# Assessment Study of Ionosphere Threat Model using Multi-Shell Algorithm approach over Sub-Saharan African region

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## ABSTRACT

The study of ionosphere variability is essential to navigation and positioning systems like Satellite-Based Augmentation System (SBAS). It is crucial because ionosphere is the largest and the least predictable among the error sources limiting the reliability and accuracy of Global Navigation Satellite Systems (GNSS) and SBAS in safety-of-life applications. The situation becomes problematic in the Equatorial Ionization Anomaly (EIA) region, where the daytime ionization distribution is modified by the fountain effect, develops a crest at around $\pm 15^o\ to\ \pm 20^o$ magnetic equator and a trough at the magnetic equator during the late local noon. The consequence of this, results on the development of ionosphere irregularities or plasma bubbles after local sunset. This degrades further the availability and quality of service obtained from the GNSS/SBAS system at the said periods. As it is well known from the operational augmentation systems, the accuracy of the broadcast corrections decreases as the level of ionosphere disturbances increases. Walter et al. [1] reported that when ionosphere is disturbed at middle latitudes, the confidence bound of Wide Area Augmentation System (WAAS) significantly falls short when bounding the true error. In order to provide accurate ionosphere corrections to the user of GNSS in the African EIA region and meet stringent integrity requirements, a certified ionosphere threat model that accurately characterizes the sampled and under-sampled threat with the full capacity to over-bound the residual error will be uncompromised.

A threat model that describes the anticipated events that corresponds to the EIA scenario, and able to protect the user against any condition by providing reliable safe confidence bound should be used [2]. Using a fixed thin-shell based height algorithm for ionosphere corrections in EIA region could limit the optimization of GNSS applications in some particular period of time.

This study presents an ionosphere threat model with a multiple-shell strategy, which could be useful in the development of the ionosphere corrections and its confidence bound in the Sub-Saharan African region. The method aims to cater for the equatorial plasma vertical drifts. It takes into account the typical large spatial and temporal gradients in the EIA region. The ionosphere vertical profile-based algorithm captures better the potential threat in both sampled and undersampled of horizontal and vertical gradients, and detects small and large scales structure of ionosphere irregularities in time, space and seasons by performing the Chi-Square test of all the used Ionosphere Pierce Point (IPPs). The study is one of the TREGA (Training on EGNOS-GNSS in African) project outcomes focusing on the methodology to construct the SBAS ionosphere delay corrections at the Ionosphere Grid Points (IGPs) and its confidence bounds over the sub-Saharan African region.

The maximum search radius of target IPPs considered for the estimation of ionosphere delay at the IGPs is 800 Km with the minimum number of 8 IPPs. Whereas in WAAS as example,

the minimum number of IPPs used to construct an IGP is 10 and maximum number of target is 30. Also the minimum search radius distance is 800 Km and the maximum search radius of target is 2100 Km [3,4].

An ionosphere scenario based on a semi-empirical NeQuick 2 model was generated to assess the method over the studied area (Figure 1). In this case NeQuick 2 model was driven by the solar flux (F10.7) parameter. International Telecommunication Union-Radio (ITU-R) as a procedure for TEC estimation [5] has adopted the model. To some extent, it allows the creation of a realistic and a controlled ionosphere [6], and help the authors as a primarily approach to isolate the ionosphere contribution from other error sources and system biases.

Figure 1 presents the preliminary result of the constructed vertical ionosphere delay obtained in the East and West of the sub-Saharan African region, taking into account the local time difference. Figure 2 shows the daily distribution of the ionosphere error ratio computed by the users at two different arbitrary locations in East and West. This is the ratio of the residual and the ionosphere bounding standard deviation at the user IPPs.

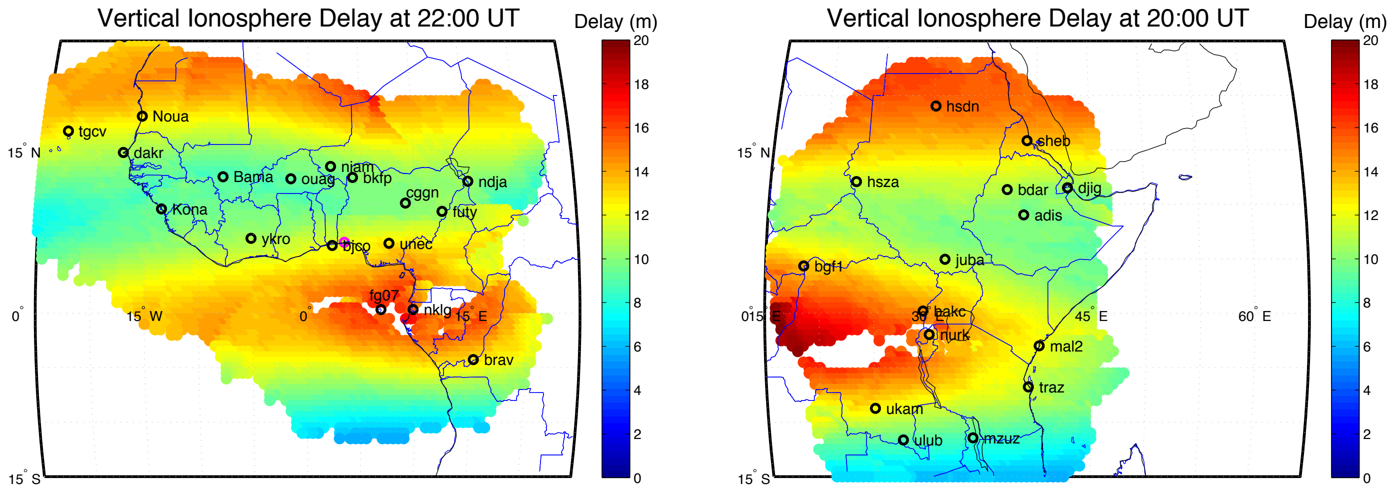


Figure 1: Constructed vertical ionosphere delay at West (left) and East (right) of African sub-Saharan region

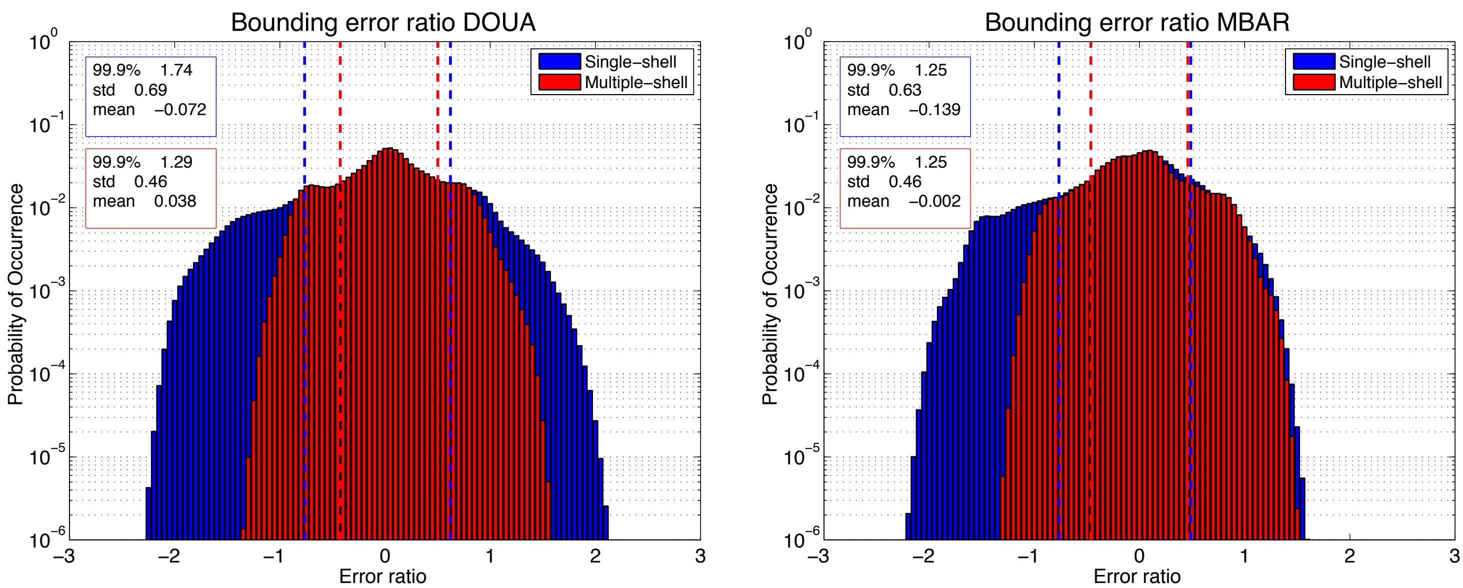


Figure 2: User bounding error ratio at Douala Cameroon (West, left) and Mbarara Uganda (East, right) for the single-shell (blue) and multi-shell layer approach

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