Chapter 2
Analysis of Polar Ionospheric Scintillation Characteristics Based on GPS Data

Lijing Pan and Ping Yin

Abstract Ionospheric scintillation is one of the important factors that affect the performance of satellite navigation system, so ionospheric scintillation monitoring has been drawn more attention. Based on ionospheric scintillation monitoring data at South Pole station in Antarctica, we are able to investigate ionospheric scintillation characteristics over there. Through analyzing scintillation data of 354 days at this site in the year of 2011 we can estimate the statistical occurrence rate of phase scintillation and amplitude scintillation. The temporal, diurnal, monthly and seasonal variations of the characteristics of ionospheric phase scintillation have been studied, as well as the correlation between phase scintillation and geomagnetic disturbance index (Kp). Statistical results show that phase scintillation activities are more pronounced than amplitude scintillation activities at South Pole. The Antarctic ionospheric scintillation were relatively quiet and the phase scintillation index (Sigma phi) with Sigma phi >0.3 took place infrequently only with the occurrence rate of is 0.14 % throughout the year. The occurrence rate of phase scintillation in March, April, September and October is higher than that in other months. The highest occurrence rate is in April and October and the lowest in January. In April, September and October, phase scintillation mainly appeared on the 12–18 UTC, and the different intensities of phase scintillation have a similar time variation characteristics. As shown in the results, higher kp always correlates with stronger phase scintillation.

Keywords Ionospheric scintillation · Antarctica · Statistical analysis · GPS · Sigma phi

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J. Sun et al. (eds.), *China Satellite Navigation Conference (CSNC) 2014 Proceedings: Volume I*, Lecture Notes in Electrical Engineering 303,
DOI: 10.1007/978-3-642-54737-9_2,

2.1 Introduction

The region between 60 and 1,000 km above the Earth's surface, known as the ionosphere, is produced by ionizing radiation. When radio waves propagate through ionosphere, they are refracted, reflected, scattered and absorbed resulting in the loss of energy. Various scales of irregular structures in ionosphere can cause the satellite navigation systems, such as the global positioning system (GPS) signals fluctuate, which is referred to the ionospheric scintillation. Ionospheric scintillation will make greatly influence on the tracking performance of the satellite navigation receivers. It will lead to signal interruption when ionospheric scintillation has a severe interference on communication and the radio broadcast. When the problem gets more serious, it even affects the positioning accuracy and reliability of the satellite navigation system [1]. With the extensive application of space-based satellite communications and navigation systems, the effects of ionospheric scintillation on ground-air communication systems can be effectively avoided or reduced by carrying out monitoring of the ionospheric scintillation. Therefore, monitoring the ionospheric activity and obtained the change law of ionospheric activities are of great significance.

The electron density and Total Electron Content (TEC) of the ionosphere are constantly changing over time and space, so the real-time monitoring is very difficult. By means of the scintillation data measured by the GPS receiver, it is possible to study the characteristics of ionospheric scintillation. Generally, scintillation activity can be roughly divided into three zones: the high latitude regions, low latitude regions and the regions between low latitude regions and high latitude regions [2]. It is shown that the ionospheric scintillation predominates at high latitudes and low latitude equator zone [3]. The ionosphere structure in the low-latitude equatorial regions is unstable due to the magnetic equator Rayleigh-Taylor instability over night, which makes the low-latitude equatorial region become one of the strongest area of the world's scintillation activity [4, 5]. Polar regions connect the Earth geographic pole with geomagnetic pole. The polar ionosphere which has a special physical form and mechanism, connects directly the Earth's magnetosphere and interplanetary space. Occurrence rate of scintillation is high in the polar region. So the research of ionospheric scintillation is more and more important [6, 7].

Currently ionospheric scintillation monitoring mostly focuses on low-latitude equatorial regions, and the scintillation data measured at high latitudes is very little. Foreign study of ionospheric scintillation start early, for a lot of research for the ionospheric scintillation, Hunsucker and others to achieve the ionosphere and its influence on the radio waves propagation to do the research; Spogli waiting for polar ionospheric scintillation research. In this paper, statistical analysis of ionospheric scintillation in Antarctic is made with 3,000,000 data samples over 354 days in 2011. The observed data is taken by a scintillation receiver in the

South Pole Station in Antarctica. The statistical characteristics of ionospheric scintillation in Antarctica region, obtained in the study, will make a certain foundation for a better understanding of ionospheric phase scintillation in this region and for making a model in the future.

2.2 Data and Analysis

Scintillation data for this study is obtained by a scintillation receiver GSV4004 installed in the Antarctica South Pole station (geographic latitude of −90°/magnetic latitude of −74°, geographic longitude 0°). GPS satellites signals have two L-band carrier frequencies, i.e., L1 (1,575.42 Hz) and L2 (1,227.6 Hz). The GSV4004 receiver can receive 11 GPS satellite signals. The main purpose of GSV4004 is to collect ionospheric scintillation data, TEC data of all visible satellites and output data, etc. GSV4004 receiver output two kinds of data, One is a kind of parameter data, computing good S4, sigma phi namely; Another kind is the original data; In this paper, the parameter data [8].

In research of ionospheric scintillation, measure of scintillation intensity index is the amplitude scintillation index S4 and phase scintillation index sigma phi. S4 index is defined as standard deviation of the average of the normalized signal intensity. The index reflects the change in the intensity of the signal amplitude. It is calculated once per minute, which is calculated as

$$S4 = \sqrt{\frac{\langle S_I^2 \rangle - \langle S_I \rangle^2}{\langle S_I \rangle^2}}$$

where, $\langle S_I \rangle$ represents the signal intensity average value. The S4 index in the analysis is the elimination of surrounding noise, which is the correction value of S4. When ionospheric scintillation enhances, S4 index will increase. When S4 index is equal to 1, it is considered as saturation of scintillation in this time. Traditionally, $S4 < 0.3$ is a weak scintillation, and $S4 > 0.6$ is the strong scintillation.

Sigma phi is defined as the standard deviation of the carrier phase in radians. The parameter is obtained by the power spectral density of the carrier phase, which represents the phase change of the satellite signal severity level caused by ionospheric scintillation. The equation is:

$$sigmaphi = \sqrt{E(\phi^2) - E(\phi)^2}$$

where, ϕ is the carrier phase, $E(\phi)$ is expectation of ϕ, outputted by GSV4004 with interval of 60 s.

Table 2.1 Occurrence rate of various levels of sigma phi and S4 of 1 year

Rate Level	Sigma phi (%)	S4 (%)
0–0.1	94.14	97.58
0.1–0.2	5.15	2.34
0.2–0.3	0.57	0.09
0.3–1	0.14	0

2.3 Results and Discussion

Using the data in the year of 2011 from South Pole station, the temporal, monthly and seasonal variations of the statistical characteristics of ionospheric phase scintillation have been studied. Analysis of the occurrence rate between amplitude scintillation and phase scintillation is made. The correlation between phase scintillation index and Kp index is studied in this region. According to the previous experience, the minimum elevation GPS satellites is limited to 20° in order to reduce the effects of multipath and other low-elevation effects.

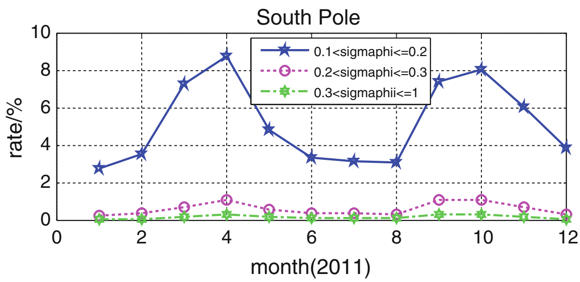
In this paper, according to previous experience about high latitudes ionospheric scintillation observations, actual observations in Antarctica and 2011 as solar activity low activity, the scintillation of sigma phi <0.3 is considered as weak phase scintillation, sigma phi >0.3 for the strong phase scintillation.

Table 2.1 shows the intensity of the different phase and amplitude of occurrence rate in year. The occurrence rate is defined as the ratio of the number of scintillation greater than a specified value in period of time to the number of all scintillation during the same period. As can be seen in the table, the phase scintillation is stronger than the amplitude scintillation. Hence, we focus on analyzing the characteristics of the phase scintillation in the following sections.

2.3.1 Monthly Variations of Phase Scintillation

Figure 2.1 illustrates the monthly occurrence rate of various levels of phase scintillation in the year 2011. As can be seen from the preliminary results of the measured data, scintillation in the year 2011 is mainly weak phase scintillation with sigma phi <0.3, and strong phase scintillation with sigma phi >0.3 has a lower occurrence rate. As can be seen from the figure, scintillation has obvious seasonal variation characteristic and has a peak in spring and autumn, and has a lower rate in winter and summer. The lowest occurrence rate is in January. In February and March, scintillation significantly increases and has a peak in April. The occurrence rate is low in May and June. In September, October, scintillation significantly enhances and get the maximum. Phase scintillation at different intensity has a good consistency.

Fig. 2.1 Month-to-month variability of the occurrence rate of different levels of the phase scintillation



2.3.2 Temporal Variations of Phase Scintillation

Figure 2.2 shows the occurrence rate of sigma phi >0.2 with UTC time from January 2011 to December 2011. The axis represents the phase scintillation occurrence rate. Can be seen from the figure in March to may, From September to November blink rate significantly stronger than the June to August, December to February, March to May, From September to November sigma phi >0.2 twinkle incidence peak appeared in UTC 12–18 UTC in this period of time.

2.3.3 Relationship Between Scintillation Index and the Kp

3-hr Kp index can be used to represent the intensity of geomagnetic disturbances. In order to study the correlation between geomagnetic disturbances and scintillation index in Antarctica, we use 2011 kp value that we obtain from SPIDR database [9] to analyse.

The relationship is analyzed among geomagnetic activity index Kp, ionosphere phase scintillation and occurrence rate of phase scintillation. We all on January to November 2011 Kp value processing, take a day of Kp is greater than a maximum of five data, as the days of ionospheric disturbance index of Kp, from all the Kp value in the statistical data of Kp is greater than 5, and will get Kp's statistics and the corresponding time of sigma phi >0.3 strong flicker frequency and the corresponding flashing incidence trend of correlation analysis. The Kp index and phase scintillation have a good relationship in the Antarctic generally. Six representative days from statistics date of kp >5 are selected to draw the figure of the Kp and phase scintillation with UTC time to do a specific analysis, as shown in Fig. 2.3.

In Fig. 2.3, the histogram plots the change of Kp values with time. The axis is UTC time and the axis is the Kp value. The other plots are the temporal variation of phase scintillation. The axis is the value of sigma phi. The circle represents values of sigma phi of the satellite in that time. As can be seen from the figure, large Kp always corresponds with severe phase value scintillation. It is interesting to note that October 25, strong phase scintillation took place with Kp up to 7.3,

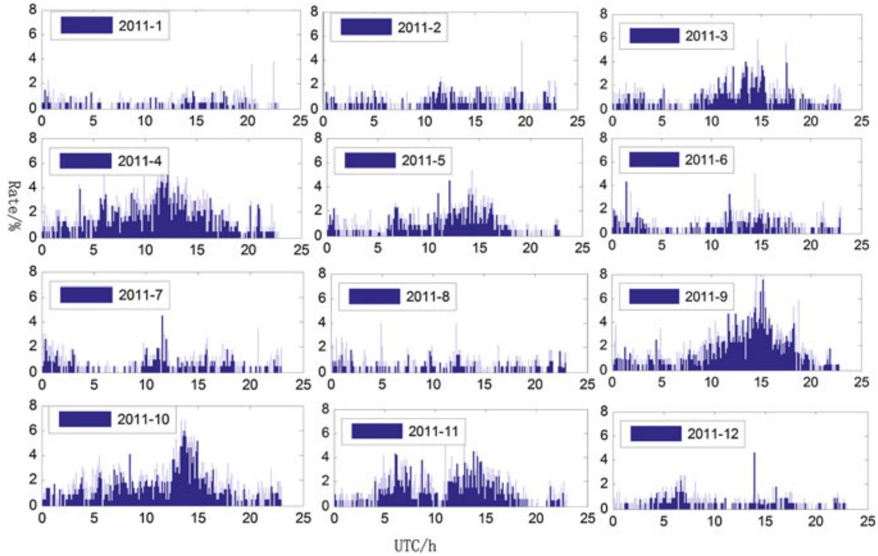


Fig. 2.2 Variability of the occurrence rate of the phase scintillation with sigma phi >0.2

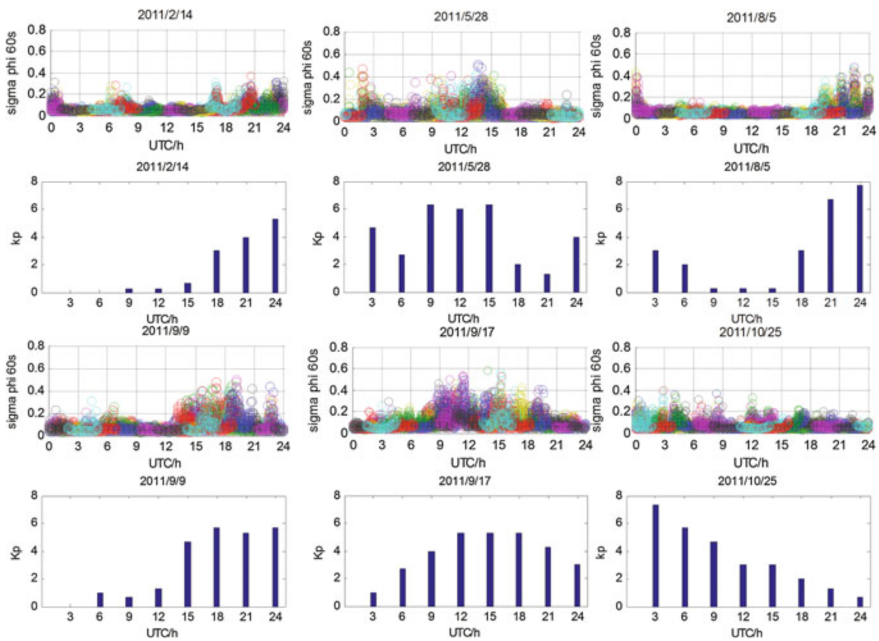


Fig. 2.3 The relationship between the sigma phi and Kp

Table 2.2 The relationship between the sigma phi and Kp

Day	4/2	14/2	1/3	11/3	29/4	28/5	29/5	4/6	5/6	5/8
Kp	5.7	5.3	5.3	5.7	5.3	6.3	5.3	5.3	6.3	7.7
Sigma phi >0.3	16	5	55	13	36	60	13	5	30	39
Rate %	0.15	0.05	0.50	0.12	0.33	0.56	0.12	0.05	0.28	0.36
Day	6/8	9/9	10/9	17/9	26/9	27/9	29/9	24/10	25/10	
Kp	6.3	5.7	5.7	5.3	6.3	5.7	5.7	7	7.3	
Sigma phi >0.3	25	78	12	176	295	17	4	45	13	
Rate %	0.23	0.73	0.11	1.64	2.79	0.16	0.04	0.42	0.12	

however, on September 26 with Kp no more than 7, phase scintillation seems to be more stronger. The underlying mechanism will be our future work (Table 2.2).

2.4 Conclusion

By analyzing GPS scintillation data of 354 days in the year of 2011 at South Pole in Antarctic, a preliminary statistics in Antarctic is made about ionospheric scintillation characteristics and correlation between geomagnetic activity index and phase scintillation index. The results show that phase scintillation is obviously stronger than amplitude scintillation in this region. In 2011, phase scintillation is dominated with weak scintillation of sigma phi <0.3, and the occurrence rate of sigma phi >0.3 is very low, which is the consistent with findings of Spogli et al. [10] research in polar ionospheric scintillation.

Phase scintillation of 0.1< sigma phi <0.2 and 0.3< sigma phi <1 has a significant seasonal variation. The lowest occurrence rate is in January. In February, March, scintillation significantly enhances and peak occurs in April. The occurrence rate of May and June declines. In September, October, scintillation significantly enhances and attaches to the maximum. Scintillation occurred mainly in 1,200–1,800 UTC and this research conclusions are consistent with Spogli et al. [10], Li et al. [11], Gwal and Jain [12].

There is a good correlation between phase scintillation index and Kp. The greater the value of Kp is, the more severe phase scintillation will be. But there is a particular case which is mentioned above, it will be carried out in subsequent Antarctic ionospheric scintillation monitoring and further study.

Acknowledgements In this paper, the data provided by the University of Bath, Professor Mitchell's research group, supported by the United States Siena College. The author is grateful to them. The funding for this issue was provided by the State Department of Education returned Scientific Research Fund.

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