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Equatorial Ionospheric Scintillations: Scintillation Onset Time at Legon, Accra Ghana, as a Function of Elevation and Longitude

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Abstract

The dependence of Equatorial ionospheric scintillations of trans- ionospheric radio signals at very high frequencies (VHF) on elevation and longitude at the equatorial station of Legon (5.65^o N, 0.19^o W, 8.47^o S dip), Accra, Ghana, has been investigated; the focus being on the dependence of scintillation onset time on elevation and longitude. A systematic analysis of scintillation records of three synchronous satellites: **ATS-3, IS2F2 and IS2F3**, each radiating at a beacon frequency of ~136MHz was carried out. Other parameters/factors that might affect scintillation onset time, e.g., season of the year and solar activity were rationalized out. The results show that; Longitude and Elevation effects contribute to scintillation onset time, with elevation being the more important contributor. When elevation effect(s) were taken into account, signals from satellites positioned more easterly on the average, began to scintillate earlier than those positioned more westerly, as would be expected (if longitude effect were to be the more important contributor). This finding reconciles earlier reports, that satellite more westerly, on the average began to scintillate earlier than the one further east.

Keywords: Equatorial ionosphere, VHF signal scintillations, equatorial scintillation onset time, elevation and longitude effects, synchronous satellites.

1.0 Introduction

Radio signals transiting the ionosphere suffer ionospheric scintillations, which are fluctuations in their amplitude and/or phase, as they traverse the ionosphere, (Koster, 1978; Amaeshi, 1978 and 2005; Iyer and Rastogi, 1978; Aarons, 1982; Yeh and Liu, 1982; Wernik *et al.,* 2003; Doherty *et al.,* 2004; and Rama Rao *et al.,* 2006). These scintillations affect adversely the integrity of trans-ionospheric radio signals, both at very high frequencies, VHF, and microwave frequencies; hence the performance of communication satellites, Koster, 1978; Amaeshi, 1978 and 2005; Iyer and Rastogi, 1978; Aarons, 1982; Yeh and Liu, 1982; Wernik *et al.,* 2003; Doherty *et al.,* 2004; Rama Rao *et al.,* 2006; and Sreeja *et al.,* 2009); and Global Navigation Satellite Systems, (GNSS), namely, global positioning system, (GPS), (Aarons and Basu, 1994; Knight and Finn, 1996; Buonsanto, 1999; Knight *et al.,* 1999; Babayev, 2001; Knight, 2001; Wernik, 2003; Doherty *et al.,* 2004; Kinter and Ledvina, 2005; Rama Rao *et al.,* 2006; and Sreeja *et al.,* 2009). In the case of communication satellite signals, scintillation can result in signal impairment, resulting in wrong interpretation of the received signal, with the attendant dire consequences. In the case of GPS in particular, scintillations have the capacity to affect both the accuracy and reliability of the system by compromising the performance of the code and carrier tracking loops of the receiver, (Aarons and Basu, 1994; Knight and Finn, 1996; Knight *et al.,* 1999; Babayev, 2001; Knight, 2001; Wernik, 2003; Doherty *et al.,* 2004; Kinter and Ledvina, 2005; Rama Rao *et al.,* 2006; and Sreeja *et al.,* 2009). One way of minimizing these adverse effects, and ensure reliable trans-ionospheric communication, and the integrity of the performance GPS receivers, among others, is to have adequate understanding of ionospheric scintillation, including the onset time and its defining parameters. Such understanding would among others, enable the construction of adequate ionospheric scintillation model, which can be integrated into communication systems and GPS planning and designs. In the particular case of the GPS, such a model will enhance the prediction of the performance of a given receiver type at any time and location. However,

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for reliable performance of both communication satellite and GPS systems on a global basis, data-driven scintillation model is imperative. As pointed out by Wernik *et al.,* (2003), constructing a single global scintillation model, given known and unknown differences in geophysical factors that control the equatorial and high latitude ionospheres could be difficult. Nevertheless, national and regional models, (such as (equatorial) African Region model), are also important; and such models could be merged if need be, or used separately. Constructing any useful practical model entails amongst others, understanding adequately, ionospheric scintillation phenomenon, including the onset time and the defining parameters; and ensuring that the model is data-driven. This demands that experimental input data for the development of such (regional/global) model(s) be contributed from stations spread across all the constituent geographical communication zones (of the region/globe), including the Equatorial African region, in the case of a global model as has been stressed by Yen and Liu, (1982), Fremouw and Secan, (1984), Secan *et al*., (1995), Amaeshi (2004 and 2005), and Wernik *et al*., (2003), among others. The resulting model, all things being equal, would be an improvement on the Wideband Ionospheric Scintillation Model (WBMOD), by Fremouw and Secan (1984), and its upgrade, by Secan *et al*., (1995). In addition, a regional model would, of great necessity, require input from a number of spread -out regional networks of stations; and, clearly, as earlier stated, an adequate model is possible only if there is clear and adequate understanding and knowledge of scintillation phenomena.

The issues raised above have provoked sustained interest in the study of scintillation problems, which, as implied above, are two-fold: (i) The study is directly related to the trans-ionospheric communication problem, such as statistics of fading, channel modeling, *etc.,* (Iyer and Rastogi, 19978; Yeh and Liu, 1982; and Wernik *et al.,* 2003). (ii) Scintillation data contain information about the geophysical parameters of the ionosphere, and proper interpretation of the data is essential for the better understanding of the physics and the dynamics of the upper atmosphere, (Iyer and Rastogi, 1978; Tereshchenko *et al.,* 1999; Aarons, 1982; Yeh and Liu, 1982; Wernik *et al*, 2003; and Amaeshi, 2004). This interest is much more pertinent in the African Equatorial Region where there has been a dearth of information, (Amaeshi, 2004 and 2005; Sreeja *et al* 2009).

Some work done in respect of the causative mechanisms of scintillations include (Koster, 1963; Wernik and Liu, 1974; Yeh and Liu, 1982; Tereshchenko *et al.* 1999; Wernik *et al,* 2003; Dandekar and Groves, 2004; Amaeshi, 2005; and Chen *et al.,* 2005), others on factors on which it depends, such as (i) hour of the day, and seasons of the year, have been undertaken by (Koster, 1972; Amaeshi, 1978 and 2005; Iyer and Rastogi, 1978; Aarons, 1982; and Yeh and Liu, 1982); (ii) solar and magnetic activities, (Koster, 1978; Dabas *et al.*, 1989; Kumar and Gwal, 2000; Knight, 2001; and Kumar *et al.,* 2005), (iii) frequency of the signal, (Iyer and Rastogi, 1978; Koster, 1976; Bhattacharyya and Rastogi, 1990; and Richaria, 1990), (iv) geometrical considerations, such as zenith, distance of the irregularity at the ionospheric layer, (Amaeshi, 1978; and Wand and Evans, 1975), and (v) propagation angle relative to earth's magnetic field, (Koster, 1963; and Rino *et al.,* 1978). And the work done on scintillation characteristics includes the classical work of Aarons, (1982), and Yeh and Liu, (1982). However, not much has been reported on scintillation onset time, vis-à-vis, its dependence on longitude and elevation, (Koster, 1978; and Amaeshi, 2005), especially in the equatorial African region, and more especially, at Legon.

The problem of investigating scintillation dependence, especially its onset time, on elevation and longitude, at Legon is rather a difficult one, because of unavailability of a variety of satellites to work with. There have been quite a few satellites to west of Legon over the years, but not many to the east, for any length of time. Analyses of scintillation records from three spaced synchronous satellites over a period of six months, have been accomplished, (Amaeshi, 1978, and 2005). One finding is that scintillation seems to start on western satellite more frequently than at satellite further east. But, since equatorial scintillation is a nocturnal phenomenon, (Koster, 1972; Amaeshi, 1978 and 2005; Iyer and Rastogi, 1978; Aarons, 1982; Yeh and Liu, 1982; and Dabas and Reddy, 1986), and seems to be triggered by ionospheric sunset, one expected to find scintillation starting first on the eastern satellite of an

E-W pair more frequently than on the western one; this was rather a puzzling result. And, although some plausible explanations were attempted therein, (in Amaeshi, 1978, and 2005), it has been suggested that further investigations are required to resolve the issue unambiguously.

In this work, effort has been made to resolve the above issues. Further investigation on the dependence of ionospheric scintillations at VHF, vis-à-vis, the onset time on elevation and longitude, has been carried out by systematic analysis of scintillation records obtained at Legon, Ghana, from three synchronous satellites, observed over a very much length of time, and each radiating at a beacon frequency of ~ 136MHz. Legon is at Latitude 5.65° N, Longitude 0.19° W; and magnetic dip of 8.47° S. The study would contribute to our present knowledge and understanding of equatorial ionospheric scintillation phenomenon and characteristics at VHF signals; and this would also eventually contribute to the development of the much-needed global ionospheric scintillation model(s), (Aarons, 1982; Yeh and Liu, 1982; and Fremouw and Secan, 1984) necessary in planning and design of reliable and efficient trans-ionospheric communication system.

2.0 Methodology

This investigation was carried out by systematic analysis of scintillation records of three synchronous satellites: **ATS-3, IS2F2 and IS2F3**, each radiating at a beacon frequency of ~136MHz. The method of the scintillation observation and recording- the instrumentation, setup and the recording – was similar to that reported by the author in previous works, (Amaeshi, 1978, and 2005), and Koster, (1972). This time, however, the satellites in question were observed for a much longer period of time; thus, much more data were collected and analyzed. The satellites were observed daily, and data collected respectively over the following periods: ***ATS-3: from 01/09/71 to 21/10/76; IS2F2: from 06/10/71 to 28/09/72; and IS2F3: from 28/09/72 to 16/11/74***. In all, data for 3 and six months were collected and analyzed accordingly. During the respective periods of observation ATS-3 was stationary at elevation and longitude of 12^0 and 70^0W respectively. IS2F2 moved slowly eastward, and eventually disappeared below the eastern horizon. IS2F3 on the other hand, rose from the west to an elevation of about 80^0 before subsequently, but slowly, dropping and disappearing below the western horizon. The two satellites however, were east of ATS-3, and at an elevation above 60^0 during the periods they were observed.

Each day's satellite's record was examined, and the onset time of scintillation was read directly from the (strip) chart. The daily records for each satellite, from 1800 hrs to 2400 hrs were grouped into 24 units of 15 minutes interval each. The diurnal time range was limited to 1800 – 2400 hrs since equatorial scintillation is essentially a nocturnal phenomenon, (Koster, 1972; Amaeshi, 1978 and 2005; Aarons, 1982; and Yeh and Liu, 1982) and the onset follows ground sunset by one to two hours; and one is interested mainly in scintillation onset time, especially on an E-W satellite pair, and post-midnight observed scintillations have already set in, (Amaeshi, 1978).

The scintillation index (S.I), for each of the 15 minutes interval for each satellites was calculated, using the definition by Whitney *et al.,* (Whitney *et al.,* 1969), and adopted by many workers in the field, including Amaeshi (1978 and 2005), Koster (1978), Aarons (1982), and Yeh and Liu (1982). It is given by:

$$(S.I) = \left(\frac{P_{\max} - P_{\min}}{P_{\max} + P_{\min}}\right) \times 100 \qquad \ldots 1$$

where P_{max} and P_{min} are the power level (in dB), of the 3rd highest peak, and the 3rd lowest peak in the interval, respectively.

3.0 Data Analysis, Results And Discussion

The data available for analysis consisted of:
i. 15 minute scintillation indices for ATS-3, from 1st Sept. 1971 to 21st Oct.1976.
ii. 15 minute scintillation indices for IS2F2, from 6th Oct. 1971 to 28th Sept. 1972.
iii. 15 minute scintillation indices for IS2F3, from 28th Oct.1972 to 16th Nov. 1974.

Three main levels of analysis were carried out, in order to resolve the puzzling result reported earlier by this author, (Amaeshi, 1978, and 2005), which, as stated, motivated this investigation. The result/ observation is: satellites more westerly, on the average began to scintillate before the one further east, of an E-W pair, contrary to expectation, *for*, since scintillation is a nocturnal phenomenon, and seems to be triggered by ionospheric sunset, one would expect the opposite. Thus, the following questions were raised: could the puzzling result be:

i. Just a statistical fluctuation from using too small data, in other words, could a different result be obtained using much data?

ii. Due to genuine longitudinal variation in frequency and intensity of scintillation?

iii. Explained in terms of difference in elevation, as the author tried to proffer therein in that earlier reports (Amaeshi, 1978, and 2005), since the eastern satellite was usually at relatively high elevation compared to the western satellite?

These questions are addressed below.

3.1 Could The Puzzling Result Be Just A Statistical Fluctuation From Using Too Small Data?

To answer this question, the first level of analysis considered the records on a "yes-no-neither" basis. In this first attempt all the available data were used. But, no use was made of actual values of the scintillation index. ATS-3, at 70^0W longitude and an elevation of 12^o, as seen from Legon, was compared in sequence, with IS2F2 and IS2F3, both with varying coordinates but, always east of ATS-3, and each at elevations of above 60^o most of the time during the period it was simultaneously observed with ATS-3.Thus, were respectively designated as eastern (E) satellite, with respect to ATS-3, which was designated as western (W) satellite.

The data between 1800 and 2400 hrs discussed in Section 2 were treated as follows:

i. A day was accepted if at least one satellite, (of the pair), had a value of SI>0

ii. Days with no scintillation on either satellite were considered as quiet

iii. Days with missing data were rejected.

iv. Days with scintillation starting first on the E satellite, were counted, and as 'Yes'.

v. Days with scintillation starting first on the W satellite, ATS-3 were counted, and as 'No'.

vi. Days showing simultaneous beginning of scintillation were counted, and as 'Neither'.

The result of the analysis is shown in Table 1.

It is seen that the results of a three-year period of observation confirm earlier results, (Amaeshi, 1978; 2005): Scintillation began more frequently on the western satellite than on the eastern one, of a pair of satellites separated in longitude. Clearly, the results are not due to just, a statistical fluctuation from using too small a data.

3.2 Could the result be due to genuine longitudinal variation in frequency of scintillation?

As suggested by Amaeshi, (1978; 2005), to answer this question one would like to compare a large amount of simultaneous data from satellites at comparable elevations, but with very different longitudes. Unfortunately, again, this is not possible with the data available. There was relatively little or no data from satellites to the east of Legon. IS2F2 did move to the eastern horizon. However, it was moving very rapidly at the time, and it disappeared completely within a few days, according to available records. Indeed, much of IS2F2 data were from much higher elevations, not less than 60^o, as against that from ATS-3, which was at a constant elevation of 12^o. This leaves the longitude effect still unclear. However, the third scenario is considered, to see if a clearer picture will emerge.

Table 1: Results of analysis: On the 'Yes-No-Neither' Basis

Period of Observation	Total No. of Records (Days)	No. of Days with East Satellite Scintillating first	No. of Days with West Satellite Scintillating first	No. of Days with simultaneous Onset of Scintillation on both Satellites.	Total No of quiet Days	Total No of Days with rejected Records
6^{th} Oct. 1971 – 16^{th} Nov. 1974	1138	414	461	146	61	56

3.3 Can the unusual result be explained in terms of difference in elevation of the two satellites?

To answer the question the following approaches were adopted: Initially only the records of those nights on which scintillation appeared on both satellites were included in the analysis. This is because it has been observed that a low elevation satellite frequently shows relatively small scintillation indices when an overhead satellite shows none at all, (Amaeshi, 1978; 2005; and Koster, 1978). As explained by the authors, this could be due to the much longer ionospheric path traversed by the signal from the low elevation source; it could also be due to rather enhanced scintillation effects from rays incident on the ionosphere at near glancing incidence. But, Amaeshi, (Amaeshi, 1978; 2005), has shown that the effect of the latter is negligible. All other conditions in the analysis were unchanged, vis-à-vis, scenario 3.1. However, days showing scintillation on one satellite only were listed as quiet. The result is shown in Table 2.

Clearly, the results now agree with our expectation: on the average, the eastern satellite began to scintillate before the western one. The previous results seem to be due to the effect of days having no scintillation at all on the high-elevation satellite, the eastern one in the context. Both elevation and longitude dependence of scintillation could contribute to the above result. However, elevation seems to be the more important one. And, further analyses were made to clarify things the more.

Further clarification of elevation dependence

Two separate, but similar analyses were made in this regard. In the first case, called Case A, only ATS-3, the constant coordinate satellite, and IS2F2 were used. In the second, Case B, ATS-3 and IS2F3 were used. It is to be recalled that IS2F3 was observed when IS2F2 disappeared from reception. In each case data were confined to those days on which the elevation of IS2F2/IS2F3 was equal or greater than 60^o. This means that the particular satellite was between $\pm 25^o$ of the longitude of Legon, and the ionospheric point within $\pm 2^o$ of the longitude of Legon. ATS-3 was 70^oW of Legon, corresponding to ionospheric point longitude of 12^o west of Legon. Clearly, it was further west than either satellite. Also, in both cases, only the days on which S.I. of 60% or greater appeared on IS2F2/IS2F3 were considered. The results are summarized in Table 3.

As can be seen from Table 3**,** the results show that in both cases, scintillation on the average started first more frequently on the satellite further east than on the one further west. The ratio is 90/47 H" 1.91 for IS2F2, while it is 121/96 H" 1.26 for IS2F3, each with respect to ATS-3, the western satellite. It has to be stated that on the average IS2F2 was further east of Legon than was IS2F3. And, one would expect that, other things being equal, scintillation would start more frequently on IS2F2 than on IS2F3. The above ratios seem to support the expectation. However, if there were a serious longitude dependence, with scintillation less probable to the east of Legon than to the west, as results obtained by Basu *et al*., (1976), from *in-situ* measurements by OGO-6 satellite, seem to show; (reproduced here, Figure 1, for clarity of this discussion**; LE** in the diagram stands for Legon, our station***)***, the ratio would have been reduced, rather than enhanced, *vis-à-vis*, IS2F2 compared to IS2F3. This result seems to suggest a rather, weak longitude effect compared to elevation effect. But one might ‘quickly’ argue that things are not equal in the above comparisons, that for one thing, IS2F2 and

Table 2: Results of the analysis

Period of Observation	Total No. of Records (Days)	No. of Days with East Satellite Scintillating first	No. of Days with West Satellite Scintillating first	No. Days with simultaneous Onset of Scintillation on both Satellites.	Total No of quiet Days	Total No of Days with rejected Records
6^{th} Oct. 1971 – 16^{th} Nov. 1974	1138	391	318	167	202	60

IS2F3 were not observed simultaneously. However, it is equally argued that whatever effect that could have been caused by the non-simultaneous observation of the two satellites would, definitely, have been (relatively) taken care of, since they were each compared against the same satellite, ATS-3, which was at a fixed elevation. This strongly suggests that indeed, elevation effect is the more important contributor than longitude effect.

3.4 Further Observations/Results in Support of the Dominance of Elevation Effect

It has been reported earlier by Amaeshi, (1978; 2005), and Koster, (1978); and here, that a higher elevation satellite shows a lower percentage occurrence of scintillation than a lower elevation one. This is readily inferred from the graphs of the diurnal variation of percentage occurrence of scintillation on two satellites at different fixed coordinates, hence elevations. This is depicted in Figure 2, which is reproduced here for clarity from Amaeshi, (1978; 2005). The satellites were GOES-1 and Symphonie, respectively at the fixed coordinates: elevations of 6° and 72°; and longitudes of –74.8°, and –12.6°, which correspond to sub- ionospheric point longitudes, (F-Long.) of -15° and –1.06° respectively. They were observed simultaneously from 1st Nov.1976 to 31st Jan. 1977. It is seen that the high elevation satellite (Symphonie) shows a lower

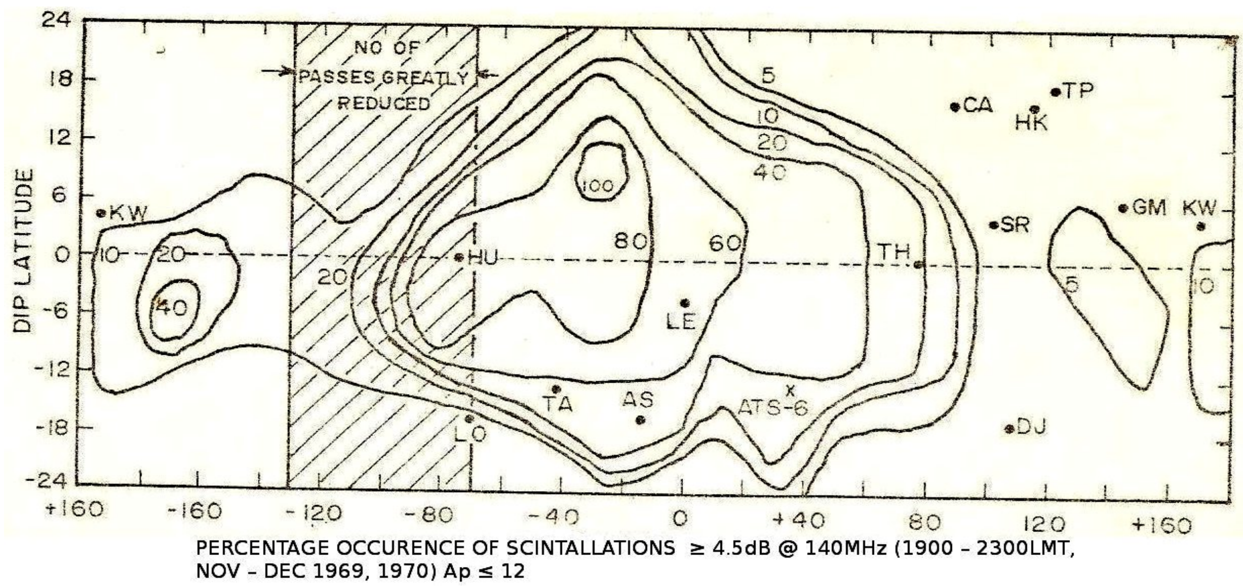

Figure 1: Scintillation Estimate (from Ogo-6 data). Model of estimated scintillations $\geq$ 4.5dB over the equatorial region. The contours equivalently represent the percentage occurrence of electron density deviation $\Delta N \geq 10^{10} m^{-3}$. Note: LE stands for Legon, our station. (Source: Amaeshi, 1978).

Table 3: Results of Cases A and B Analyses

CASE	Period of Observation	Total No. of Records (Days)	No. of Days with East Satellite Scintillating first	No. of Days with West Satellite Scintillating first	No. Days with simultaneous Onset of Scintillation on both Satellites.	Total No of quiet Days	Total No of Days with rejected Records
A: ATS- 3 with IS2F2	7th Oct. 1971 – 14th May 1972	222	90	47	46	34	5
B: ATS-3 with IS2F3	27th Jan. 1973- 15th March 1974	413	121	96	38	151	7

percent occurrence than the low elevation one (GOES-1) (throughout the night). It is also seen that the curve of the high elevation satellite is narrower than that for the low elevation one. The half-power points and their respective midpoints are also depicted. The midpoint between the half-power points shows the expected time lag. The high elevation (eastern) satellite, Symphonie, leads the lower elevation one, GOES-1 in time, by about 60 mins, which is in good agreement with the theoretical value of 56 mins - the time equivalence of the difference of 14^{o} between their sub-ionospheric point longitudes. These two satellites were used in the above analysis, though they were not the main

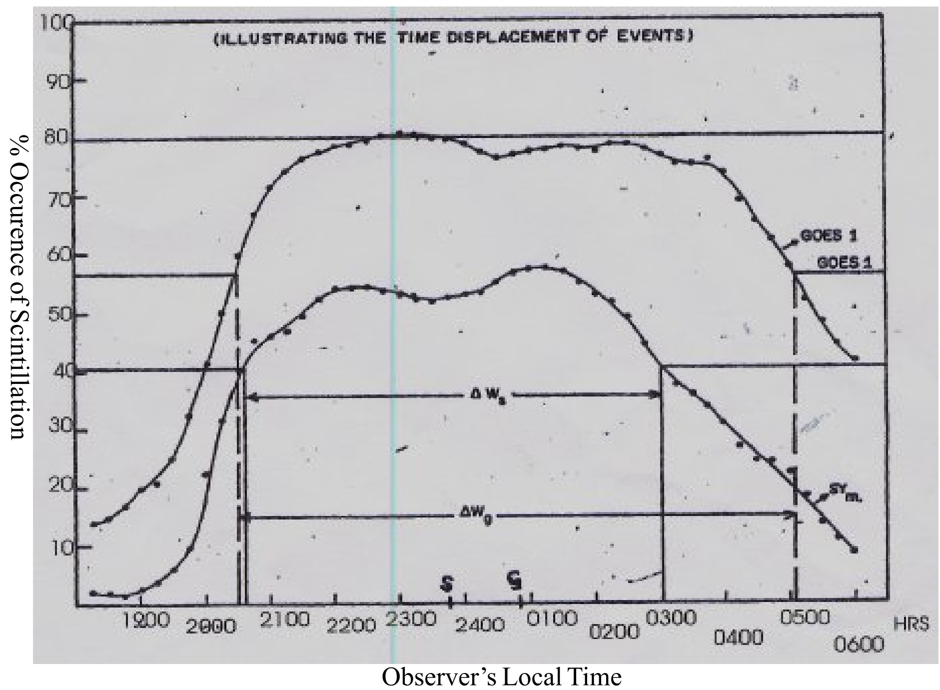

Figure 2: Diurnal Variation of Percentage Occurrence of Scintillations on GOES-1 (Elevation: 6^0; and F-Long: - 15.07^0) Symphonie (Elevation: 72^0; and F-Long: -1.06^0), Showing also the 'Time Displacement of Events'. (Source: Amaeshi, 1978).

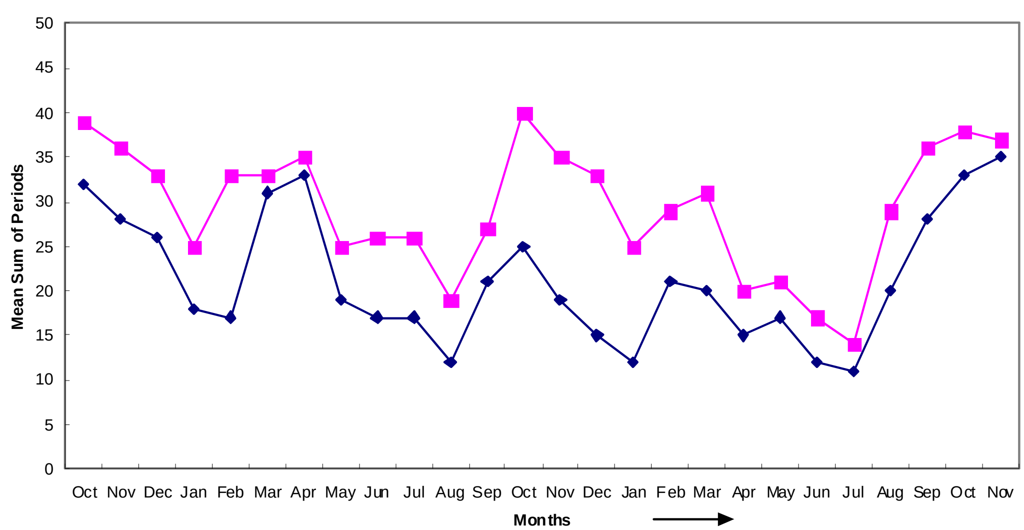

Figure 3: Mean *Daily Sum of 15 minute periods* showing Scintillation Index > 10 for ATS-3 and IS2F2/IS2F3, October 1972 to November 1974 inclusive; Note: - ATS-3 was at a fixed elevation of 6f; while IS2F2/IS2F3 were both East of ATS-3, and at elevation e" 60f each, during the period of the investigation.

satellites whose records were analyzed in this report, because they, being at constant coordinate, they enabled us to compare results from satellites at different fixed coordinates. Besides, as stated in Section 1, the results of the analysis of the scintillation records of the two satellites Amaeshi (1978; 2005) triggered of this work. Koster, (1978), reported that the curves of the diurnal variation of the mean value of scintillation index exhibit similar characteristics as the curves of the percentage occurrence of scintillation, as described above. A similar result is also revealed when the monthly variation of the mean daily sum of 15 minute periods showing S.I.>10, is plotted for ATS-3 and for IS2F2/IS2F3, (at varying, but higher elevation). This is depicted in Figure3. It is seen that the curve of ATS-3, the lower elevation satellite, lies above that of IS2F2/IS2F3, the higher elevation one. The results show that a higher elevation satellite, not only does it exhibit a lower percentage of scintillation occurrence than a lower elevation one, it also exhibits a smaller scintillation depth, (measured by S.I.).

The above results show why when one observes two satellites at very different elevations, the lower elevation one may frequently begin to scintillate first before the higher elevation one, even though the former is positioned west of the latter. Thus, elevation effect is a more dominant contributor to the onset, frequency and depth of scintillation, compared to the effect of longitude.

From Figure3, it is also seen that the curves exhibit maxima about the equinoxes: September/October, and March/April; and minima about the solstices: January/February and June/July, respectively. This is in agreement with expectation: that scintillation is more probable near the equinoxes and less probable near the solstices at equatorial latitudes (Whitney *et al.,* 1969; Amaeshi, 1978, and 2005; Koster, 1978; and Dabas and Reddy, 1986).

4.0 Conclusions

Clearly, from the analysis and results of Section 3, Subsection 3.1 through 3.4, it is seen that:

i. Equatorial ionospheric scintillation onset time depends, amongst others, on both longitude and source elevation, but

ii. elevation effect is much more dominant than longitude effect. This explains why when one observes two satellites at different coordinates; the lower elevation satellite would often begin to scintillate before the higher elevation one, even though the former is positioned west of the latter. And when elevation effect(s) were taken into account satellites more easterly often, begin to scintillate before the ones more westerly, as would be expected, if longitude effect were to be the more important contributor. In other words, the comparative effect(s) of longitude and elevation on scintillation onset time have been resolved unequivocally - elevation effect is the more important contributor.

iii. Also, elevation effects contribute much more than longitude effects to both the frequency (% occurrence) and depth (degree of fading, measured by Scintillation Index), of scintillations; with the results showing that the lower the elevation the greater both the frequency and depth of scintillation, which is in conformity with earlier reports by Amaeshi (1978; 2005), and Koster (1978).

Amaeshi, (1978; 2005), has offered plausible explanations for this particular observation, in terms of the column of ionospheric irregularities traversed by signal, which is greater, the lower the source elevation. Since ionospheric scintillations are caused by electron density irregularities in the ionosphere, then for all intent and purposes, both the frequency and depth of scintillation would increase, the lower the elevation, as observed.

It is suggested here that, the same reason, be it implicitly, explains the dominant effect of elevation on scintillation onset time, as reported here. It is argued that there is a ‘critical mass’ of ionospheric irregularity necessary to cause the trans-ionospheric signal to scintillate, and this value is more readily obtained the greater the column of irregularity traversed; and this column is greater, the lower the source elevation. Thus, a lower elevation satellite is more likely to scintillate before a higher elevation one, even if the latter is east of the former, as observed.

In final conclusion, it is reiterated that this work in the main, has resolved unequivocally the comparative effects of longitude and elevation on (equatorial) ionospheric scintillation onset time, at least at Legon: elevation effect is the greater contributor, every other thing being equal; with a lower elevation satellite often starting to scintillate before a higher elevation one, even though the former is positioned west of the latter. The plausible reason for this has also been proffered.

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