Comparison of Phase Scintillations During Low and High Solar Activity Periods

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***Abstract*—This study compares and analyzes phase scintillation σ_ϕ during periods of low and high solar activity. This study focused on the low solar activity from July 2007 to June 2008 (sunspot number (SSN) ranging from 0 to 10) and the high solar activity from July 2013 to June 2014 (SSN 37-103). The data were obtained from a GISTM receiver at the Wireless and Radio Science Centre, Universiti Tun Hussein Onn Malaysia (1°52'N, 103°06'E). Results show that the monthly mean σ_ϕ value is within the range of 0.051 and 0.064 rad during high solar activity. Meanwhile, the value during low solar activity ranges between 0.026 and 0.042 rad. The hourly mean σ_ϕ is also higher during the period of high solar activity. The findings can be attributed to the increase of solar activity during the period of July 2013-June 2014.**

Keywords—Phase scintillation; equatorial region; solar activity

I. Introduction

An ionospheric scintillation is a rapid fluctuation of radio-frequency signal phase and/or amplitude and is generated when a signal passes through the ionosphere. The scintillation occurs when a radio frequency signal traverses a region of small-scale irregularities in electron density [1]. Previous work has shown that the scintillations of the ionosphere vary with different solar activity intensities. The scintillations were normally higher during maximum solar activity and lower during minimum solar activity.

The study observed the variations of ionospheric phase scintillations caused by different solar activities during low solar activity period (daily SSN 0.9–10.1) and high solar activity period (daily SSN 36.9–102.8). This study focused on the periods from July 2007 to June 2008 and from July 2013 to June 2014, representing low and high solar activities, respectively. Data utilized in this work were obtained from a GPS Ionospheric Scintillation and TEC Monitor (GISTM) receiver located at the Wireless and Radio Science (WARAS) Centre, Universiti Tun Hussein Onn Malaysia (UTHM) (1°52'N, 103°06'E).

II. Ionospheric Phase Scintillations

Ionosphere is a layer of the earth's atmosphere that is located between 60 km and 1000 km from the surface of the earth. The ionosphere contains free electrons that may affect radio wave propagation depending on the density of free electrons in the ionization process, which is generally caused by solar activity.

The effect of the ionization process is influenced by the strength of the received radiation, which affects electron density. Events related to the effects of the sun on the earth affect the ionization process. The radiation intensity is higher during the day than at night. Similarly, the strength of radiation in winter is less than that received in the summer. The geographical location also affects the strength of the radiation received. Therefore, the impact ionization process in a region of the ionosphere also depends on the latitude of a specific area.

Irregularities smaller than about 1 km produce both amplitude and phase scintillations and larger irregularities produce only phase scintillations [2]. Phase scintillation can cause Doppler spread in the signal and may also affect the phase lock of the signal within GPS receivers. Scintillations can be a problem for the availability and continuity of the GNSS services [1]. Scintillations are the strongest in the equatorial, auroral, and polar cap regions [2].

III. Methodology

The GISTM receiver at WARAS Centre, UTHM is configured to measure the amplitude and phase scintillation from the L1 frequency (1575.42 MHz). The receiver collects phase measurements and then detrends with a 6^{th}-order Butterworth high-pass filter with cutoff frequency of 0.1 Hz. The standard deviations, σ_φ of the phase over 1-, 3-, 10-, 30-, and 60-second intervals are then calculated by the receiver [3]. The 60-second σ_φ is the indication normally used for the phase scintillation occurrence.

Data from this station from July 2007 to June 2008 and from July 2013 to June 2014 were analyzed. These periods correspond to low and high solar activity, respectively. The daily SSN for July 2007–June 2008 is between 1 and 10, and its value is between 37 and 103 in July 2013–June 2014. Fig. 1 shows the SSN for the last 13 years and also the forecast from the Royal Observatory of Belgium in Brussels.

An offline program, Parseismr.exe, was used to extract the data recorded by the GISTM receiver. The phase scintillation data collected before the phase detrending filter converged is eliminated by deleting the lock time data for L1 and L2 signals that are less than 240 seconds, where convergence has not yet occurred. Large phase scintillation data are deleted to avoid confusion with actual scintillation events. Therefore, all values greater than 2 rad are eliminated.

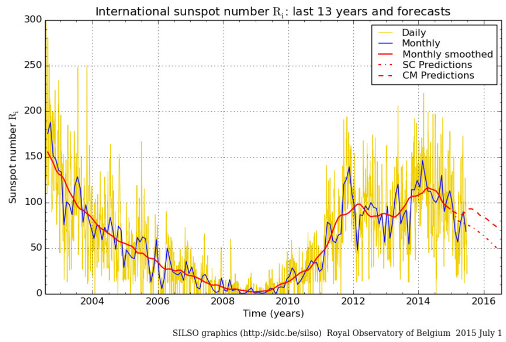

Fig. 1. SSN data produced by Royal Observatory of Belgium (http://sidc.be/silso).

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Data analysis was conducted by considering the mean of σ_ϕ, which was plotted by the minute, hour, and month. Moreover, the geomagnetic index, K_p, was utilized in analyzing the data. K_p index exceeding 5 indicated the state of disturbed ionosphere, whereas K_p index less than 5 represented quiet ionosphere.

IV. Results and Analysis

A. Monthly mean phase scintillation

Fig. 2 shows a comparison of the monthly mean phase scintillation σ_ϕ for both solar minimum and maximum periods. The graph indicates that the monthly mean σ_ϕ was higher during the solar maximum period. The highest monthly mean σ_ϕ for solar maximum was in March 2014 at 0.064 rad. This result was followed by April 2014 with a mean σ_ϕ of 0.060 rad. However, the maximum value of the monthly mean σ_ϕ for the solar minimum period was 0.042 rad in July and August 2007.

B. Hourly mean phase scintillation

The comparison of the hourly mean σ_ϕ was also conducted for the first three days of each month of the low and high solar activity periods. Four months were selected in each period: August 2007 and August 2013, September 2007 and September 2013, January 2008 and January 2014, and April 2008 and April 2014. Fig. 3 shows a comparison between the hourly mean σ_ϕ in August 2007 and August 2013 for the first three days of both months. Daily SSN was 0–7 (1–3 August 2007) and 69–82 (1–3 August 2013). The hourly mean σ_ϕ in August 2013 was higher than that in August 2007 compared to that during high solar activity. On 2 August 2007, an hourly mean σ_ϕ of 0.066 rad during 2 UT was observed. This value was the highest during these six days, that is, during $K_p < 5$.

Fig. 4 shows the differences in the hourly mean σ_ϕ between 1–3 September 2007 (daily SSN 6–14) and 1–3 September 2013 (daily SSN 50–61). The highest mean for σ_ϕ in September 2007 was 0.049 rad, while the hourly mean σ_ϕ in September 2013 was approaching 0.1 from 13 UT to 17 UT.

The comparison between the hourly mean σ_ϕ on 1–3 January 2008 (daily SSN 7) and 1–3 January 2014 (daily SSN 87–107) is shown in Fig. 5. The highest hourly mean σ_ϕ on 2 January 2014 at 20 UT is 0.073 rad. The daily mean σ_ϕ was higher in the three days in January 2014 than in January 2008.

Fig. 6 shows the hourly mean σ_ϕ on 1–3 April 2008 (daily SSN 9–16) and 1–3 April 2014 (daily SSN 71–100). The highest hourly mean σ_ϕ during the period of low solar activity was 0.092 rad on 3 April 2008, whereas the hourly mean σ_ϕ during the period of high solar activity was 0.134 rad on 2April 2014. Based on all four-month comparisons, the daily mean σ_ϕ was higher during the period of high solar activity than in the period of low solar activity except in August 2007. The daily mean σ_ϕ during this period of observation is summarized in Tables I and II.

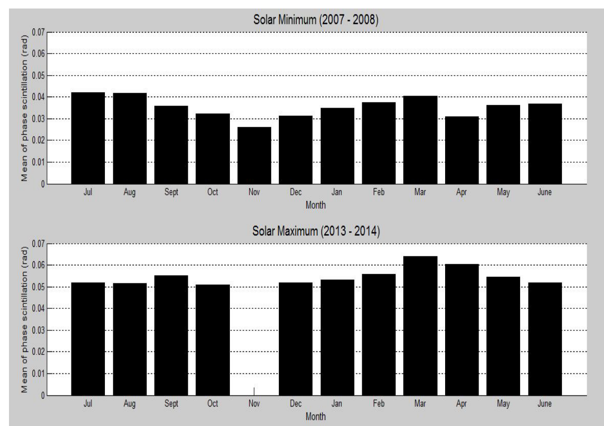

Fig. 2. Comparison of monthly mean phase scintillation σ_ϕ at low and high solar activity periods. In November 2013, the GISTM receiver had technical problems that caused no data to be obtained for the month.

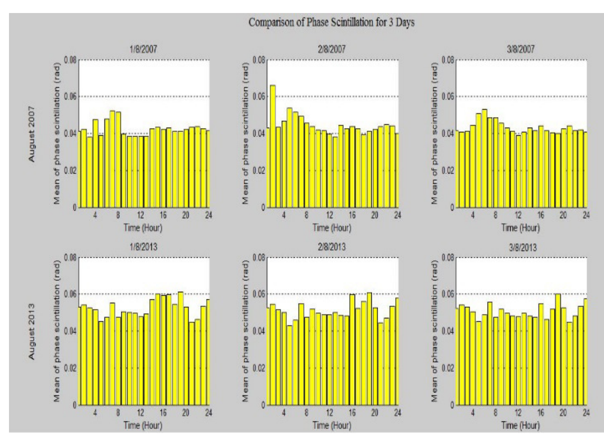

Fig. 3. Comparison of hourly mean σ_ϕ for three days in August 2007 and August 2013.

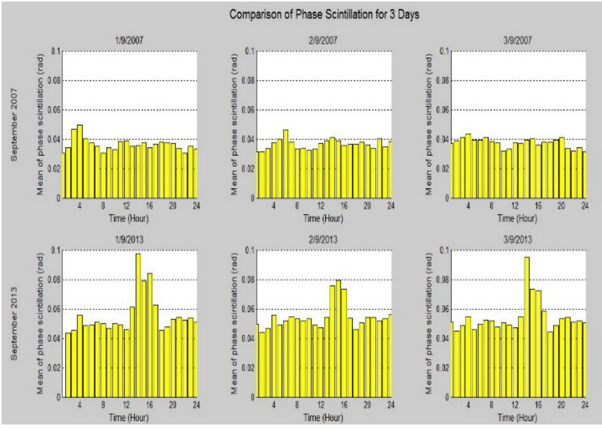

Fig. 4. Comparison of daily mean σ_ϕ for three days in September 2007 and September 2013.

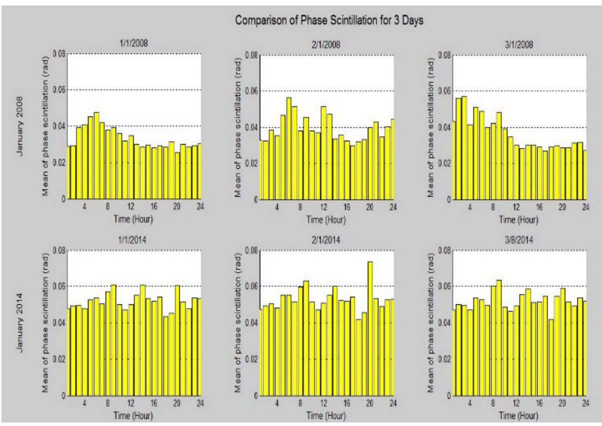

Fig. 5. Comparison of hourly mean σ_ϕ for three days in January 2008 and January 2014.

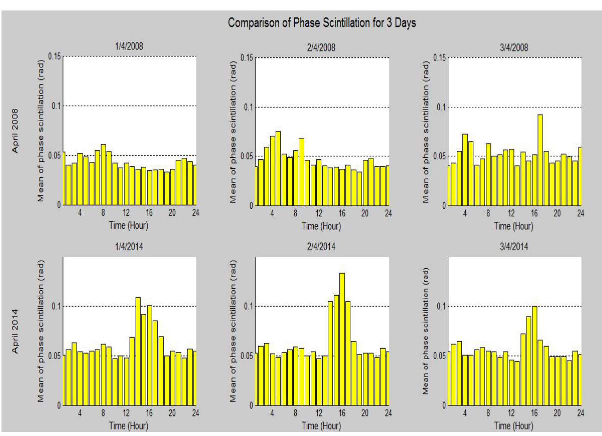

Fig. 6. Comparison of daily mean σ_ϕ for three days in April 2008 and April 2014.

C. Minute mean phase scintillation

Table III presents a summary of the findings for the minute mean σ_ϕ for both high and low solar activities. The highest mean σ_ϕ of 0.470 rad for low solar activity was recorded on 2 August 2007. The highest σ_ϕ value for high solar activity was 0.483 rad, which was observed on 18 December 2013. This high σ_ϕ lasted for a few minutes. As mentioned, K_p indices that were less than 5 represented quiet ionosphere. A study conducted in Jicamarca, Peru (11.9°S, 76.9°W) during high solar activity (November 2012 to June 2013) concluded that the scintillation frequency occurrence was independent of the geomagnetic activity [4].

TABLE I. COMPARISON OF HOURLY MEAN σ_ϕ FOR THREE DAYS DURING LOW SOLAR ACTIVITY

Year	Month	Hourly mean σ_ϕ (rad)	
		Min.	**Max.**
2007	August	0.038	0.066
	September	0.031	0.049
2008	January	0.026	0.057
	April	0.033	0.092

TABLE II. COMPARISON OF HOURLY MEAN σ_ϕ FOR THREE DAYS DURING HIGH SOLAR ACTIVITY

Year	Month	Hourly mean σ_ϕ (rad)	
		Min.	**Max.**
2013	August	0.044	0.061
	September	0.044	0.098
2014	January	0.042	0.073
	April	0.044	0.134

TABLE III. HIGHEST VALUE OF σ_ϕ DURING LOW SOLAR ACTIVITY

Date	σ_ϕ (rad)	Geomagnetic index, K_p
2 August 2007	0.470	1
13 March 2008	0.424	2

TABLE IV. HIGHEST VALUE OF σ_ϕ DURING HIGH SOLAR ACTIVITY

Date	σ_ϕ (rad)	Geomagnetic index, K_p
18 December 2013	0.483	1
25 December 2013	0.418	2
2 January 2014	0.418	2

Another study conducted at Universiti Kebangsaan Malaysia yielded a minimum σ_ϕ of 0.02 rad, whereas the maximum σ_ϕ was 0.2 rad. The study was conducted from January 2010 to September 2010 [5]. The SSN recorded for this period was between 7.9 and 25.2.

The data were compared at the same station (WARAS, UTHM) on February 2009 and February 2014. The phase scintillations (i.e., $0.2 < \sigma_\phi < 0.4$) occurred during the period of high solar activity in February 2014 (SSN: 66–154) for about 0.06% of the time, whereas nothing significant (i.e., $\sigma_\phi >$

0.2) was observed during the period of low solar activity in February 2009 (SSN: 0–9) [6].

V. Concluding Remarks

During the low solar activity period, the minimum monthly mean of σ_ϕ was 0.026 rad, and its maximum value was 0.042 rad. These values increased to 0.051 rad and 0.064 rad, respectively, during the period of high solar activity. The daily mean σ_ϕ in all of the months observed was higher during the period of high solar activity than during the period of low solar activity, except in August 2007. Individual phase scintillations yielded certain values (i.e., > 0.2 rad) both during low and high solar activity periods but showed no dependency on geomagnetic activity.

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