GPS Amplitude Scintillation Monitoring at Equatorial Region Using GPStation-6

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Abstract

As technology advancement progresses throughout the years in this modern age, every technology has its part to play in that the world is moving towards a brighter future. GPS (Global Positioning System) has diverse application in current globalized world, its application has pervasive benefits not only to navigation and positioning, it is pivotal in industries like logistics, shipping, financial services and agriculture. Since the decision to shut down the Selectivity Availability (SA) by former U.S. President, Bill Clinton, ionospheric effect is now the primary concern of error contributing factors in GPS. Ionospheric scintillation induces rapid fluctuations in the phase and the amplitude of received GNSS signals. These rapid fluctuations or scintillation potentially introduce cycle slips, degrade range measurements, and if severe enough lead to loss of lock in phase and code. A GPS Ionospheric Scintillation and TEC Monitor (GISTM) receiver, GPStation-6, has been installed at Melaka, Malaysia (2.31° N, 102.32° E) to study the ionospheric variability at a low-latitude location. The GPS receiver was recording the scintillation indices for both L1 and L2C GPS signals. This paper presenting the preliminary results for the data collected and analyzed for the period of 3 months with sample of every 60 seconds for 24 hours daily. The scintillation amplitude, the elevation angle and availability of GPS satellites were reported.

1. Introduction

Space weather can be defined as changes in conditions of sun's ambient plasma, magnetic fields, radiation and in the solar wind that affects the earth's magnetosphere, ionosphere, and thermosphere. It can influence the performance and reliability of space-borne and ground-based technological systems [1]. Adverse conditions in this environment can cause disruption of satellite operations, communications, navigation, and electric power distribution grids, leading to a variety of socioeconomic losses [2].

GPS signal can be defined as electromagnetic wave generated by an oscillating energy from GPS satellites. Many factors affect the signal quality as the signal strength decreases as the distance between the satellites and GPS receiver increases. This is essentially due to attenuation caused by geometric spreading and the attenuation in the troposphere and ionosphere layers.

Unlike the troposphere, the ionosphere is a dispersive medium extending between 50 km and 1000 km above the earth's surface. It is highly concentrated with electrically charged atoms or molecules (ions) that are formed primarily by solar radiation ionization. Ionospheric irregularities where the electron density can differ significantly from the ambient plasma cause both refraction and diffraction of radio signals [3]. The largest effect is on the speed of the signal, and hence the ionosphere mainly affects the measured pseudorange. The magnitude of the refraction is a function of the refractive index of the ionosphere in the path of the GNSS signal.

The sun entering a period of increased activity approximately every eleven years called solar maximum which influences the amount of irradiance received from the Sun on earth. In 2013, it is expected that the sun activities reach to its maximum period, so this paper analyzes the maximum GPS scintillation in an important period.

The ionospheric scintillation can be defined as the rapid fluctuation of the amplitude and phase of the satellite radio signals when they propagate through the ionosphere due to electron density irregularities. The amplitude scintillation generally being dominant at low latitudes or equatorial region, and the phase scintillation at high latitudes or polar region. GPS receiver operation can be severely impeded by diffraction or scattering via amplitude and phase scintillation. The received signal quality (i.e. carrier-to-noise density ratio) in a GPS receiver is directly impacted by amplitude scintillation and subsequently degrades both pseudorange and carrier phase measurements [4]. It can be sufficiently severe to cause signal fades as large as 30 dB and thereby forcing loss of lock. Phase scintillation can easily stress phase-lock loops (PLL) in GPS receivers resulting in a loss of phase lock and thus impeding carrier phase measurements.

Equatorial ionosphere is a region consisting of two ionization belts located approximately ($\mp 15^{\circ}$) of the magnetic equator where scintillation activities at the maximum. Genarally, the ionospheric scintillation events in

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equatorial region occur more often after local sunset time and before local sunrise as a result from irregularities happening in equatorial ionosphere layer.

The ionospheric irregularities that cause scintillation are characterized by a pattern of multiple spots as shown in Figure 1. The spots of irregularities produce scintillation as these spots move through the ray paths of the individual GPS satellite signals. The sizes of irregularities can be as large as several hundred kilometers for large-scale structure and as small as 1m for small-scale structure.

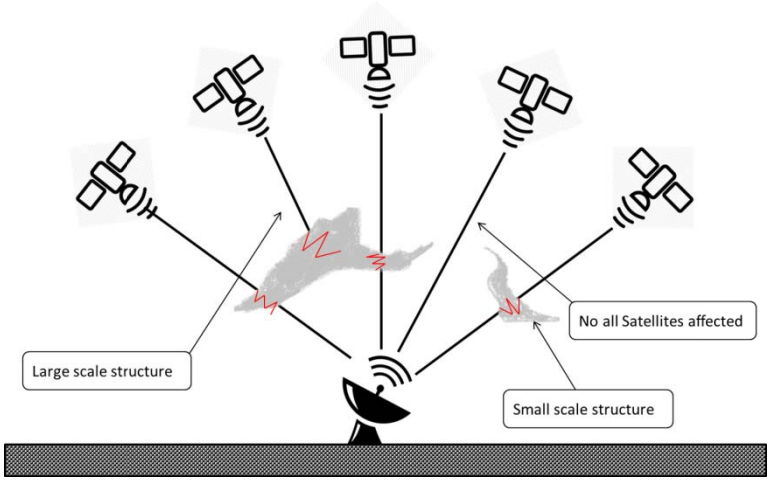


Figure 1. Varying effects of scintillation on GPS channels.

2. Ionospherric scintillation monitoring using GPStation-6

Ionospheric scintillation monitors began in the mid 1990's when GPS Silicon Valley modified a standard NovAtel GPS receiver that by 2000 had evolved into the specific GSV4004 series dual frequency series. It provided true amplitude, single frequency carrier phase measurements and TEC values for up to 10 GPS satellites and up to 3 SBAS signals from WAAS, EGNOS and MSAS geostationary satellites to provide L1 measurements and scintillation data (but no TEC) [5]. In 2011, it was discontinued due to a new era in GNSS signal modernization [6] and replaced with GPStation-6.

GPStation-6 is used to record the data of ionospheric scintillation and total electrons content (TEC) at Melaka, Malaysia. The GPStation-6 receiver provides a unique platform to support local monitoring of ionospheric effects on GPS. The receiver record scintillation data once every second, which includes 50 Hz amplitude and phase measurements and 1 Hz TEC measurements. The receiver also records extended summary messages every 60 seconds that include additional information and calculations for each tracked signal, including elevation angle, C/N_0, lock time, code-minus-carrier, calculations of different amplitude scintillation (S4), phase scintillation, and TEC statistics.

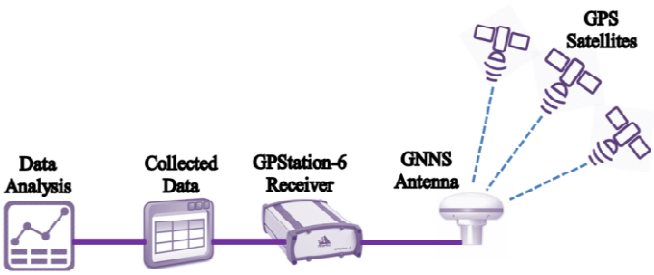


Figure 2. Experimental setup.

Figure 2 shows the experimental setup to measure and analyze the GPS scintillation. The used dataset for this study will be collected Melaka, Malaysia (2.3139^o N, 102.3183^o E), using scintillation monitor developed by GPStation-6 GISTM Receiver.

3. Results and Analysis

The first ever result for equatorial ionospheric amplitude scintillation from GPS L2C was shown in Figure 3. It shows the variation of the intensity of amplitude scintillations for L1 and L2C GPS signal for Week 1766 (11th November 2013 to 17th November 2013). This confirms the expected close correlation between the traditional L1 C/A and new L2C

measurements. However, the overall S4 values for L1 signal are always higher than L2C signal. It is due to these new signals are stronger so should have lower noise in periods of high ionospheric activity.

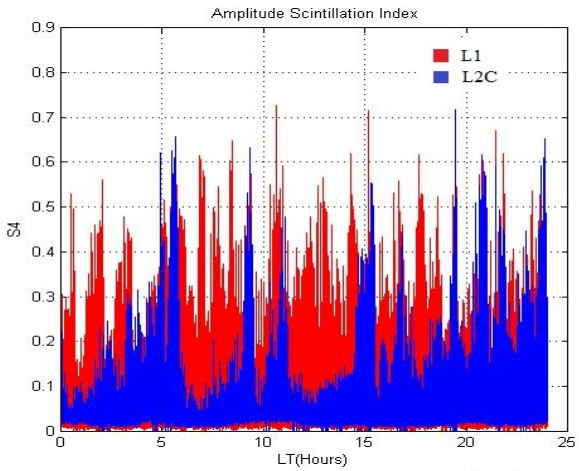


Figure 3. Variation of the intensity of amplitude scintillations for L1 and L2C GPS signal for Week 1766

The GPS amplitude scintillation index S4 has been calculated from the collected data and analyzed at different range of the elevation angles (Elv > 30° and Elv < 30°) for the both L1 and L2C signals considering all the available GPS satellites. Figure 4 shows the daily diurnal amplitude scintillation index variations for GPS pseudo random numbers (PRNs) (only those who are visible on that particular day) for October, November, and December 2013. The S4 index for L1 signal is presented by green curve, while the red curve represents L2C signal. Each plot shows the S4 index for the corresponding month versus the universe time (UT) for the two cases (Elv > 30° and Elv < 30°) as shown in Figure 3 (a) and (b) respectively. It is clear that, many values of S4 index greater than 0.4 arise obviously when the Elv < 30°, where satellites with low elevation angles suffer large fluctuations due to multipath effects. In addition, it is confirm that S4 values for L1 signal are always higher than L2C signal. Interestingly all the indices show that amplitude scintillation are not always correlated over this time.

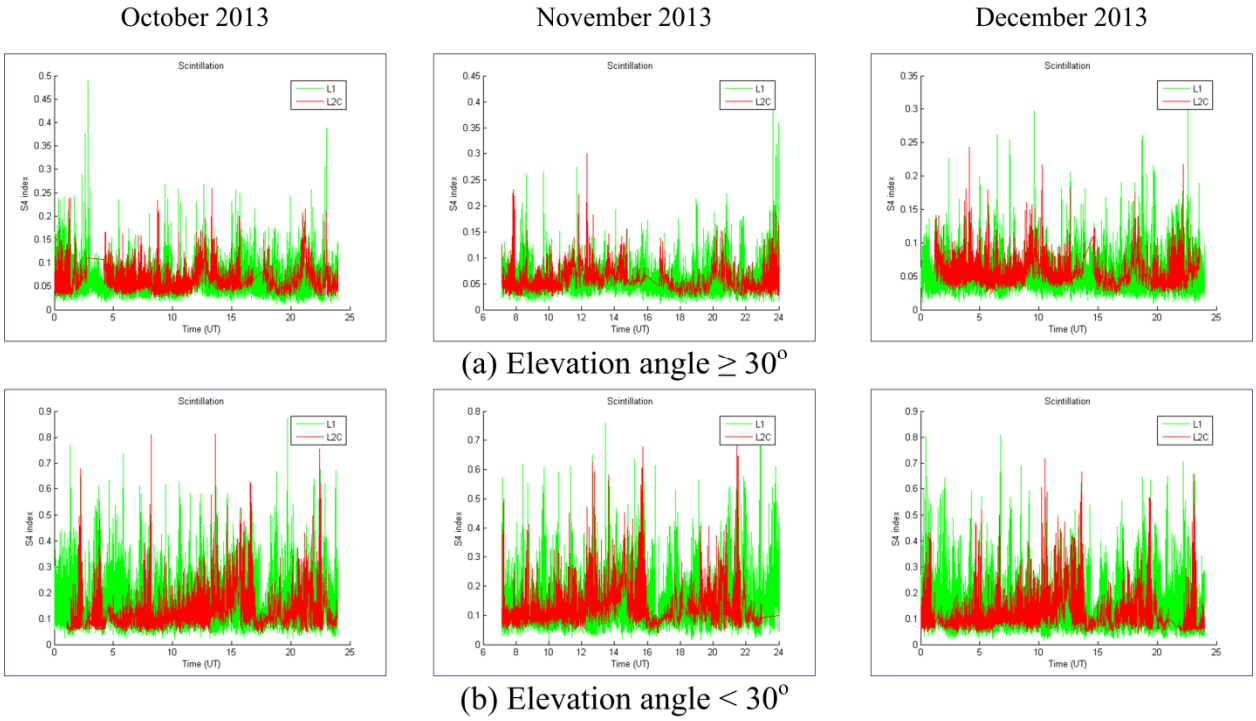
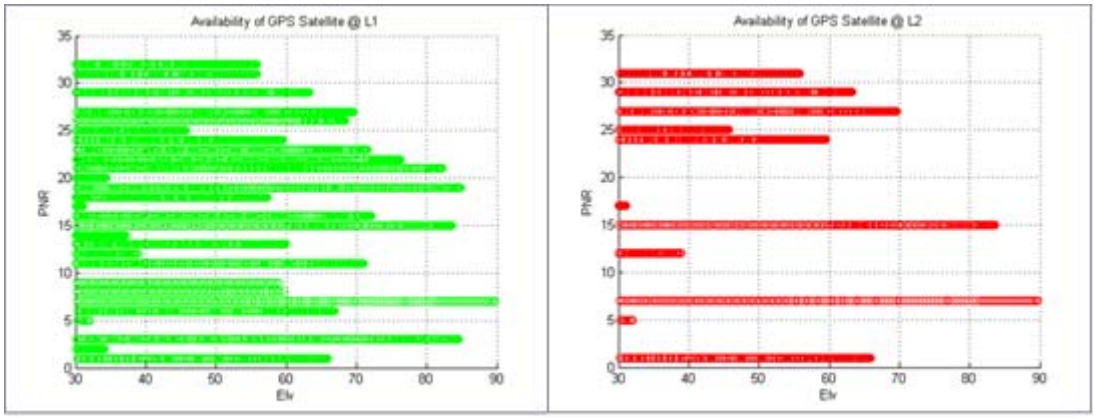


Figure 4. GPS S4 observations at UTeM, Malaysia for 3 months 2013 with elevation angle (a) Elv > 30°, (b) Elv < 30°.

There are 32 GPS satellites available around the earth (PRN 01 - 32), but it is not all available for one region on the surface of the earth. Figure 6 (a) and (b) show the availability bars of GPS satellites for one day at November 2013 as example, for the dual frequency L1 and L2 respectively. It is very clear that the total number of available satellites for L1 GPS is more than its for L2 GPS.



(a) L1 frequency (b) L2 frequency

Figure 6 Availability of GPS satellites at (a) L1 frequency, (b) L2 frequency.

4. Conclusion

Ionospheric scintillation has been experimentally investigated using GPStation-6 at Melaka, Malaysia station for the dual frequency L1 and L2 at three months October, November, December 2013. The preliminary results confirm correlation between the traditional L1 C/A and new L2C measurements of amplitude scintillation. It is also reported that S4 values for L1 signal are always higher than L2C signal. It is due to these new signals are stronger so should have lower noise in periods of high ionospheric activity. Interestingly, all the indices show that amplitude scintillation for L1 and L2C signals are not always correlated over this time. Extensive data collection and analysis are needed to further verify this phenomenon.

5. Acknowledgments

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