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CERTIFICATE OF CORRECTIONS FOR MR. JACOB KENNEDY OWUOR'S MSC PROJECT RESEARCH- JUNE 2021

This is to issue a certificate of corrections to Mr. Jacob Kennedy Owuor for his M.Sc. project thesis titled: **"A study of effects of ionospheric scintillation intensity using GPS data at low latitudes."**

The work has been accomplished to my satisfaction.

DR. GEOFFREY.O. OKENG'O, PH.D.
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UNIVERSITY OF NAIROBI

A STUDY OF EFFECTS OF IONOSPHERIC SCINTILLATION INTENSITY USING GPS DATA AT LOW LATITUDES

BY

JACOB KENNEDY OWUOR

I56/34713/2019

A Project Submitted in Fulfillment for the Degree of Masters of Science in Physics of the University of Nairobi

June 2021

DECLARATION

I declare that this project is my original work and has not been presented for a research elsewhere or in any university for examination, award of degree or publication. Where other people's work or my own work has been used, this has properly been acknowledged and referenced in accordance with the University of Nairobi's requirements".

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This project is submitted for research with our approval as research supervisors:

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DEDICATION

I dedicate this project to my late father. I also dedicate it to my entire family, as well as friends for their immense support. To Dr. O. Saoke and Dr. S. Otoi, former undergraduate classmates who challenged me to pursue Master's Degree in Physics after having stayed away from classroom for 11 years, thank you.

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ABSTRACT

Low latitude areas are highly exposed to the effects of ionospheric scintillations caused by the activities in the sun's corona. Ionospheric scintillation occurs when there are rapid deviations in the signal amplitude or phase frequency as radio signals travel through areas of non-uniformity in the ionosphere. These changes cause adverse effects on Global Navigation and Satellite Systems (GNSS) by producing propagation impairment hence disturbing the satellite systems accuracy in positioning. When scintillations are stronger, satellite receivers can lose lock posing threats to GNSS applications and positioning. Scintillation effects worsen during solar maximum. The receiver-satellite geometry is poorly messed up when the effects of scintillations are higher. Due to the adverse effects posed by irregularities in the ionosphere, there is need to carry out research to study the extent to which scintillation effects can affect navigation tools and propose solutions to improving precision on positioning as well as receiver satellite geometry. This research work presents a detailed study of occurrence of scintillations in the region of Darwin, Australia, at latitude 12.4637° S, a low latitude area. Ionospheric data for Darwin from sws.bom.gov.au/aims are used to analyze the extent of scintillations for the period ranging between January 2020 and April 2021. Amplitude scintillation index and phase scintillation index are used to plot graphs using the gnuplot. The results from the graph show that scintillation is prevalent throughout the period of study, an indication that radio frequency signals passing through the ionosphere is affected adversely. Being a low latitude area, GPS stations located in this place, will need to be monitored for scintillation. Ground based GPS data receivers can be positions at angles that lower the receiver distance from the space satellites. Radio signals with scintillations will have to be corrected before they can give a clear signal for communication.

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LIST OF ABBREVIATIONS/ACRONYMS AND SYMBOLS

C/NOFS - Communications/Navigation Outage Forecasting System

GLONASS - GLObal NAvigation Satellite System

GNSS - Global Navigation Satellite System

GPS - Global Positioning System

ISMR - Ionospheric Scintillation Monitor Receivers

L1 - Level 1

L2 - Level 2

PLL - Phase Locked Loop

RF - Radio Frequency

SCINDA - Scintillation Network Decision Aid

CHAPTER 1

INTRODUCTION

1.1 Research background

The ionized part of our planet's atmosphere called the ionosphere contains free electrons and ions in significant quantities enough to produce enormous interference on Radio Frequency (RF) signals. Fountain effect causes irregularities in plasma density (Davies, 1965; Liu et al., 2017) leading to ionospheric scintillation associated with rapid fluctuations in signal phase and amplitude when the RF signals traverse the non-uniform parts of the ionosphere. It is well established that geomagnetic activities and the sun modulate scintillation (Fallows et al., 2016; Guo et al., 2017)

In the solar cycles besides active geomagnetic storms, ionospheric turbulence increases hence affecting how radio signals propagate through space. The global distribution of ionospheric scintillation is such that more activities are prevalent in the polar and equatorial regions (Aarons, 1982; Basu et al., 1988).

The Ionospheric scintillation events lead to strong spatial and temporal dependencies. During autumnal and vernal equinoxes, there is found to be a higher degree of prevalence for scintillations (Mezaoui et al., 2014; Paznukhov et al., 2012; Prikryl et al., 2016). Scintillation shows global distribution during the auroral to polar as well as in the equatorial regions (Aarons, 1982; Basu et al., 1988).

The effect on scintillation on GNSS intensity fading on signals is a subject under extensive research. The relationship between the likelihood of cycle clips occurrence and fading duration was developed by (Oliveira et al., 2014) after they studied characteristic of fading from scintillation data ranging for a period of one month. They arrived at a finding that scintillation can severely lower the performance of GPS receiver with Carrier Power to Noise (C/N_0) power threshold or above 30 dB Hz can be uncovered due to deep fading. For the scintillation intensity amplitude fading features on GPS L5, L1 and L2C signals at the regions around the equatorial zones, fading does not affect all the GPS bands simultaneously (Jiao et al., 2018). Seo et al. (2016) analyzed and characterized data based on commercial software receiver for 45 minutes and 50 Hz C/N_0.

Moreover, a fading duration model beneficial for the design of aviation receivers having small reacquisition interval to reverse the hostile effects was built. The data however, were collected within a short time and not based on sets with severe scintillation events. These studies fell short of tackling the issues related to the challenges that signal fading has on the performance of receivers and how tracking loop performance is interrelated to fading.

1.2 Statement of the Problem

Is it possible to predict scintillations? In communication that relies on links between ground stations and satellites, scintillation happens to bear the greatest effect on trans-ionospheric radio signals. Most equipment for communication on the Earth surface depend on data that is sent from navigation satellites located in space exposed to adverse solar activities. Since these equipment send radio frequency signals through the irregular ionospheric layers, any amount of scintillation may end up degrading their operations. It is therefore crucial that the extent of scintillation and its effects on the GPS data be analyzed and then the answer to the question on what can be done to mitigate such effects can be developed. This research is intended to assess the extent to which ionospheric scintillations occur at low latitudes and its effects on the GPS data.

1.3 Research objectives

1.3.1 Main objective

The main objective of this research is to study the effects of ionospheric scintillation using GPS receivers located at low latitudes.

1.3.2 Specific objectives

The specific objectives of this research are as follows:

i. To acquire the GPS datasets comprising of S_4 and sigma60 for the period ranging from January 2020 – February 2021 for low latitude area of Darwin from https://www.sws.bom.gov.au/World_Data_Centre/1/11/.
ii. To import this data into python and Gnuplot or Matlab and analyze the scintillation intensity.
iii. To model scintillation effect during the period of study.
iv. To provide recommendations on mitigation of the resulting scintillation effects at the end of this project

1.4 Research justification and significance

Satellites in space play an important role in collecting and relaying information for a range of uses including weather forecasting, global positioning and entertaining among others. Examples of areas where such data is used include phone towers, airports and marine navigation systems.

The security of these equipment in relation to the data received rely on accurate relay of information which can be compromised if there is degradation or interferences. Hence in cases of irregularities in the ionosphere, data received by ground receivers in ships, data centers would be compromised and the accuracy of information won't be reliable. A study of low latitude ionospheric scintillations is therefore an important undertaking to provide not only an understanding of what goes on in the space, but also how the activities would affect communication. Once this is clearly understood, ways of mitigating the effects would be possibly laid out or a research on how to prevent the changes will then take place.

CHAPTER 2

LITERATURE REVIEW

Aeronomy which is the study of the upper atmosphere is continuously drawing interest of many scholars in a wider span of years so far, Henry R. and Owen K (1966). The upper part of the atmosphere is normally characterized based on chemical compositions, dominance of physical processes and temperature of the section under question (Chapman, 1950). Ionosphere is one of the layers of the immediate atmosphere above our planet which is composed of charged particles, negative and positive ions.

Many studies have been conducted to analyze the nature of composition of the ionosphere and ionospheric scintillations. The findings of these studies have led to the conclusion that the charge distribution and density of the ionosphere is not uniform, hence scintillation occurs in its regions affecting radio frequency signals. Yeh and Liu in 1982 established that at low latitudes, fountain effects is the major cause of irregularities in ionospheric plasma. A similar conclusion was made by Davis in 1990. According to these researchers, the irregularity in ionosphere is the underpinning cause of scintillation which is associated with high signal phase and amplitude fluctuations when radio frequencies pass through this irregular region of our atmosphere.

(Akala et al., 2012) investigated how ionospheric scintillation affect GPS receivers in the equatorial and trans-equatorial applications in the aviation. They concluded that strong scintillations affected the geometry of satellite receivers. Moreover, they established that deep signals do fade above some threshold frequencies. This led to outages in the navigation during most nights when this investigation was conducted.

The African region forms the larger part of the globe that enjoys enough exposure to the equatorial geomagnetic landmass. However, limited studies have been done in this region in terms of scintillation activities compared to other parts of the globe. This is because there are very minimal numbers of ground based ionospheric scintillation equipment. (Ngwira et al., 2013) dedicated their investigation on the intense East African low latitude scintillations of 8 April 2011. These intense scintillations were according to their research, instigated by activities of deep plasma bubble generated by Eastward electric field seen by measurements of C/NOFS plasma drift. The study used data from both C/NOFS and SCINDA over East Africa region as the first research of its kind in this area where very few or no ground equipment for such investigation existed.

(Guo et al., 2019) in their analysis found extreme scintillation effects which degraded the performance of satellite communication equipment. They established the fact that fading characteristics variation is such that maximum scintillations gradually decreases with the increasing value of S4 up to a value of 1.0 when it begins to reduce again, showing an inverse relationship. Moreover, assessment of the maximum fading duration and minimum fading depth are not proportional linearly to the levels of scintillations. Using scintillation index range of $0.3 \leq S4 \leq 1.4$, they observed a gradual decrease with increasing value of S4. The decrease stops at some level remaining roughly the same thereafter indicating correlation of deeper fading with strong scintillations. The scintillation at Presidente Prudente which was their area of study was seen to be quite frequent over three months running from October to December of 2014, the year that Guo et al, 2019 study focused on. They observed an inverse relationship between duration and the depth of fading. GPS data is adversely affected by signals fading that are around -20dB.

(Sreeja et al., 2012) investigated the relationship associated with the levels of scintillation and how this affects the performance of GNSS receiver tracking, GLONASS, L1 and L2, and GPS L1C/A, and L2C and arrived at conclusions that different receivers would perform differently hence warranting the need to model scintillations effects with specific receivers in mind.

They observed that strong scintillation occur almost daily during between October and December of 2014 with $S4 > 0.7$. A total number of fading detected amount to 144891 which are in the range of -15 to -5dB lasting for about 1 s. Their observation also revealed an inverse relationship with depth of fading and duration. Moreover, this study also revealed that fading with depth of -20dB can cause more damages and degradation to loop performances. The PLL error variance is highly increased by the shorter fading. Guo et al. (2019) research also established that scintillation is not the only cause of fading in the loop performance, since intensity measurements also contain some ambience noise which produces similar interferences.

According to Akala et. al. (2012), GPS navigation measurements suffer adversely due to equatorial scintillations. It reduces the number of satellites that readily provide data that would be useful in calculating navigation solutions. In their study they postulated that in an ideal situation four satellites are necessary to have a valid calculation on navigation solutions. Analyzing data from Ascension Island GPS in the solar maximum of March 2002, they observed deep signal fading in most nights leading to navigation outages. Their finding confirmed the conclusion made by (Seo et al., 2007). At times they would see that impacts of scintillation plunged below the minimum requirement. Local equipment that suffers the effects of scintillations still needs further investigation and providing recommended mitigation measures. The deep signal fading witnessed in the nights can be a source of major damages to equipment more work has to go on to unearth these effects with an aim to provide or recommend solutions.

The rapid growth and development in worldwide civil aviation is overstretching the conventional navigation infrastructure which is based on sensors. Implementation of GNSS was meant to improve quality enhance performance, but still give cost saving results in the civil aviation communication (Cabler and Decleener, 2002) especially the GNNS compasses, GPS, GLONASS, Galileo systems Augmentation-Space Based Augmentation Systems (SBAS) and Aircraft Based Augmentation Systems (GBAS) and Aircraft Based Systems (ABAS).

Ionospheric scintillation is delaying implantation of GNSS for global aviation applications, (Akala et al., 2012, 2011; Olwendo et al., 2012). Scintillation is more prevalent in the regions above the equator, very low at mid-latitudes and also much elevated at high latitude (Aarons, 1982; Basu et al., 1988). Effect of scintillation on GPS tracking loop performance makes the satellite signals to fade (Akala et al., 2012). Dual frequency mechanisms combine two frequencies (L1 and L2) to clock, broadcast, and ephemeris as wells as compute ionospheric corrections.

Dual frequency GPS aviation receivers that are onboard aircrafts are not yet in use. The common applications for aircrafts are the SBAS receivers at the reference station that work on dual band frequency mode. For the dual frequency systems, loss of lock on either L1 or L2 that occurs as a result of fading inhibits corrections expected from the results calculated during the period when the lock is lost. This can extend to a few seconds after regaining lock leading to errors in navigation (Béniguel et al., 2009; El-Arini et al., 2003; Kim et al., 2003; Strangeways, 2009).

Civilian codes (L1 and L5:1.17645 GHz frequencies) with dual frequency will be used for GNSS future aviation (Seo and Walter, 2014; Walter et al., 2008). The frequency order L1 and L5 is anticipated to mitigate the impact of availability of scintillation on GPS aviation (Akala et al., 2012, 2012).

Ionospheric irregularities make C/No satellite values to rapidly fluctuate. Whether signals emanating from the satellites propagate through a patch of irregularities in the ionosphere will indicate the extent of scintillation modulations (Akala et al., 2012).

CHAPTER 3

THEORETICAL FRAMEWORK

3.1 Ionosperic irregularities cause scintillation

There are several sources of information that attempt to remarkably describe scintillation theory. (Lovelace et al., 1969), and (Yeh and Liu, 1982) have done a thorough work in providing the mathematical theories explaining scintillations. This review concentrates on the amplitude and phase scintillation indices for forward perturbation, involving radio waves traversing the irregularities in the ionospheric components where electron density is non uniform.

3.2 Categorizing scintillation intensity

Radio wave propagation through irregular medium is described by Maxwell's equation resulting in the derivation of Helmholtz scalar wave equation for irregular medium where predominant scattering of waves occur. Moreover the regions where such scattering occurs have large scale sizes greater than the wavelength of radio waves signals.

The Helmholtz wave equation used is given by

$$\nabla^2 A + k^2[1 + \epsilon_1(\vec{r}')]A = 0 \qquad (1)$$

In this equation, A represents the electric fields complex amplitude, k denotes the signals wavenumber, $\vec{r}'$states the position of the irregularities and $\epsilon_1$is the free space permittivity deviation.

With an assumption that the solutions involved evolve on a timescale slower as compared to the wave propagation, Green's function is used, (Kintner et al., 2007).

One of the solution to equation (1) takes the form,

$$A(r) = -\frac{\exp[ik(r+R)]}{4\pi(r+R)}\left[1 + \frac{ik}{2}\int_{-\frac{L}{2}}^{\frac{L}{2}} \epsilon_1(0,0,z')dz'\right] \qquad (2)$$

Here R represents the distance from the source of radio frequency signal to the irregularities, r is distance from the signal receiver to the irregularities, k denotes the wavenumber for the radio signal, z' stands for the direction of the ray and L is the thickness of the irregular ionospheric layer. This can be illustrated using the diagram below.

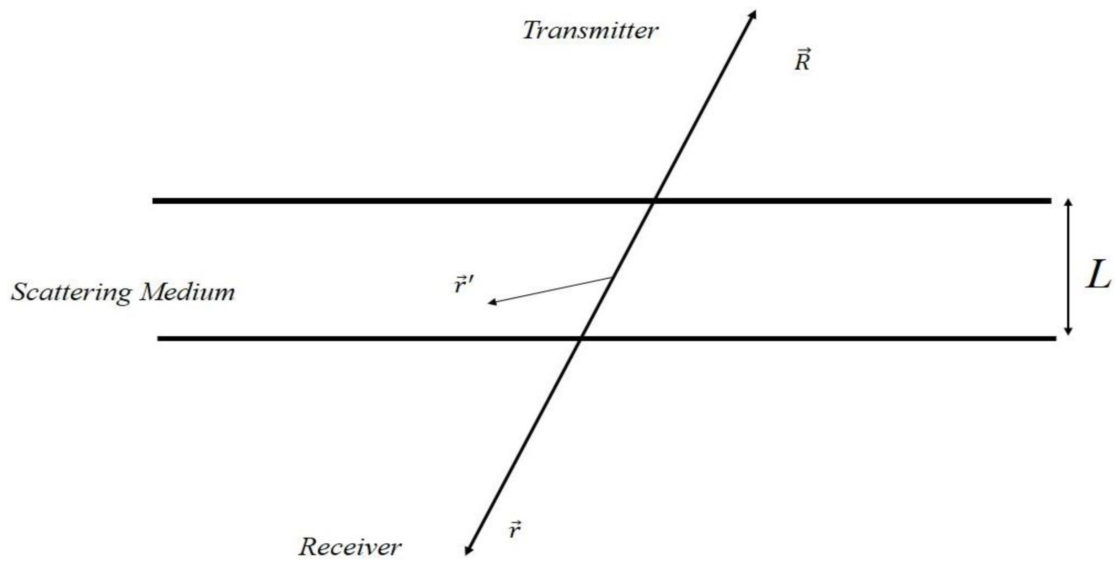

Figure 1: Wave propagation coordination system through the ionospheric irregularities

Equation (2) has solutions which are functions of the wave number and inversely proportional to the frequency of the wave. This has an implication to the fact that different frequencies broadcasted from the same source experience different effects from the irregularities of the ionosphere. This difference is a factor of the strength of signal scattering.

As the radio signals pass through the irregularities, Amplitude and phase perturbations can be very intense. These perturbations are categorized into amplitude scintillations and phase scintillations. Amplitude and phase scintillations lead to radio signal fading.

3.3 Signal amplitude and phase modeling

It is possible to model the fundamental effects on wave transmission through Fresnel-scale electron density as an integral function of the permittivity fluctuations in the path of signal rays. This kind of modeling was first done by Booker et al 1950.

The equation (3), below is useful in describing amplitude perturbations.

$$\Phi_1(q) = \Phi_\emptyset(q) sin^2\left(\frac{q^2 r_F^2}{8\pi}\right) \quad (3)$$

Where $\Phi_\emptyset$ represents the wave power spectrum, Φ_1 is the signal intensity autocorrelation functions' Fourier transform, q represents horizontal wave number, $r_F = \sqrt{2\lambda r}$is Fresnel radius, λ denotes incident the wavelength for the incident signal. The term $sin^2\left(\frac{q^2 r_F^2}{8\pi}\right)$ represents what is known as the Fresnel filtering and it provides the upper limit for irregularities scale size which occurs when sin^2term tends to one or the equation resolves to $\frac{(2n-1)\pi}{2}$ radians.

For phase deviations,

$$\Phi_p(q) = \Phi_\emptyset(q) cos^2\left(\frac{q^2 r_F^2}{8\pi}\right) \quad (4)$$

3.4 Amplitude and phase scintillations equations

Phase scintillation index is symbolized by σ_φ (sigma phi) while amplitude scintillation index is represented by S_4 (Guo et. al. 2017). To describe amplitude scintillation index, the equation below is applicable.

$$S_4 = \sqrt{\frac{\langle I^2\rangle - \langle I\rangle^2}{\langle I\rangle^2}} \quad (5)$$

The S4 index in this equation represents the normalized standard deviation of the signal power. It relates to the peak-to-peak fluctuation in intensity (Guo et al., 2019).

I, denotes signal intensity while the brackets$\langle \quad \rangle$ signify averaging over a given signal time interval, usually 60. To get signal intensity, complex amplitude A, of the signal is used as follows (Kintner et al., 2007).

$$I = A^2 \tag{6}$$

To describe phase scintillation index, $\sigma_{\emptyset}$ (sigma-phi) equation (7) is used:

$$\sigma_{\emptyset}^2 = \langle \Phi^2 \rangle - \langle \Phi \rangle^2 \tag{7}$$

This research concentrates on analysis of amplitude and phase scintillation intensity fadings providing assessment on how these fadings affect performances of different receiver settings.

CHAPTER 4

METHODOLOGY

4.1 Source of Data

GPS data that is available freely in the Space Weather Services (SWS) website, www.sws.bom.gov.au, was downloaded for January 2020 to April 2021. Darwin Australia was chosen as an area of interest. This data was extracted using zip applications and the data analyzed for presence of S4 and sigma60 values.

4.2 Data analysis and tools

After downloading the data, Gnuplot has been used to produce different graphs comparing variations expected in the ionospheric scintillations. Single graphs for amplitude scintillations S4 were plotted separately. The data for sigma60 were also plotted on different graphs. Thereafter combined graphs for different months were plotted for January 2020 to April 2021 showing scintillations occurrence for the entire period.

CHAPTER 5

RESULTS AND DISCUSSION

5.1 Scintillation index, S4 variation with time for January 2021 to April 2021

Figure 2 shows different plots for amplitude scintillation index observed from January to August 2020. The plots were meant to show how scintillations represented by S_4 index varied with time in a given month. This would help to investigate whether ionospheric irregularities is a daily issue or whether there are times when the ionosphere is regular. All the graphs indicate the variation of amplitude scintillation index S_4 with time of the day. The date 20^{th} was chosen for each month. Comparing the graphs leads to a finding that strong scintillations occur throughout all the moths that the study concentrated on.

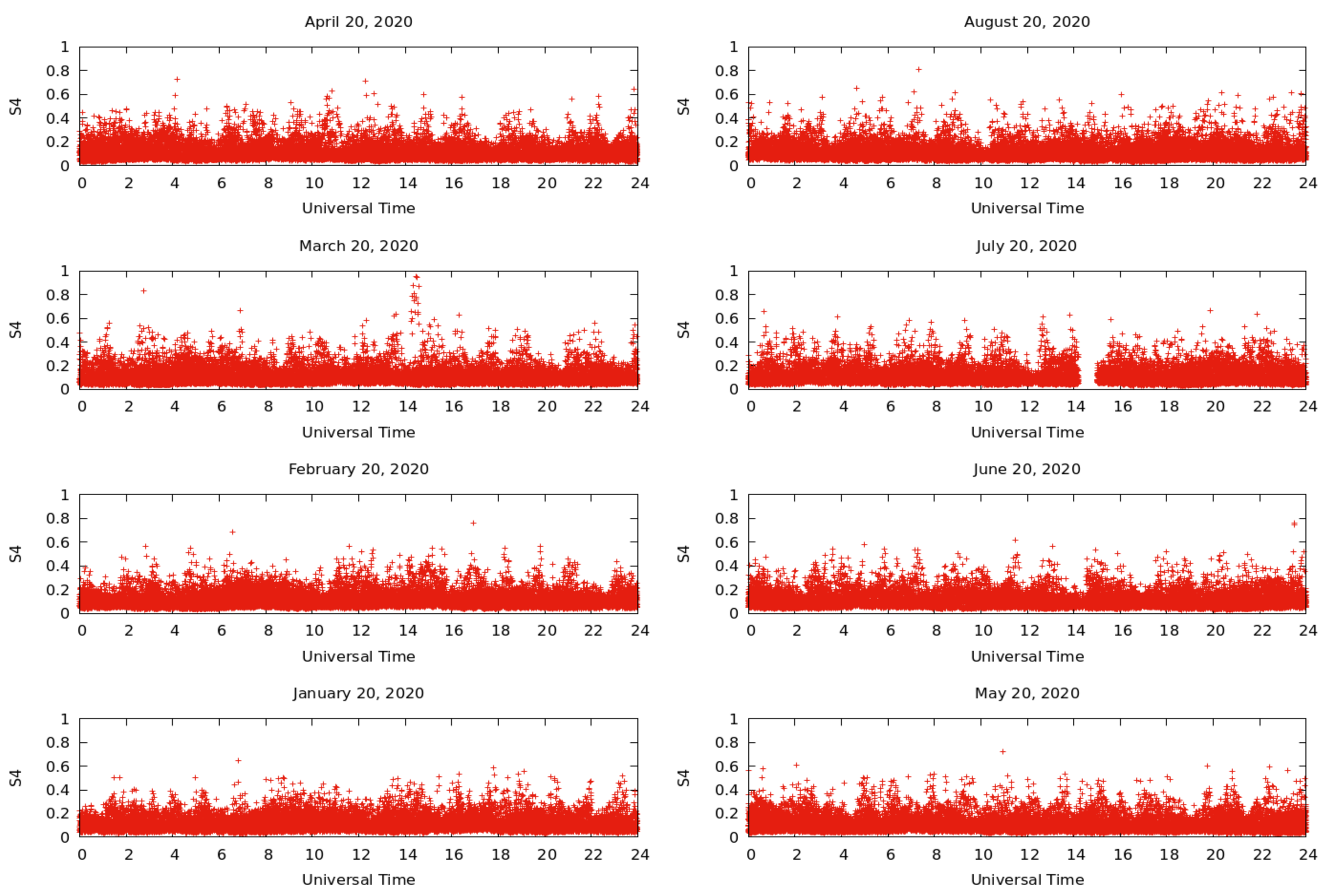

Figure 2: Variation of S4 as a function of time for January 2020 to august 2020.

Figure 2 shows plots for another 8 months, running through April 2021. Scintillations are observed to have occurred the whole of the year 2020. This is the same trend in 2021, see also figure 3 below. There were no scintillations data recorded for 20th July 2020 between 1400hrs and 1500hrs as evidenced by the gap seen the graph of figure 2. In all seasons through the year, ionosphere perturbations are prevalent. Some months recorded bursts of high S4 index, especially 20th of March and October 2020 where S4 index reached 1.0. These are very strong scintillations in the frequency amplitude index, S4. Other months registered S4 bursts above 0.4 in most hours of the day. This is strong enough to interfere with radio frequency signals indicating that technology equipment should be monitored or properly set to ensure that GPS data receivers are not exposed to high interferences. It is clear that the ionosphere is always actively irregular affecting signal frequencies as radio signals pierce through the ionosphere.

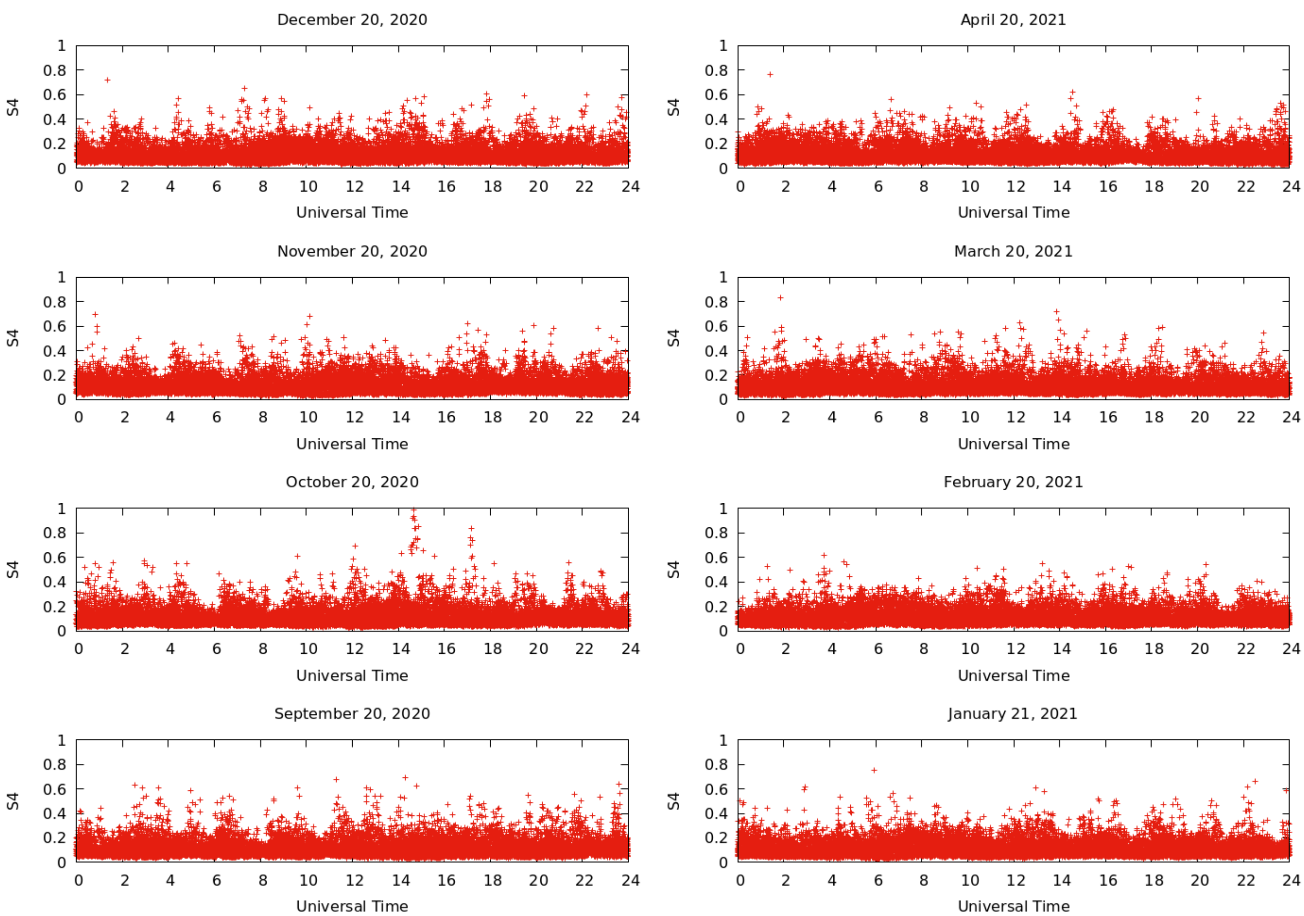

Figure 3: S4 against time for September 2020 to April 2021.

5.2 Amplitude and phase scintillation index for January to December 2020.

The following plots looked into the strength of scintillation for both phase and amplitude indices. Stronger scintillations for both amplitude and phase scintillation indices through January to April 2020 were noted. Looking at figure 4 and 5, it can be quickly observed that a similar scintillation trends appear throughout the year. Burst of scintillations occur for both indices. In all the plots scintillations are strong. However, some months reported stronger scintillations than the others. Uniquely higher bursts were mostly seen around 1200hrs to 1600hrs in March 2020. This is repeated for April 2020 at around 1000hrs to 1600hrs. These observations show that scintillations occur at all times of the day. Radio frequency signals experience interferences throughout. There is no particular day in the year 2020 when scintillations were not registered.

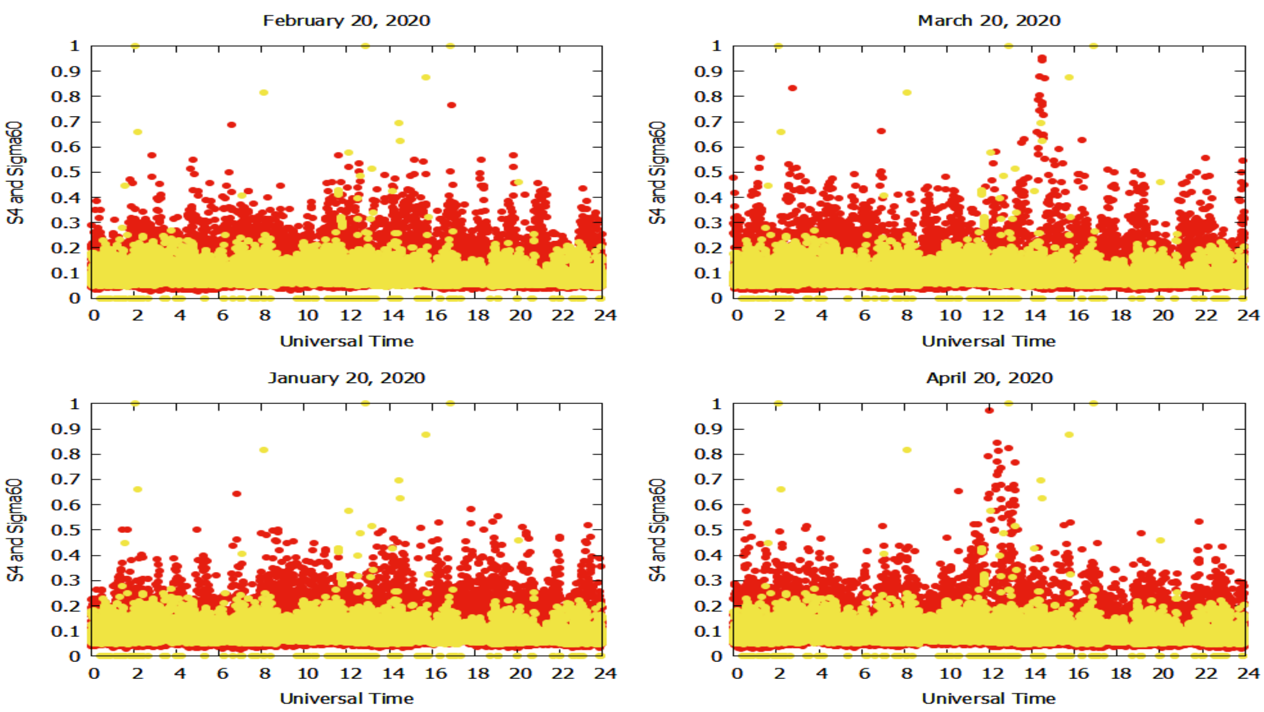

Figure 4: Plots showing S_4 and Sigma60 as a function of universal time for the months of January to April 2020. The red points show amplitude scintillations index, S4. Yellow plots represent phase scintillations index sigma60. All plots are for 20th day of each month

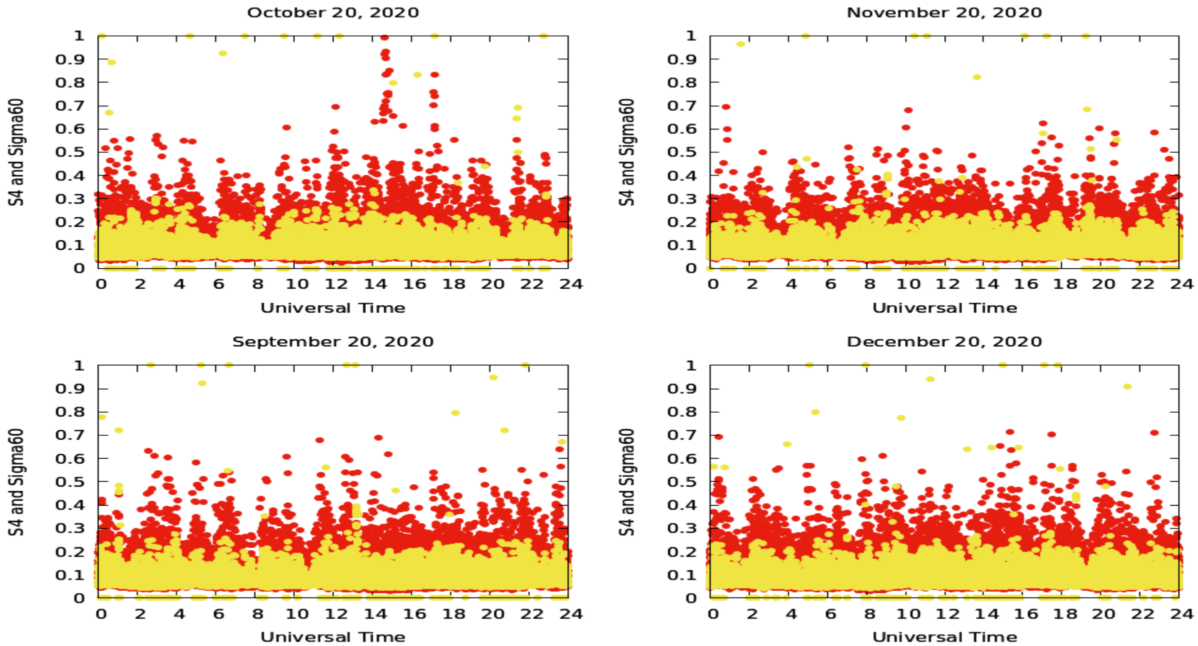

Figure 5: S_4 and Sigma60 plotted against time for May to August 2020.

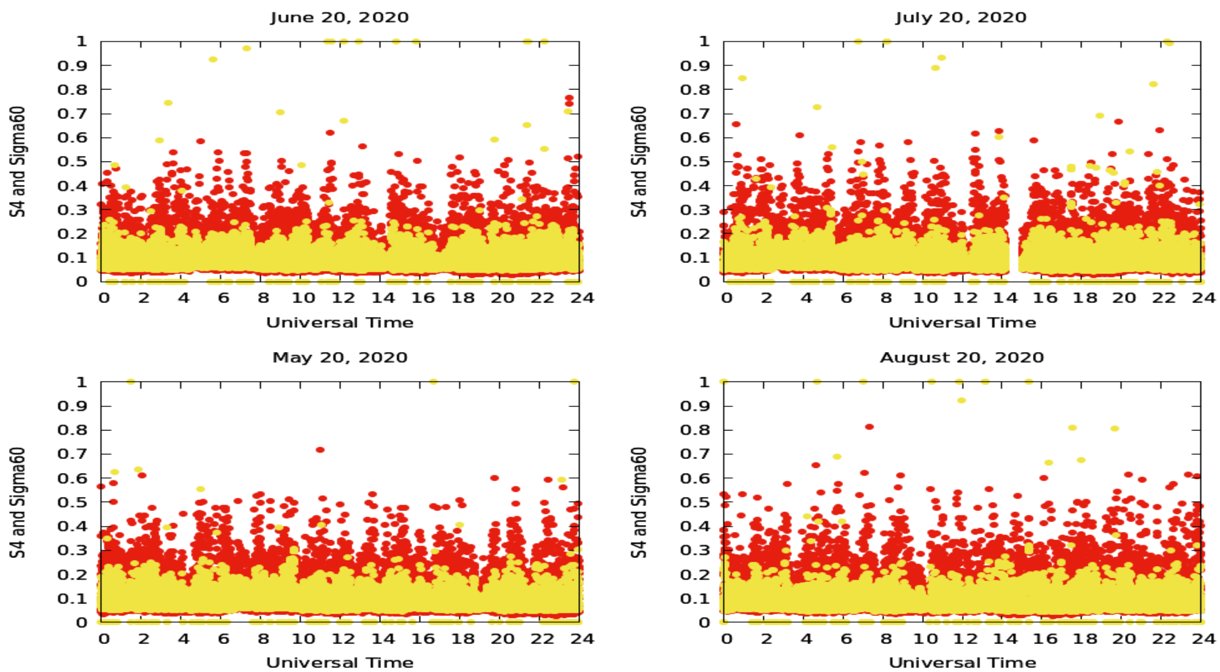

Figure 6: Phase and amplitude scintillations graphs for September to December 2020.

In all the plots, it is noted that strong amplitude and phase scintillations indices are characteristics of signal interference through the year 2020.

5.3 How satellite's angle of elevation affects ionospheric scintillations intensity.

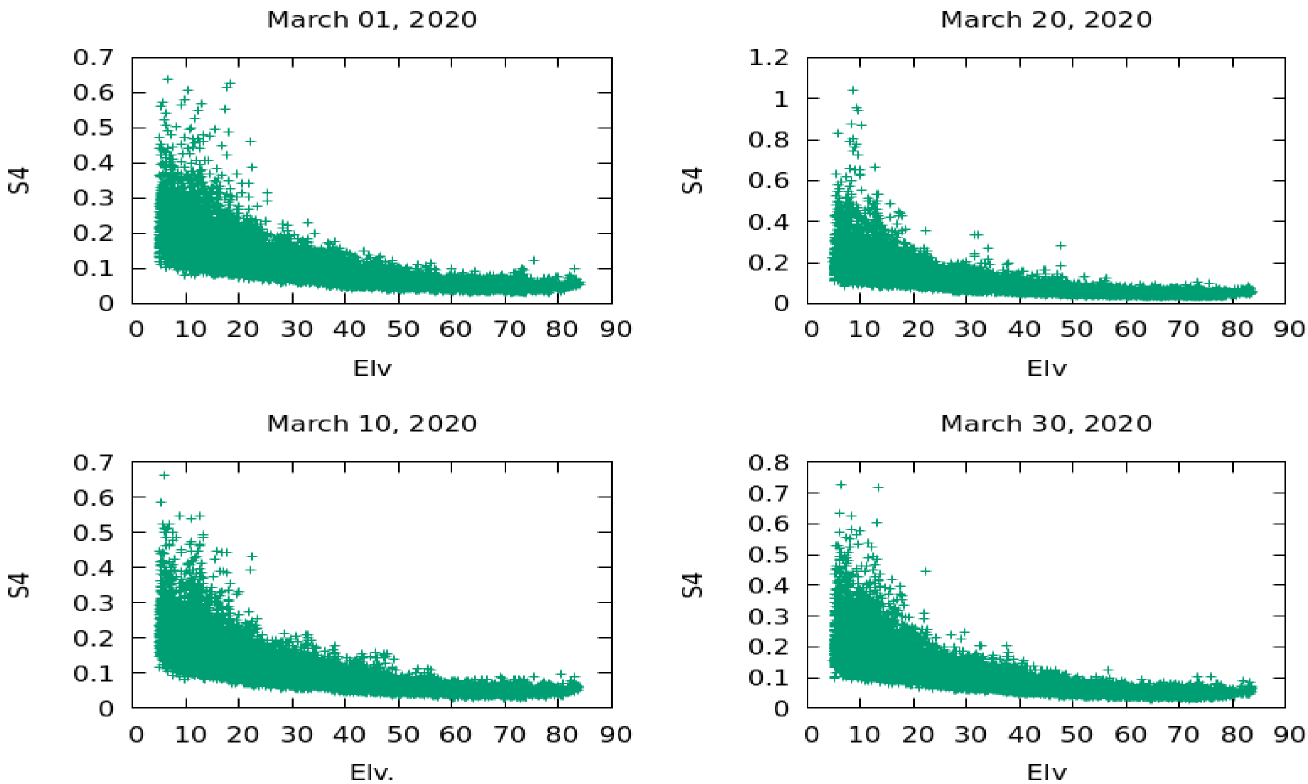

Figure 7: Plot of S4 as a function of satellite Elevation Angle (Elv) for tracked signal. The minimum Elevation Angle is 5o below which no signal can be tracked. The Maximum Elevation Angle is 90^o.

From the plots, when the angle of elevation for satellites is small, the intensity of amplitude scintillation index is high. This gradually reduces with increasing elevation angle. Radio signals travel longer distance through the irregular parts of the ionosphere. This is because at higher elevation angles radio signals have a shorter distance to trace through the ionosphere. This explains why the scintillation interferences are much less at 90^o. At $5^0 < x < 20^0$, scintillations are registered in the range of $S_4 > 0.3$. While at high angles $x > 20^o$, lower scintillations registered are below 0.3. Scintillations are categorized as follows, $S_4 \leq 0.2$, $0.3 < S_4$ 0.4 is medium while $S_4 > 0.4$ is considered high (Seif et al. 2015). Large angles of elevation indicate lower scintillations. More bursts of amplitude scintillations of up to 1.2 are registered for the

20th of April 2020. This indicates an active ionosphere for the lower angles of elevation on that particular day. A similar trend is seen in March 2020 and repeated in March 2021. Although scintllations still occur where the elevation angle is greater than 20°, the effect on radio frequency signals is much lower. Quality signals can be achieved when the angle of elevation is greater. This is when the satellite GPS reciever is pointed almost directly towards the target satellites.

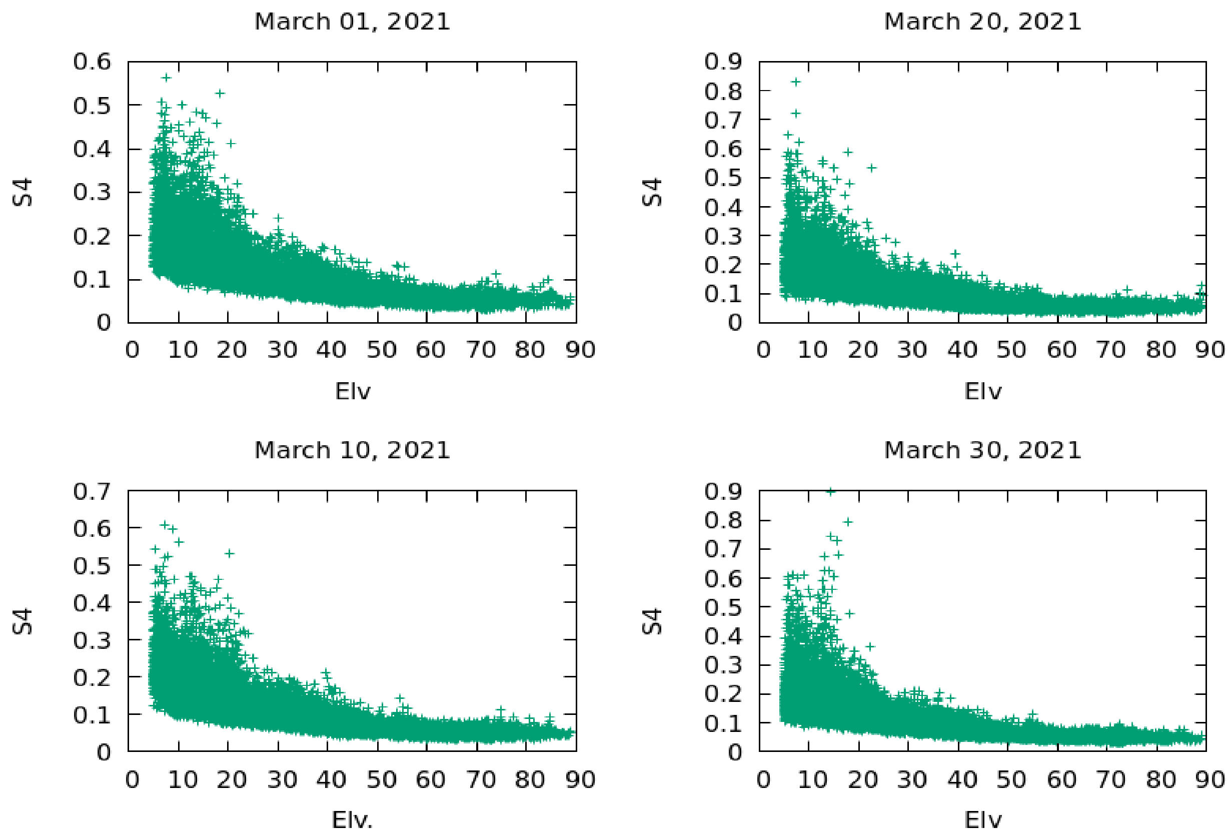

Figure 8: S_4 as a function of satellite Elevation Angle (Elv) for March 2021.

Figure 7 and 8 are compared for the same months and different year. The result seen shows a similar trend in March 2021 as was the case for 2020. The irregularities in the ionosphere is not a seasonal issue but a permanent property of the atmosphere. The only solution is to modify technology in such a way that propagated signals do not experience interference or only achieve minimal disturbances.

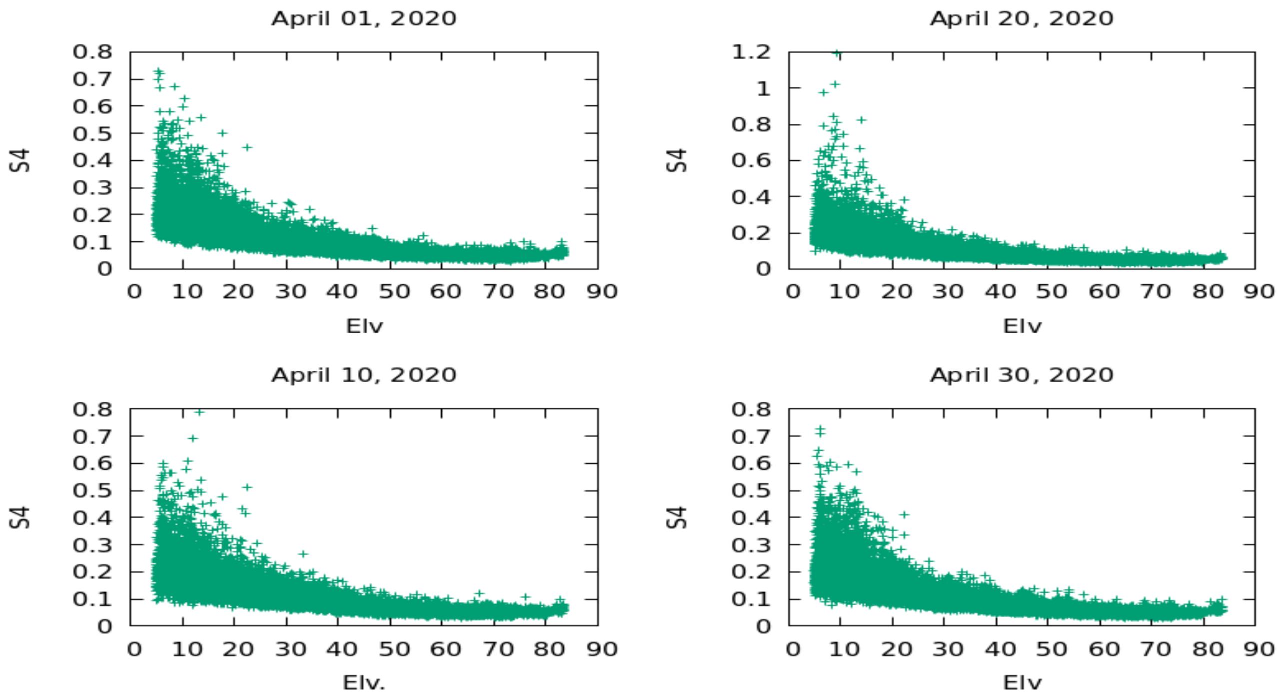

Figure 9: S_4 as a function of satellite Elevation Angle (Elv) for April 2020.

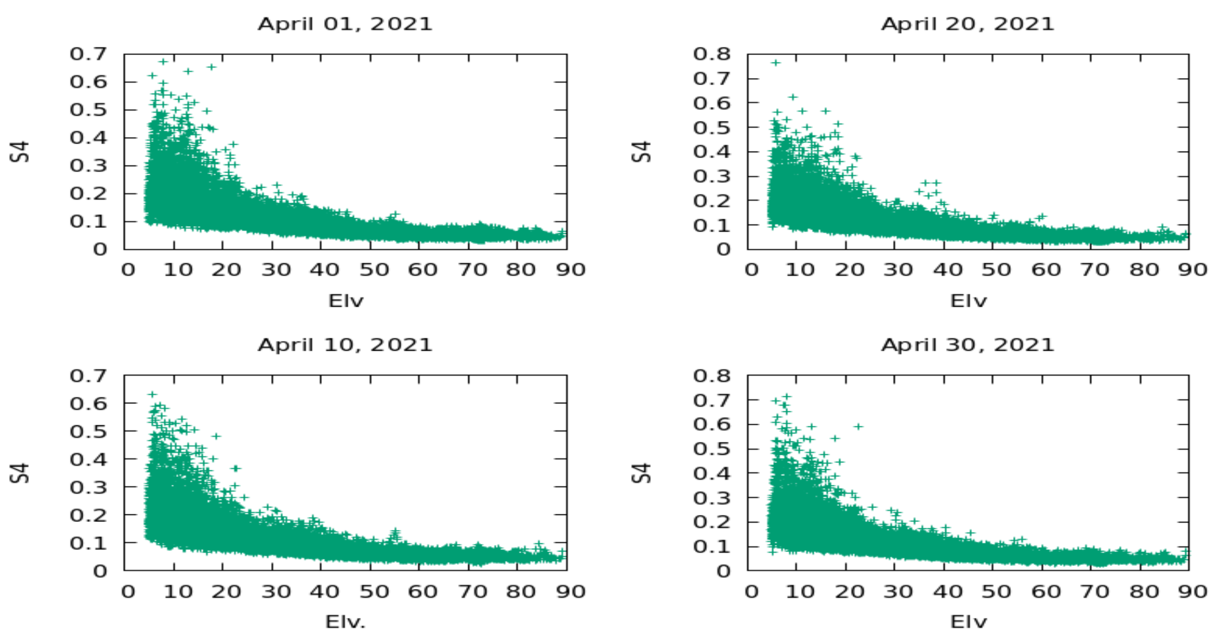

Figure 10: S_4 as a function of satellite Elevation Angle (Elv) for April 2021.

Figure 9 and 10 are graphs plotted to compare the trends for April 2020 and 2021. It is quickly seen from these graphs that the ionosphere is always actively experiencing scintillations.

5.4 Plotting angle of elevation for Satellites for May-December 2020

Selecting different dates for each month, plots for S_4 index against the angle of elevation showed that all through the year 2020 strong scintillations were registered. An example is seen with the months of May to September 2020 where 1^{st}, 10^{th}, 20^{th}, and 30^{th} dates for the months were plotted and all these days had the same trend in how scintillations occurrence looked like.

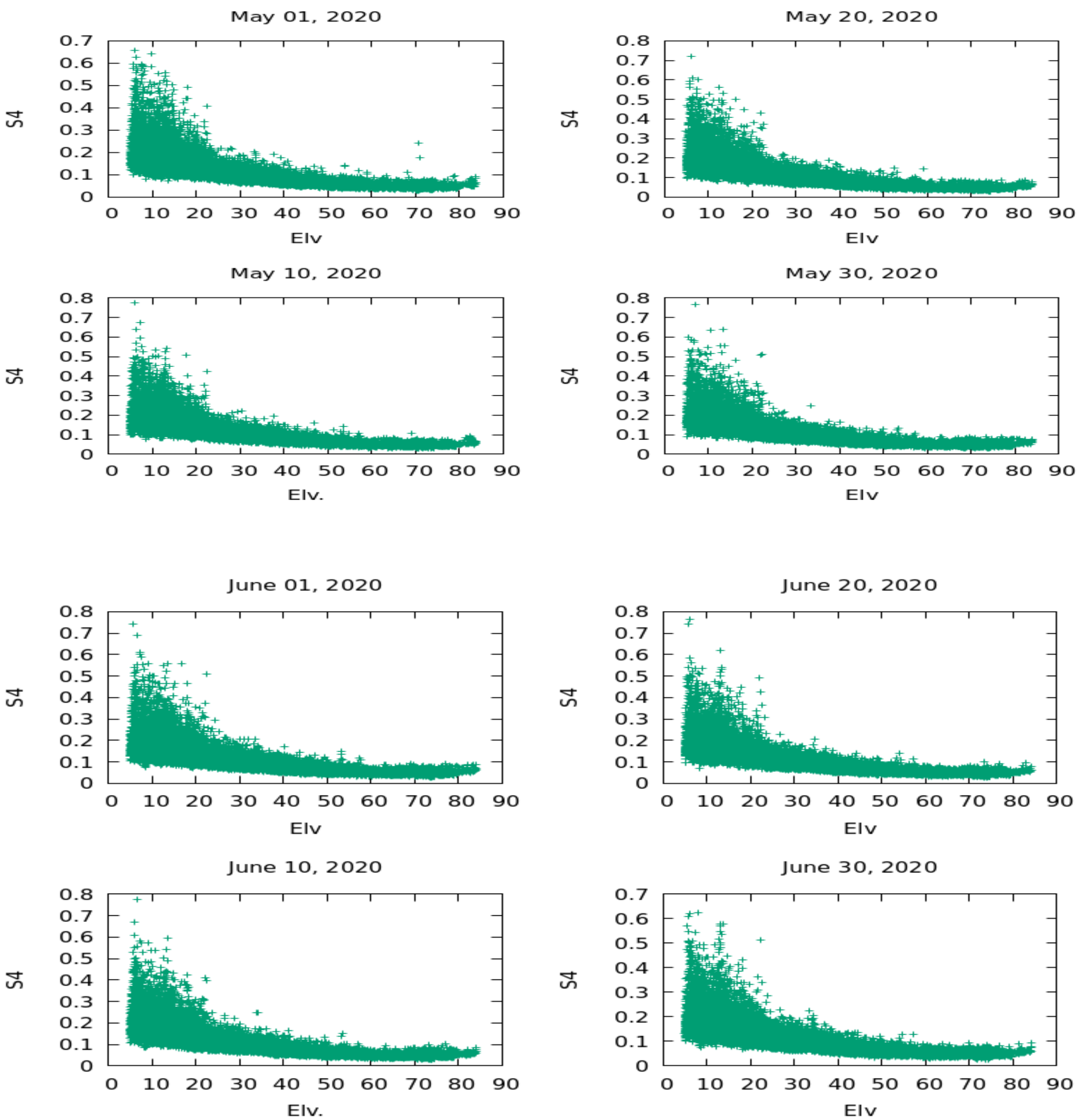

Figure 11: Graphs of S_4 index against the angle of elevation for May and June 2020.

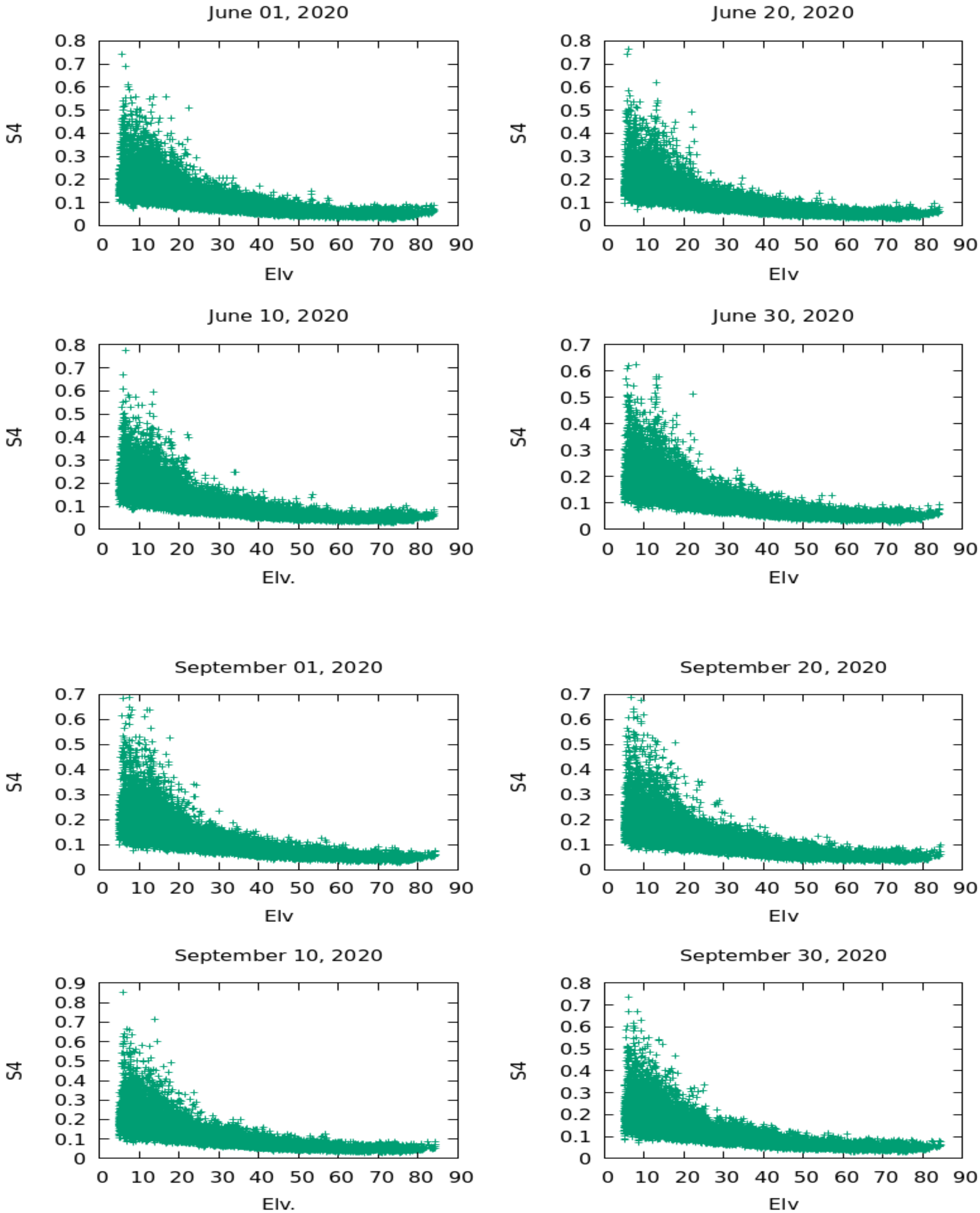

Figure 12: August and September 2020: the graph of S_4 against the angle of elevation

The months of October to December were similar in the distribution of scintillations. These are clear indicators of how irregularities in the ionosphere is prevalent. This is seen in figures 13 and 14 below.

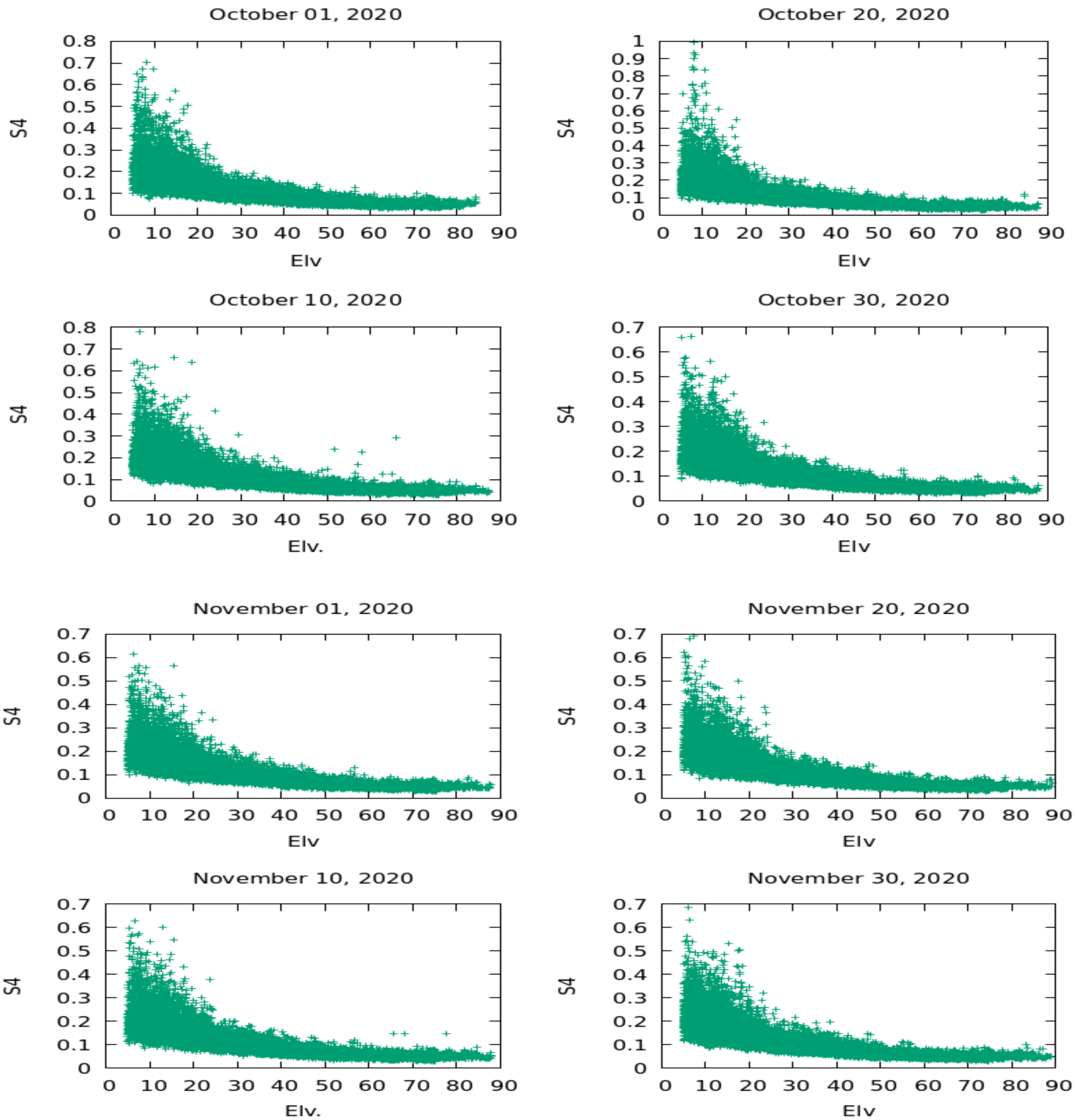

Figure 13: Scintillations S_4 index and angle of elevation for October and November 2020.

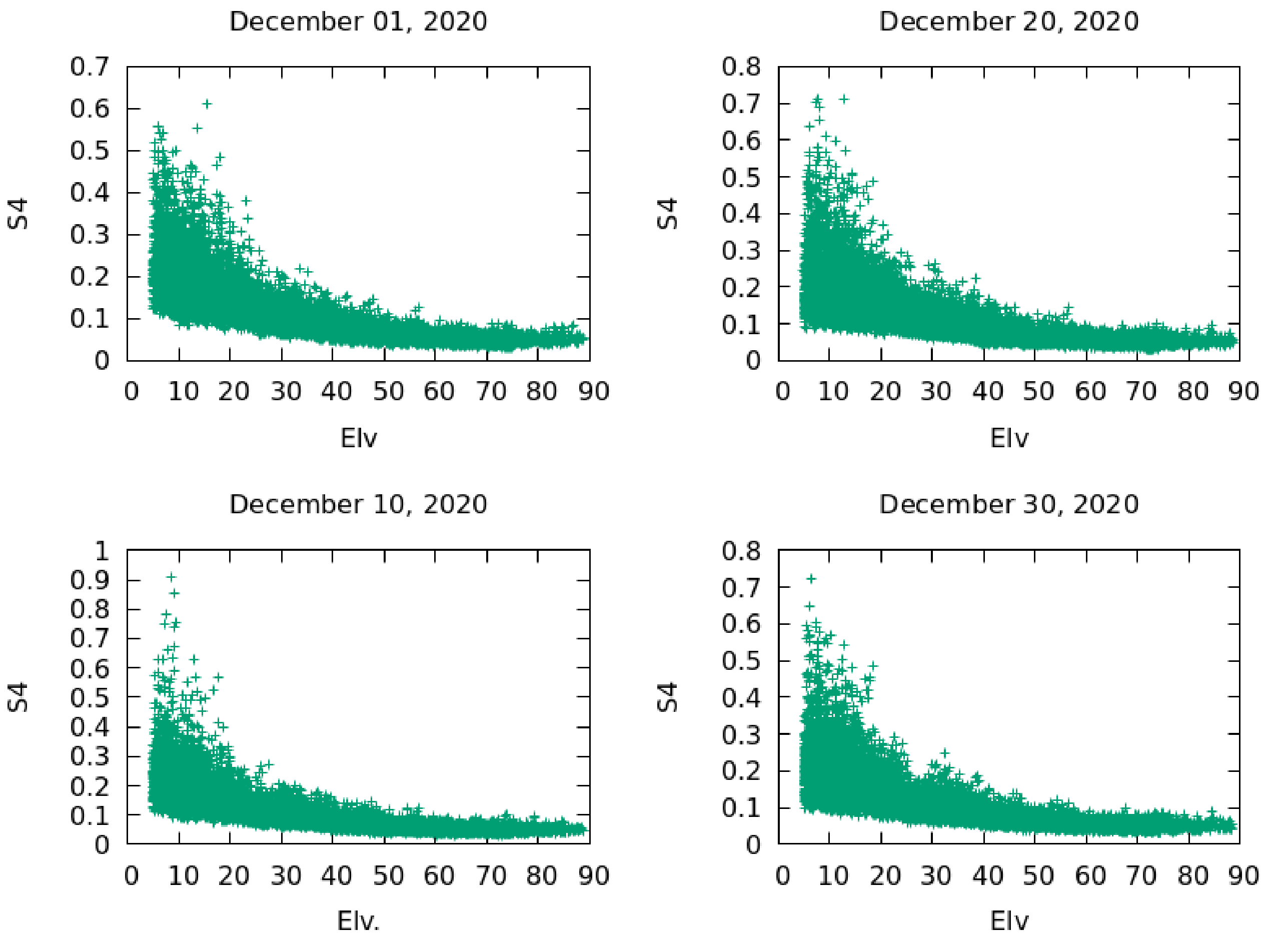

Figure 14: Scintillation S_4 Index for December 2020: all days recorded scintillations greater than 0.3, adversely affecting GPS receivers.

From these graphs, it is possible to see that angle of elevation for the satellites receivers should be set above 20^o to avoid strong scintillations which can affect signal strength cutting communication with satellite radios. When angles of elevation are 20^o and below, scintillation are stronger causing greater interference which can cut signal transmission. Knowing this can help to mitigate scintillation effects and therefore reduce intensity of amplitude scintillation index by ensuring that right angle of elevation is used.

CHAPTER 6

CONCLUSION AND RECOMMENDATIONS

6.1 Conclusions

Strong scintillations is a regular occurrence throughout the year 2020. In this research preliminary S4 data files were used to analyze the presence of scintillations for the January 2020 through 2021 April. All plots show that scintillations occurred across the period that the data was collected. Scintillations are stronger in some days than others, but in all days that the study concentrated on, S4 index is above 0.3. The area of Darwin in Australia, being around the equator at latitude 12.4637 ^{o}S is predominantly experiencing scintillations. This means that earth based GPS equipment will experience adverse effects daily throughout the year. GPS data received contains noise.

6.2 Recommendations

Due to the prevalent ionspheric irregularities, it is obvious that scintillations will occur when radio frequency signals are transmitted through the ionosphere. A number of equipment relying on satellite radio receivers will receive poor quality information or total lack of it. It is important to ensure that the data received has less or no noise. To do this, the angle of elevation for ground satellite receives must not be below 20^{o}. At angles below 20 degrees, signals from the satellites have to cross larger portions of the ionosphere. Due to irregularities in the ionosphere, the signals travelling to the receivers when they are at angles below 20 degrees would be affected and would contain a lot of scintillation noise.

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