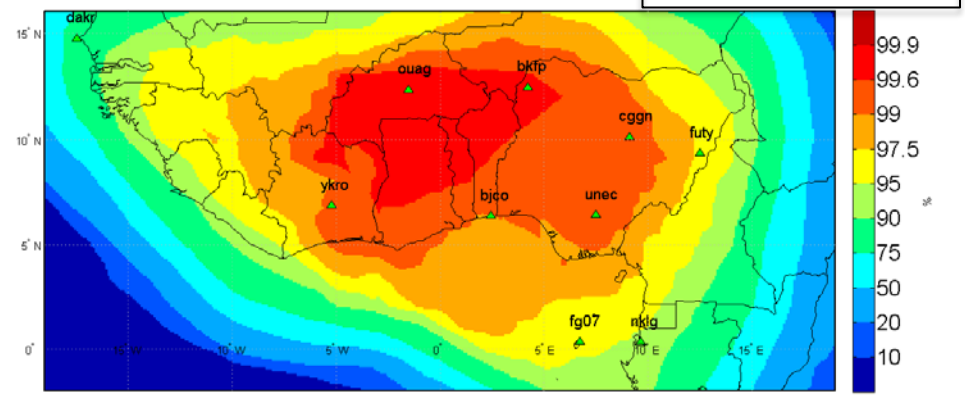
Group A



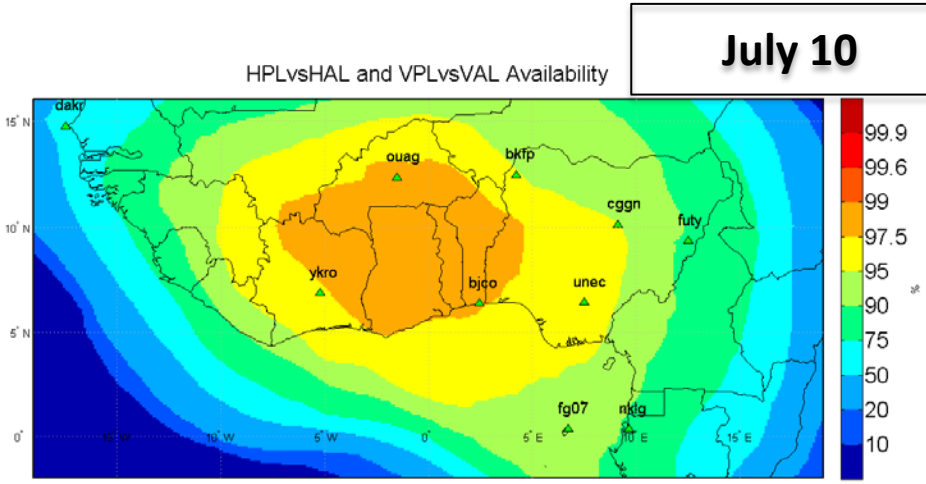
Group B

SBAS APV-1 availability maps indicating degradations in SBAS performance for July 10th

July 9



July 10



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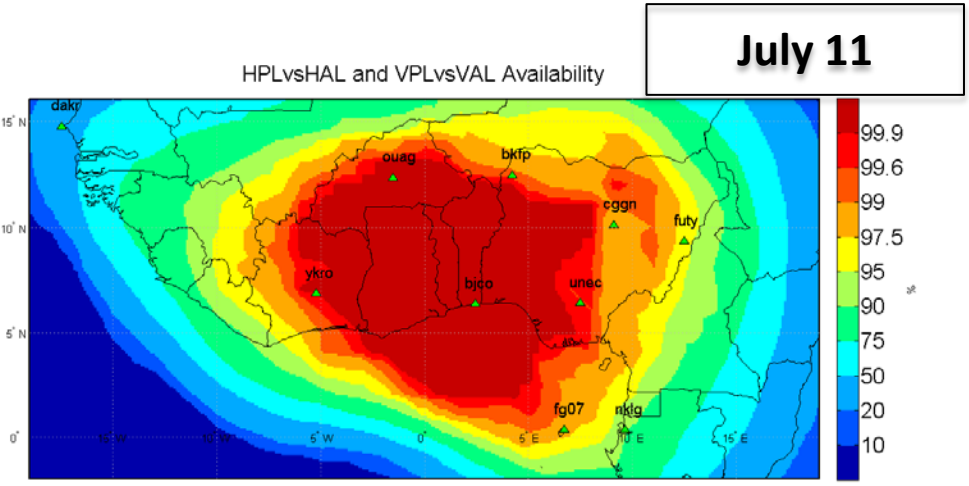
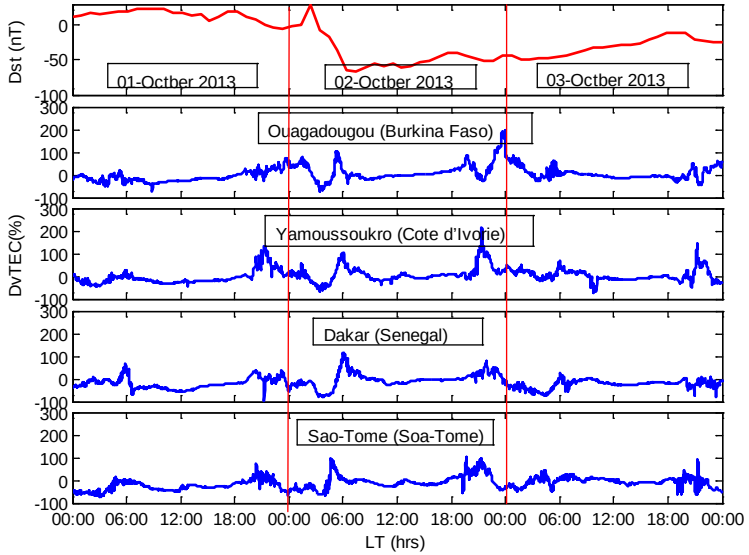
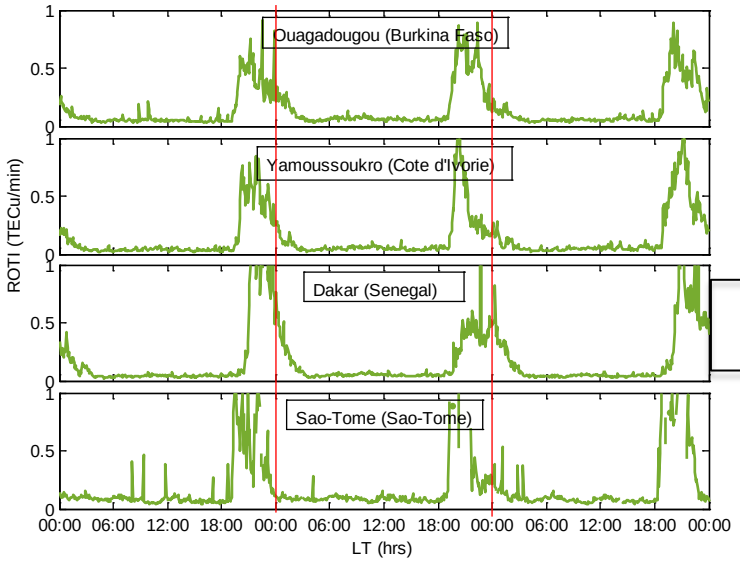
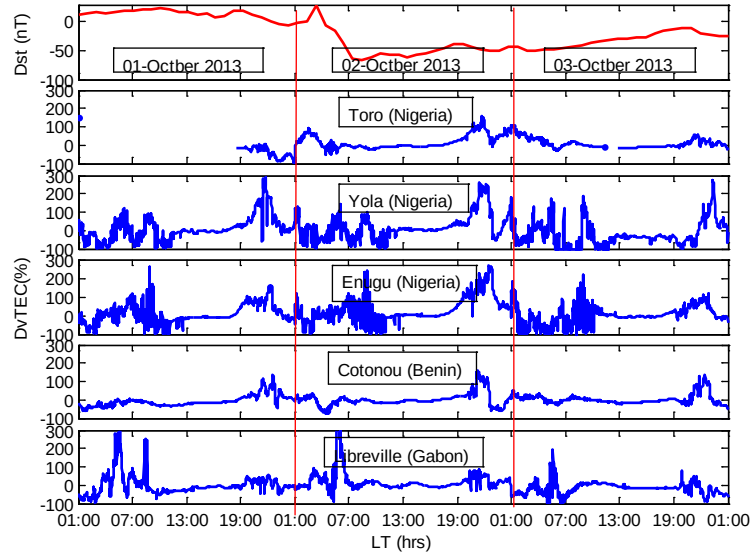


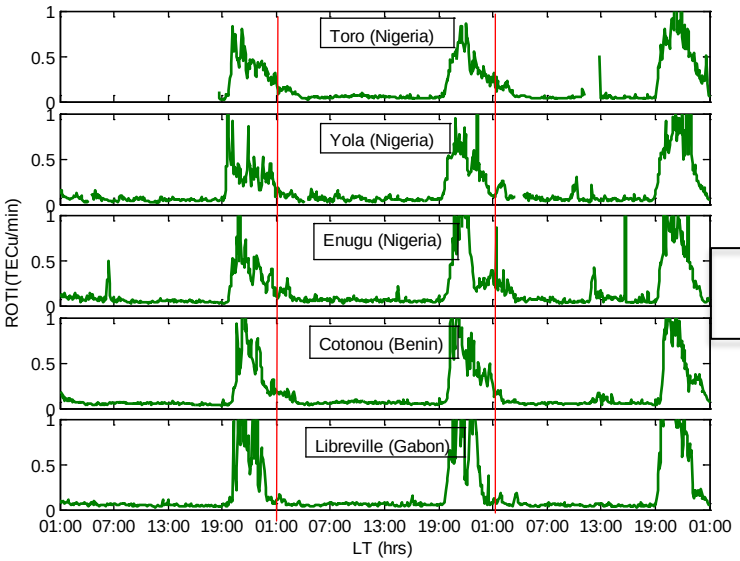
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating usual Ionospheric irregularities for 2nd October 2013





Group A

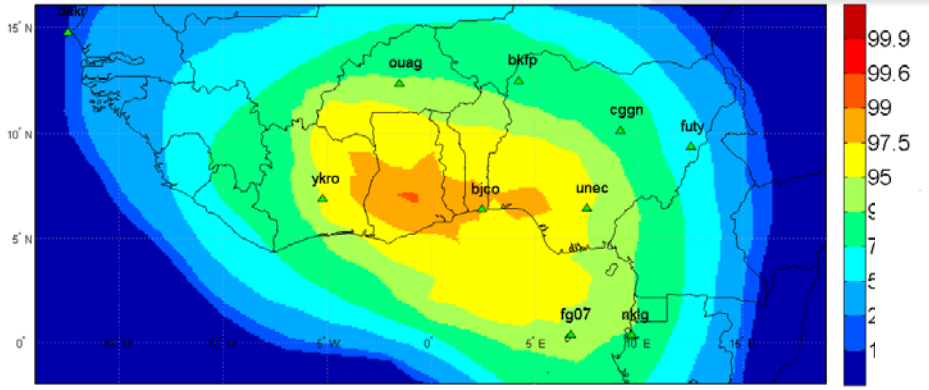




Group B

SBAS APV-1 availability maps indicating usual operation in SBAS performance for October 2nd

October 1



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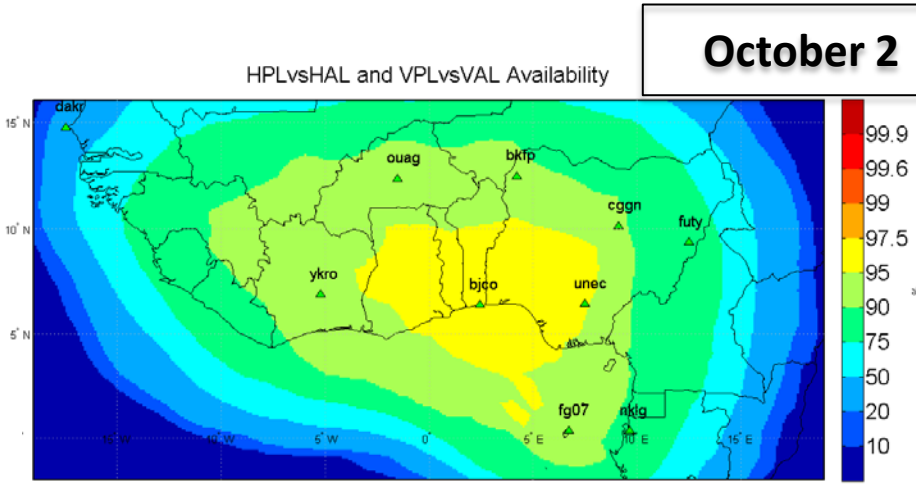

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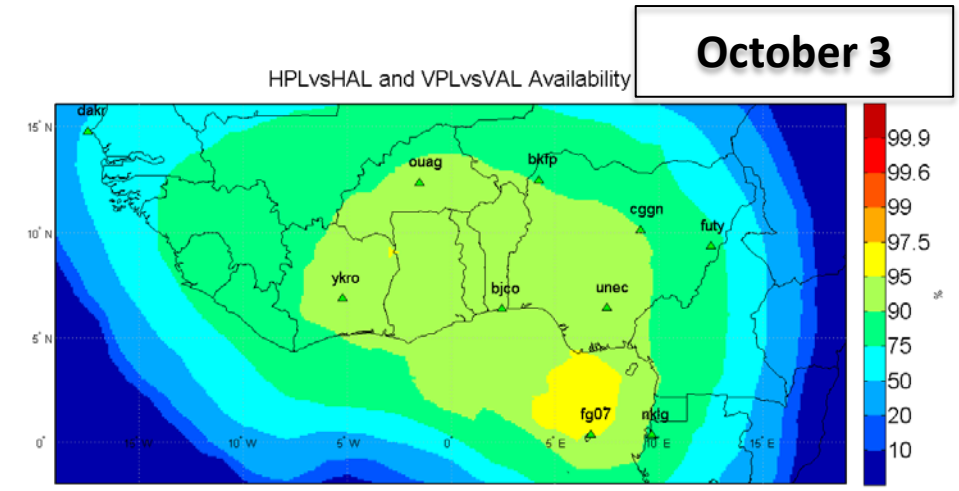
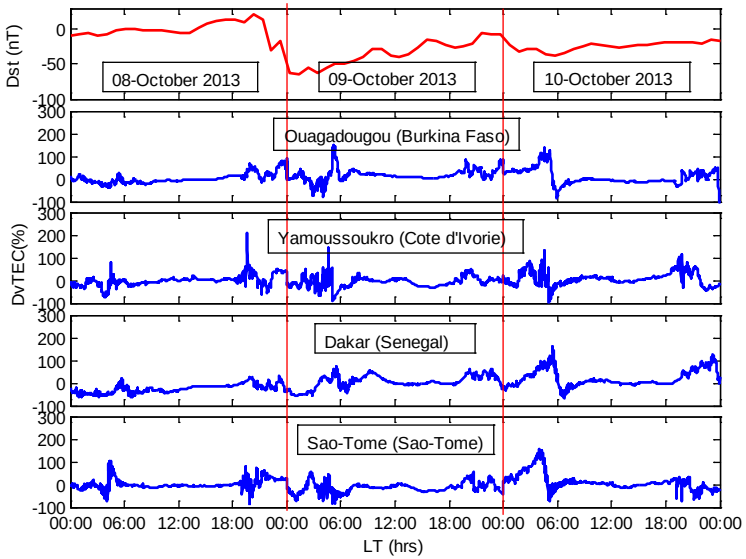
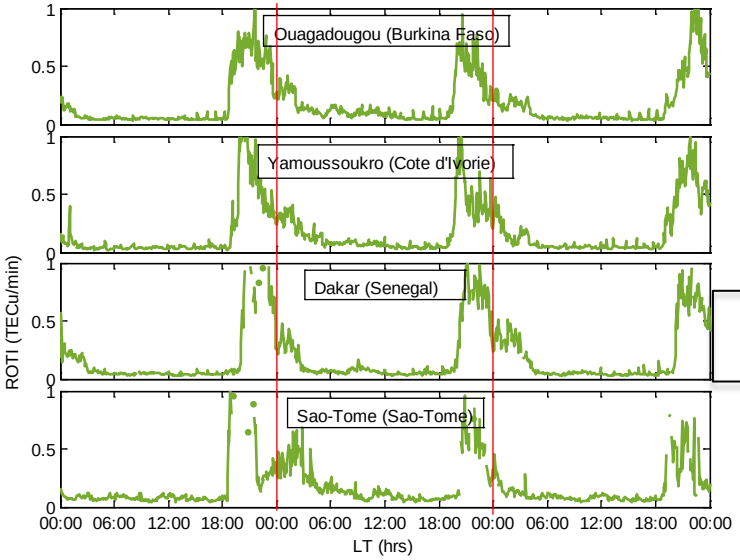
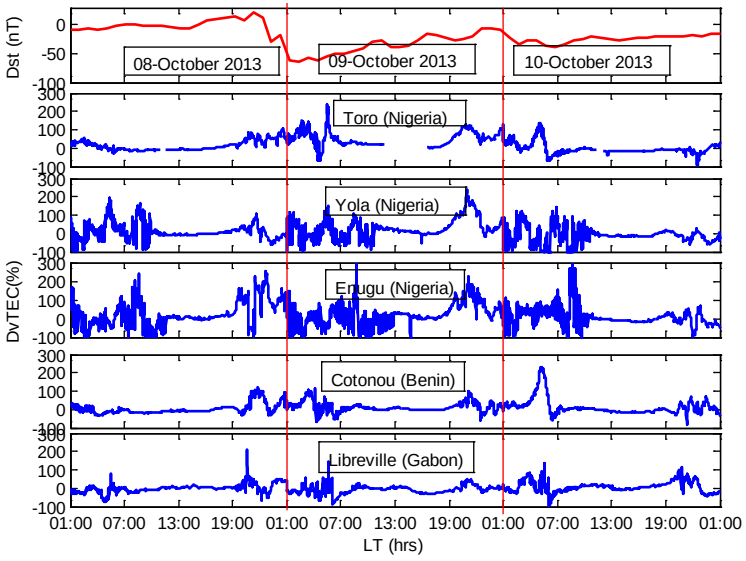


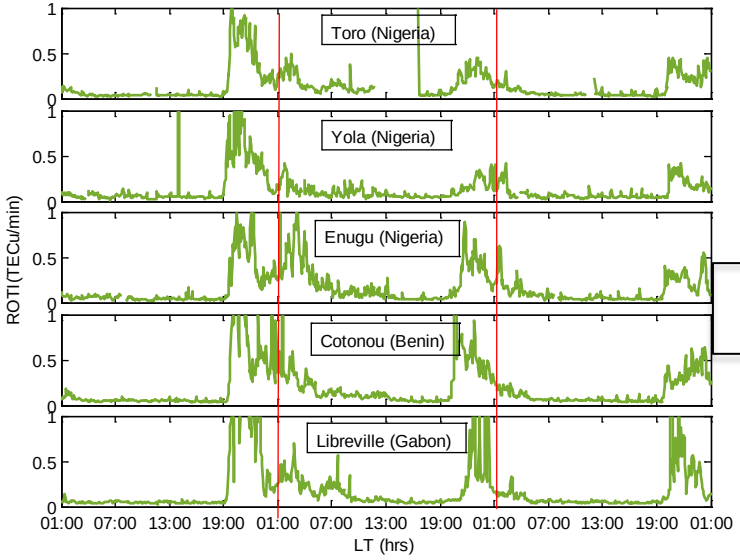
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating increased in Ionospheric irregularities for 9th October 2013





Group A

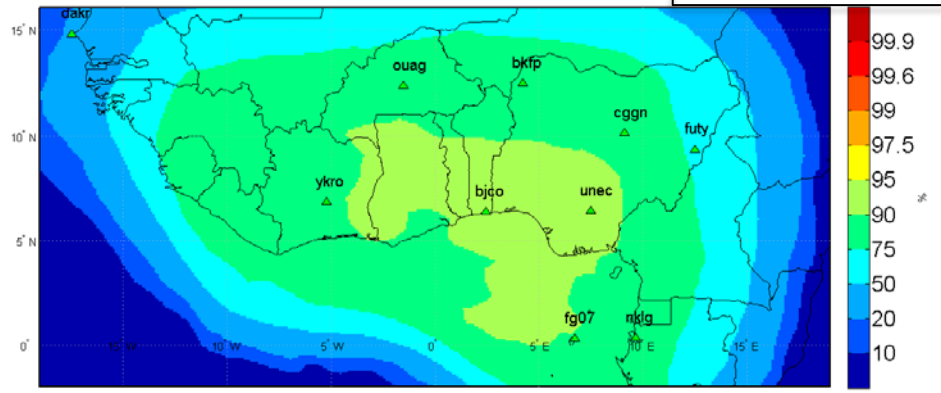




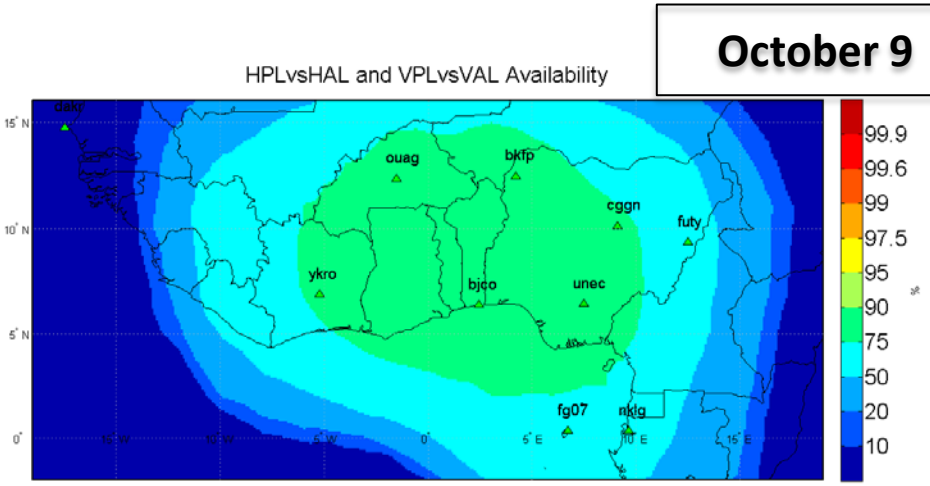
Group B

SBAS APV-1 availability maps indicating degradation in SBAS performance for October 9th

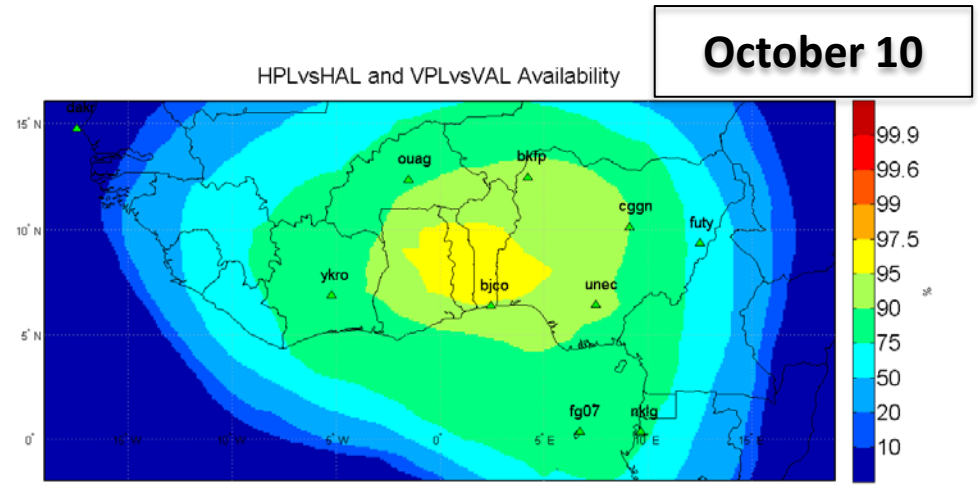
October 8



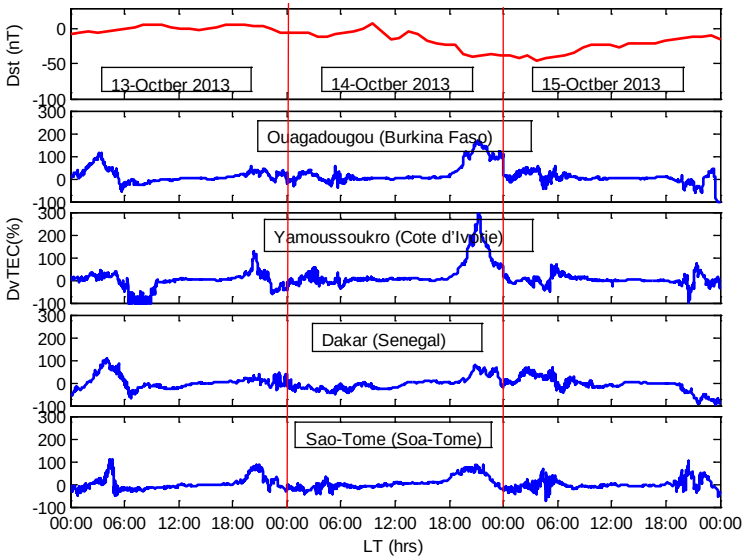
October 9

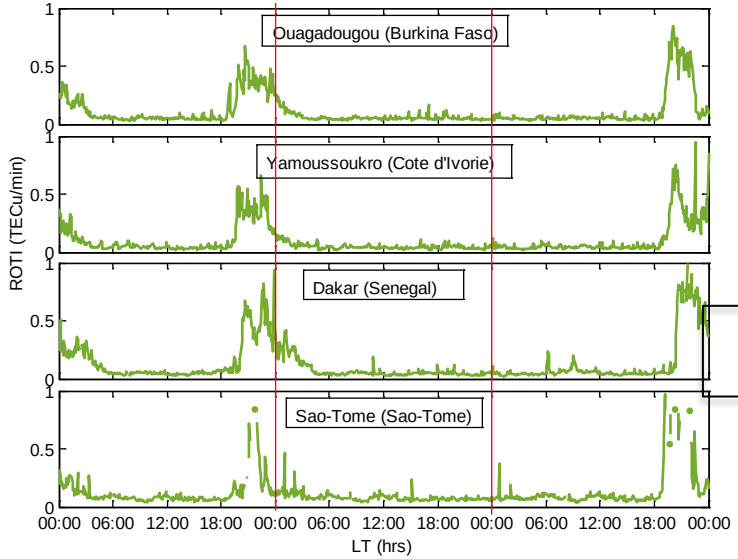


October 10

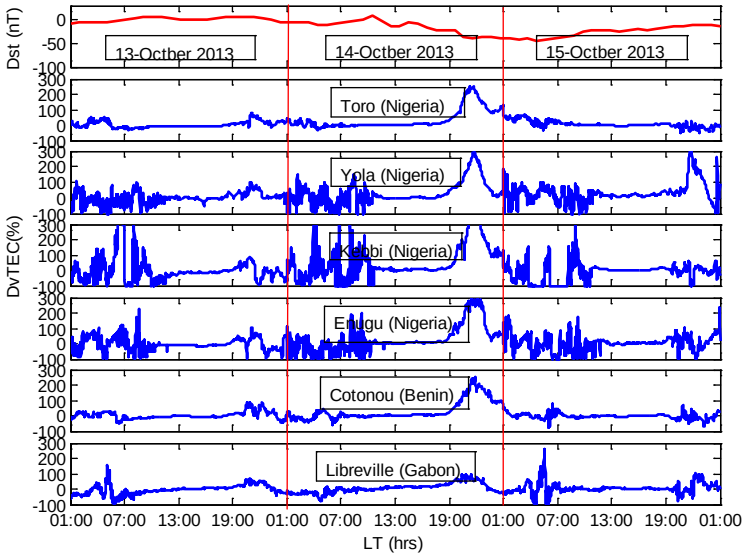


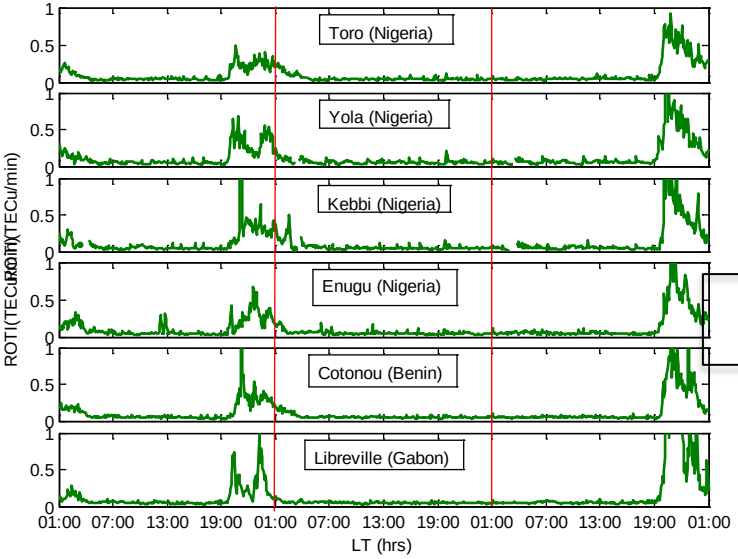
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating inhibition in Ionospheric irregularities for 14th October 2013





Group A

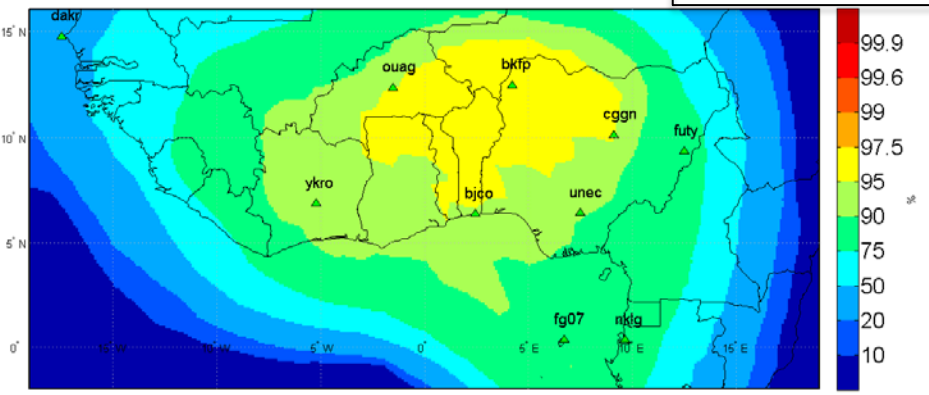




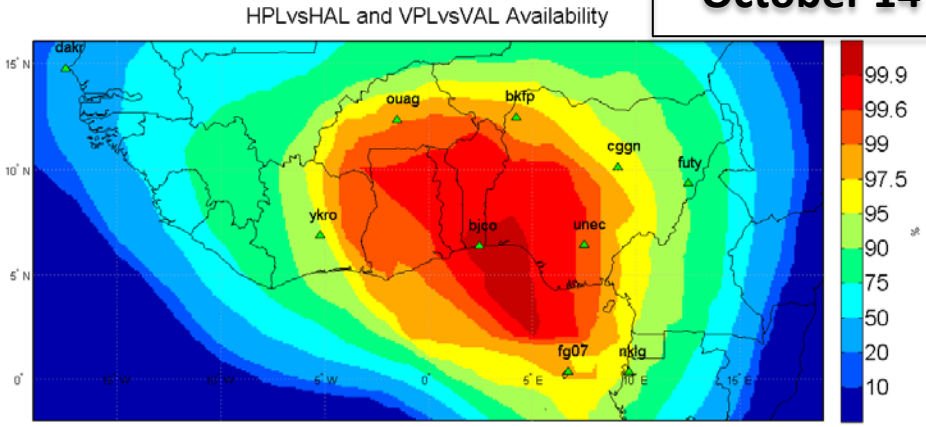
Group B

SBAS APV-1 availability maps indicating enhancements in SBAS performance for October 14th

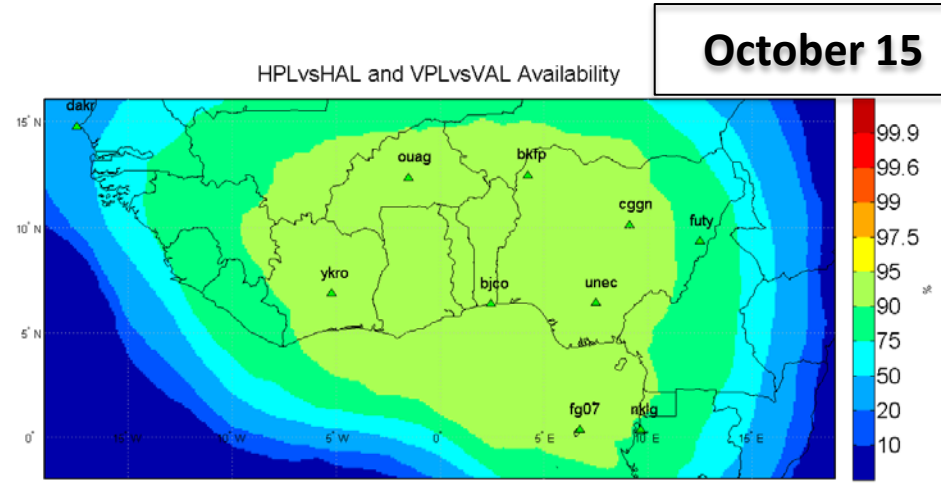
October 13



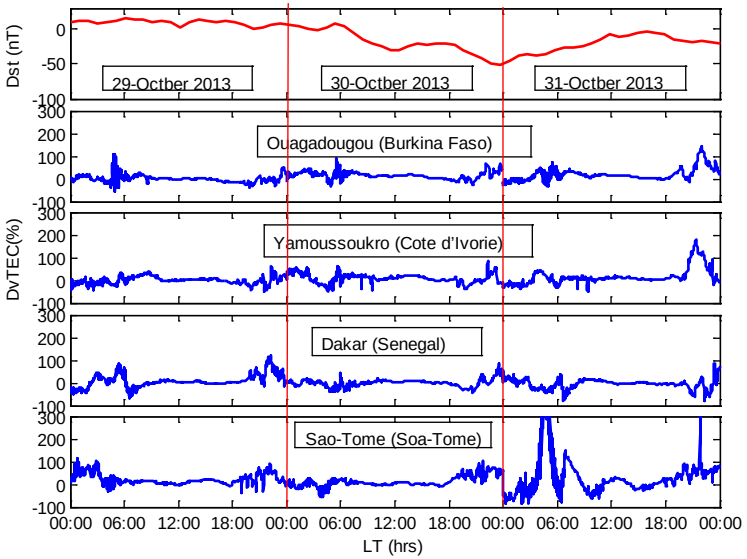
October 14

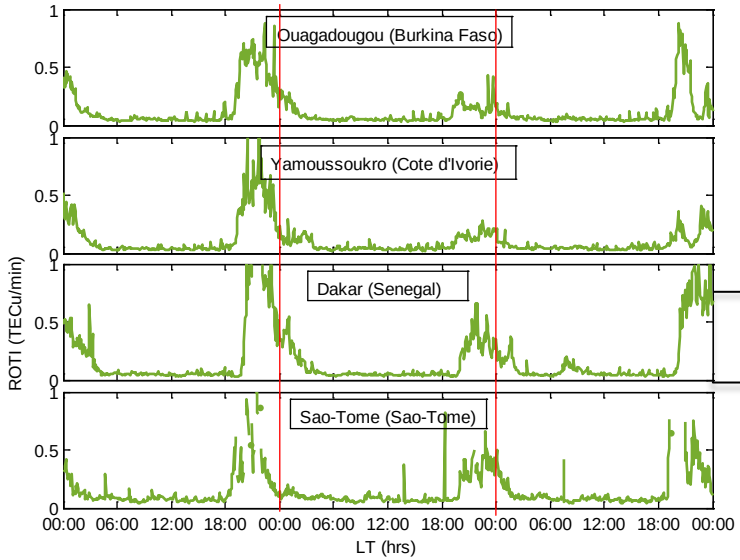


October 15

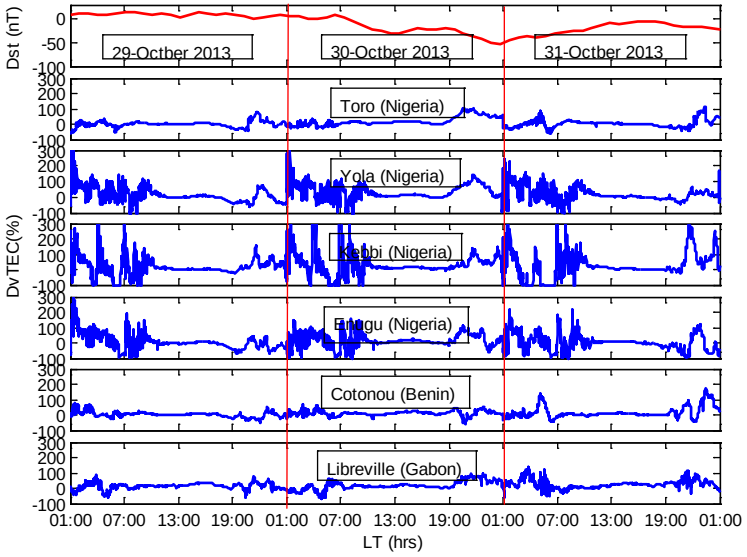


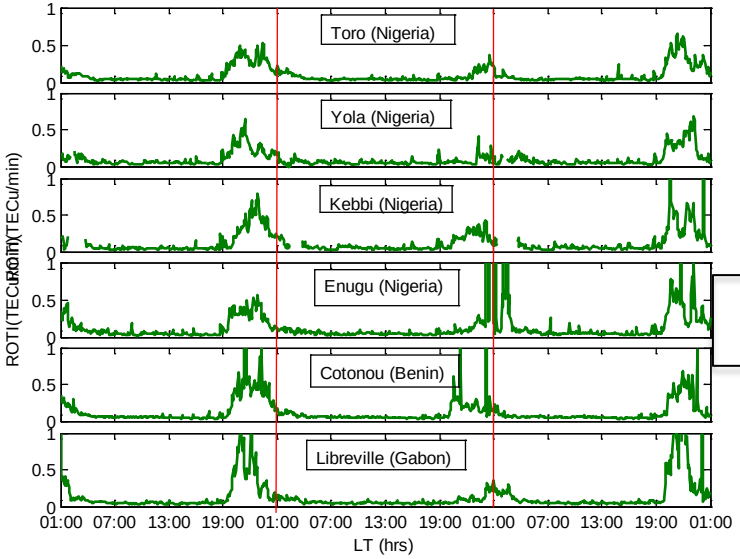
Transient Variations of Dst (red), DvTEC (blue) and ROTI (green) indicating inhibition/reduction in Ionospheric irregularities for 30th October 2013





Group A

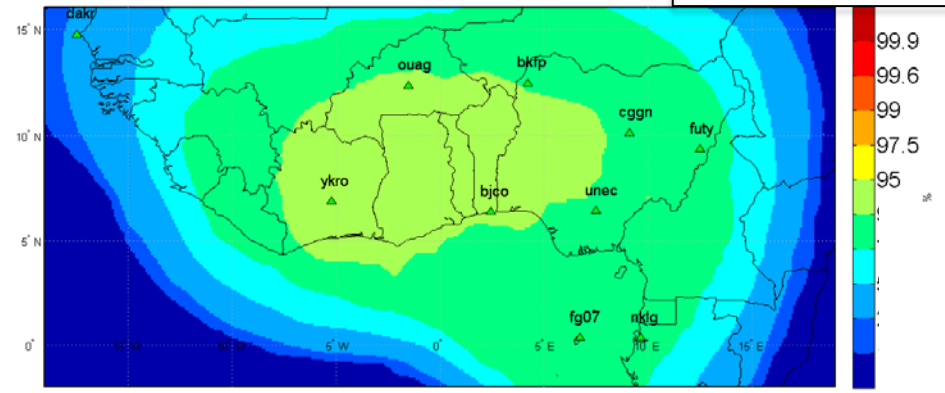




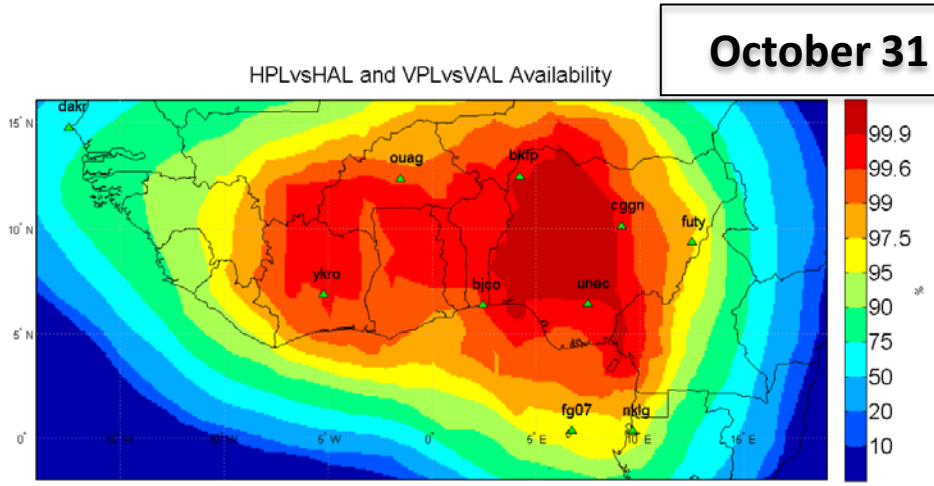
Group B

SBAS APV-1 availability maps indicating enhancements in SBAS performance for October 30th

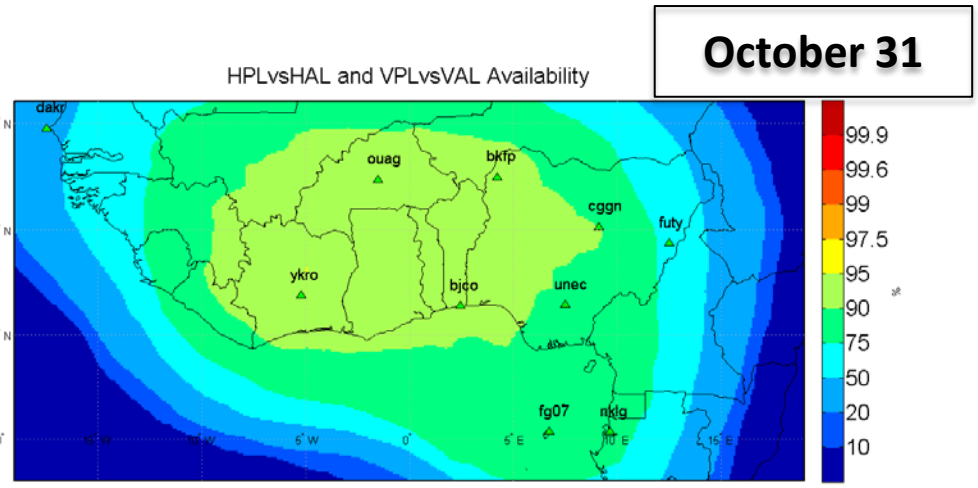
October 29



October 31



October 31



Summary

- This study assessed the effect of the ionosphere at African low-latitudes on SBAS system performance using real GNSS data stations from African equatorial latitudes during increased in Geomagnetic activity.
- Both positive and negative phases of the storm are observed; though positive phases are more frequent than negative.
- These effects modify the morphology and the physics of the ionosphere at post sunset to post mid-night periods leading to inhibition or increase of ionospheric irregularities.

- The SBAS system behaviour during an increased geomagnetic activity cannot be based only to geomagnetic indices and depends on specific conditions that influence the occurrence of ionospheric irregularities
- The present study reveals that ROTI is a good proxy to indicate such occurrence also during geomagnetic disturbed conditions.
- During the storm-time conditions considered, three out of seven geomagnetic storm induced enhancement to SBAS system performance, three reduced the system performance while one does not have effect on SBAS system performance in corresponded to ROTI values.
- ROTI is a representative index of SBAS performance: it indicates enhancements in the system performance when there is inhibition of usual ionospheric irregularities activity and degradations in system performance when there is increase of irregularities activity.

Acknowledgements

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Thanks for your attention