Correlation between ROTI and Ionospheric Scintillation Indices Using Hong Kong Low-latitude GPS Data

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Abstract: The correlation between the rate of TEC index (ROTI) and scintillation indices S_4 and σ_Φ for low latitude region is analyzed in this study, using data collected from a Global Positioning System (GPS) scintillation monitoring receiver installed at the south of Hong Kong for the periods June-August of 2012 and May-December of 2013. The analysis indicates that the correlation coefficient between ROTI and S_4/σ_Φ is about 0.6 if data from all GPS satellites are used together. If each individual satellite is considered, the correlation coefficients are above 0.6 on average and sometimes above 0.8. The analysis also shows that the ratio of ROTI and S_4 varies between 1 and 4. The ratio ROTI/σ_Φ, varies between 2 and 9. In addition, it is also found that there is a good consistency between the temporal variations of ROTI with scintillation activity under different ionospheric conditions. ROTI has a high correlation relationship with scintillation indices on geomagnetically disturbed days or in solar active months. Moreover, the data observed at low elevation angles have weak correlation between ROTI and scintillation indices. These results demonstrate the feasibility of using ROTI derived from GPS observations recorded by common non-scintillation GPS receivers to characterize ionospheric scintillations.

Keywords: Global Positioning System; Ionospheric Scintillation Indices**;** Rate of TEC Index (ROTI); Correlation Analysis

Introduction

Transionospheric radio waves may experience rapid random fluctuations in signal amplitude and/or phase when random electron density irregularities exist in the ionosphere. This phenomenon is usually termed ionospheric scintillation (Aarons 1982). Early studies have indicated that scintillations are most likely to occur near the magnetic equator in the postsunset period, the nightside auroral oval and dayside cusp and the region around the polar cap at all local times (Basu et al. 1988; Béniguel et al. 2009). At equatorial latitudes, the ionospheric irregularities often form plume-like structures extending along the magnetic field lines into altitude of over 1000 km and irregularities within well-developed plumes can cause intense scintillations (Wernik et al. 2003). At high latitudes, the large-scale plasma structures are responsible for ionospheric scintillations (Basu et al. 2002; Li et al. 2010). Ionospheric scintillations cause significant performance degradation for signals in the VHF band to C band, having a great impact on communication and navigation systems (Whitney and Basu 1977; Van Dierendonck 1999; Kintner et al. 2009).

GNSS signals have been considered a powerful tool to study the total electron content (TEC) and TEC variations along the signal paths in the presence of ionospheric irregularities and scintillations associated with these irregularities (Bhattacharyya et al. 2000). For the measurements of ionospheric scintillations, two widely used parameters are the amplitude scintillation index S_4 and phase scintillation index σ_Φ (Kintner et al. 2007). The derivation of these two parameters requires GPS/GNSS scintillation observation data sampled at high frequency (usually 50 Hz or higher). Nevertheless, most GPS/GNSS receivers that are commonly used for GPS/GNSS precise surveying do not provide scintillation data because of their low data rates. For instance, the global real-time GNSS stations managed by the International GNSS Service (IGS) deliver real-time streams at a rate of 1 second only and the non-real-time stations deliver data at an even lower rate (30 second) (Dow et al 2009; Caissy et al 2012). Numerous local, regional, national and international GPS/GNSS networks have been deployed to serve real-time-kinematic (RTK) and other applications. Similar to IGS, these networks normally record data at a rate of 1 second or 30 seconds. If the GPS/GNSS data of low sampling rate can be utilized to study ionospheric scintillations, it will significantly augment the current scintillation observation facilities, which are composed of only very limited number of GNSS monitoring stations with high sampling rate (Aquino et al. 2005; Béniguel et al. 2009; Sreeja et al. 2011; Morton et al. 2014). The huge amount of low-rate GPS/GNSS data will provide invaluable information for researchers to observe the ionospheric scintillations.

In order to statistically present ionospheric irregularities using network-based GPS monitoring system, Pi et al. (1997) proposed an index called rate of total electron content (TEC) index (ROTI) which is defined as the standard deviation of rate of TEC (ROT) over a 5 min period . The adoption of ROTI allows the use of GNSS observations from common GPS receivers, e.g. GPS receivers in the IGS global network, to characterize ionospheric activities. Usually, ROTI > 0.5 TECU/min (1 TECU refers to 10^{16} electrons/m^2) indicates the presence of ionospheric irregularities at scale lengths of a few kilometers (Ma and Maruyama 2006). Considering the coexistence of large and small scale irregularities in equatorial irregularity structures during the early evening hour, Basu et al. (1999) pointed out that ROTI measurements can be used to predict the presence of scintillation causing irregularities. Several studies have also indicated that large and small scale irregularities at scale-size of a few kilometers and several hundred meters can be investigated simultaneously with ROTI and scintillation indices (Zou and Wang 2009; Alfonsi et al. 2011; Seif et al. 2012). Previous studies showed that there are some correlations between ROTI and scintillation indices. By using data from a GPS receiver at Ascension Island (7.93°S, 14.42°W), Basu et al. (1999) found that the ratio of ROTI/S_4 varied between 2 and 10. Li et al. (2007) showed that the ratio of ROTI/S_4 varied between 0.3 and 6 using data recorded at Sanya, China (18.33°N, 109.52°E). This shows that the ratio of ROTI/S_4 varies significantly at different geographical locations. Xu et al. (2007) also showed that there was a remarkable positive correlation between the ROTI and S_4 and the correlation coefficient between them reached 0.97. To examine ROTI and scintillation indices in the polar region, Pi et al. (2013) found that the L1 phase scintillation index σ_Φ and ROTI were well correlated temporally and their correlation coefficient reached 0.763.

Hong Kong, a typical low-latitude region, started to use GNSS-based scintillation monitoring receivers to observe ionospheric scintillations since May 2012 (Xu et al. 2012; Liu et al. 2013). So far only two GNSS-based scintillation monitoring stations have been deployed at the south (22°12′N, 114°15′E) and the north (22°25′N; 114°12′E) of Hong Kong by the Hong Kong Polytechnic University (PolyU). The southern station equipped with an off-the-shelf Septentrio PolaRxS Pro receiver, and the northern station equipped with a customized NovAtel OME IV receiver, were installed in 2012 in collaboration with the Colorado State University, USA, and Wuhan University, China. In Hong Kong, there are however nearly a total of 20 Continuously Operating Reference Station (CORS) operated by the Lands Department of the Government of Hong Kong Special Administrative Region (HKSAR), the PolyU and other organizations. The Lands Department of HKSAR has been operating the Hong Kong Satellite Positioning Reference Station Network (SatRef) since 2000. In addition to the 12 GPS/GLONASS stations in the SatRef network, the Lands Department is currently adding to the SatRef network 6 new stations that have the ability to track satellite signals from the Beidou Navigation Satellite System (BDS). Moreover, researchers at the PolyU have set up a few GNSS stations to continuously record data for various research purposes. Thus the investigation of the relationship between ROTI and S_4/σ_Φ in the Hong Kong region has a twofold significance: (1) making full use of the abundant GNSS data to study the characteristics of ionospheric scintillation; (2) contributing the ionospheric scintillation knowledge gained at a typical equatorial region like Hong Kong to the research community. This work represents the first attempt to study the correlation between ROTI and scintillation indices in Hong Kong.

We analyze 10 months of data collected from the southern scintillation station to study the correlation between ROTI and S_4/σ_Φ. The data from the northern station are not used in this study because our previous study shows that the northern station equipped with a customized NovAtel OME IV receiver has much poor tracking performances under scintillations, compared to the southern station equipped with a Septentrio PolaRxS Pro receiver (Liu et al. 2013).

The next section introduces the data and methodology used in this study. We then present the correlation analysis of ROTI and scintillation indices. Finally, conclusion is given in the last section.

Data and methodology

In this study, ionospheric scintillation data and ionospheric TEC fluctuation data are collected by a GNSS ionospheric scintillation monitoring receiver installed at the Hok Tsui station (22°12′N, 114°15′E; geomagnetic: 12°23′N, 173°34′W). This receiver is capable of recording GPS, GLONASS, and Galileo pseudorange and C/N_0 data at 1 Hz sampling rate, in-phase and quadra-phase data at 100 Hz, and carrier phase measurements at 50 Hz (Liu et al. 2013). The data collected in the periods of June-August 2012 and May-December 2013 are used in the following analysis. There is a data gap from September 2012 to April 2013 due to system outage. In addition, phase scintillation data during the period May-December 2013 are not recorded due to the change of sampling rate of carrier phase measurements. In order to reduce multipath effects, only signals from GPS satellites with elevation angle higher than 30° are taken into account.

From the receiver output data, the amplitude scintillation index S_4 can be calculated as below:

$$S_4 = \sqrt{\frac{\langle SI^2\rangle - \langle SI\rangle^2}{\langle SI\rangle^2}} \tag{1}$$

where *SI* represents the detrended signal intensity and < > represents the average value over the interval of interest. The basic formula of *SI* is,

$$SI = \frac{NBP - WBP}{(NBP - WBP)_{lpf}} \tag{2}$$

where *NBP* and *WBP* are narrow and wide bandwidth power, respectively; $(NBP\text{-}WBP)_{lpf}$ is the low-frequency portion of the *NBP-WBP*. To obtain a stable S_4, $(NBP\text{-}WBP)_{lpf}$ is calculated from the average value of *NBP-WBP* over 1 minute in this study (Van Dierendonck and Arbesser-Rastburg 2001).

The phase scintillation is characterized by the standard deviation σ_Φ of the detrended phase and can be written as:

$$\sigma_\Phi = std(\delta\Phi) \tag{3}$$

where $\delta\Phi$ represents the detrended phase measurements. It should be noted that the sampling rates of the measurements for amplitude scintillation S_4 and phase scintillation σ_Φ calculation in this work are 100 Hz and 50 Hz, respectively.

ROTI, as the standard deviation of rate of TEC, is estimated by dual-frequency GPS data with the time interval of 5 minutes and represented as (Pi et al. 1997),

$$ROTI = \sqrt{\langle ROT^2\rangle - \langle ROT\rangle^2} \tag{4}$$

We estimate ROTI from 1 Hz dual-frequency GPS phase data over 5-minute period. To synchronize with ROTI data, the S_4 and σ_Φ indices derived over one 1-minute period are averaged every 5 minutes. For GPS L1 wavelength experiencing irregularities, the Fresnel scale $\lambda_F = \sqrt{2\lambda z}$, where λ is the free space wavelength of the probing radio signal (0.19 m for GPS L1 signal) and z is the altitude (350 km is assumed), is 360 m. So, a 1 Hz sampling rate is sufficient to capture equatorial irregularities with drifts of the order of 100 m/s (Beach and Kintner 1999).

Results and discussions

For the correlation analysis, we studied the correlations between ROTI and S_4/σ_Φ using data from each individual satellite as well as the amalgamated data from all the satellites. Additionally, the dependence of this correlation on geomagnetic activity and solar activity is analyzed.

Analysis of the ROTI, S_4, and σ_Φ under different scintillation conditions

Fig. 1 shows the ionospheric scintillation results observed from 1 Hz GPS L1 data on 17 June 2012 (Fig. 1) and 15 August 2012 (right panels). The top panels show the elevation angles of all GPS satellites above 30° elevation angle. The variation of ROTI with local time is shown below, followed by panels showing variation of scintillation indices S_4 and σ_Φ. For these two days the ionospheric conditions are different. The sum of Kp index, which is an indicator of the geomagnetic activity level, is 37- on 17 June and 10+ on 15 August. This indicates that the geomagnetic activity was disturbed on 17 June and quiet on 15 August. As shown by the left panels, there exist apparent amplitude scintillations on the disturbed day; enhanced scintillation structures of S_4 and σ_Φ are observed during the pre-midnight and post-midnight hours between 20:30 local time and 00:30 local time. The features of nighttime scintillations are most likely caused by ionospheric F region irregularities (Wernik et al. 2003). It is also obvious that there is a good consistency between the temporal variations of ROTI and the increased scintillation activities. Previous studies also found that nighttime amplitude scintillations at equatorial station always occur with phase scintillations and TEC fluctuations (Zou and Wang 2009; Adewale et al. 2012a). The right panels illustrate non-scintillation activity on the quiet day. In general the S_4 is below 0.2 and there also no rapid TEC fluctuations. The temporal variation of ROTI matches well with those of S_4 and σ_Φ.

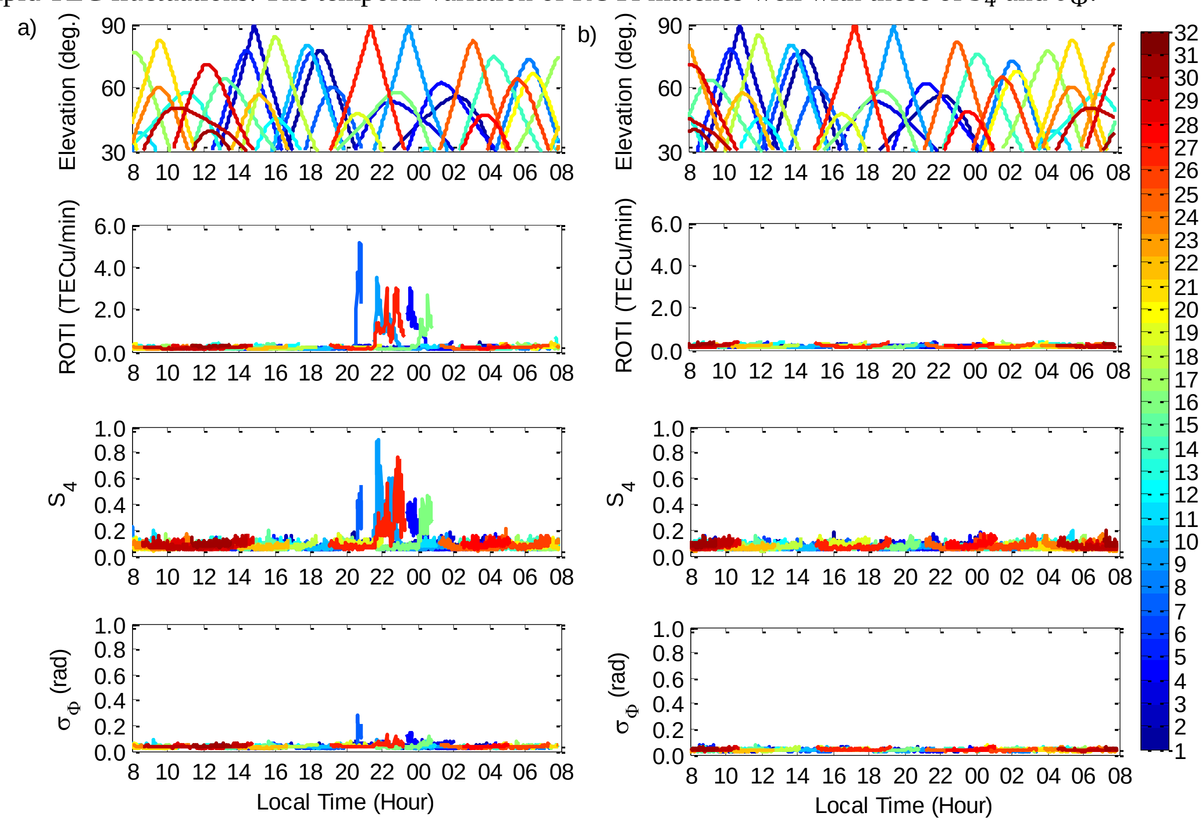

Fig. 1 Time variations of the satellite elevation angle, ROTI, S_4 and σ_Φ indices derived from GPS data collected from Hok Tsui station a) on 17 June 2012 b) on 15 August 2012

Fig. 2 presents scatter plots of ROTI and 5-min averaged S_4 and σ_Φ indices for 17 June 2012 and 15 August 2012. The top panels illustrate the scatter plot of ROTI with respect to S_4. The cases for ROTI with respect to σ_Φ are shown in the bottom panels. The solid lines in each subplot are obtained by a linear regression. To clearly show the relationship of ROTI with scintillation indices, the ROTI values are normalized using ROTI/max(ROTI). This ensures that the value of normalized ROTI is comparable to that of S_4 and σ_Φ. On 17 June and 15 August 2012, the maximum ROTI values are 5.15 TECU/min and 0.53 TECU/min, respectively.

It can be observed from Fig. 2 that the ROTI and scintillation index data show a good correlation, especially on 17 June 2012. The correlation coefficients between the normalized ROTI and S_4 and σ_Φ on this day can reach 0.819 and 0.641, respectively. On 15 August 2012, it is 0.671 between the normalized ROTI and S_4 and 0.541 between the normalized ROTI and σ_Φ. As shown in Fig. 1a, there are enhanced scintillation structures and TEC fluctuations on 17 June 2012. Thus the larger correlation coefficients on this day suggest that the correlation between ROTI and S_4/σ_Φ from all satellites would be stronger under strong scintillation activities. From Fig. 2, it should be noticed that the regression line for normalized ROTI and σ_Φ on 17 June 2012 does not fit the scatter points well. This may be caused by the lower level of phase scintillations relative to that of normalized ROTI between 20:30 local time and 00:30 local time on this day (Fig. 1a). Nevertheless, the correlation between ROTI and σ_Φ on this day is still stronger than that on 15 August 2012. The correlation between ROTI and S_4/σ_Φ from all satellites will be further discussed below.

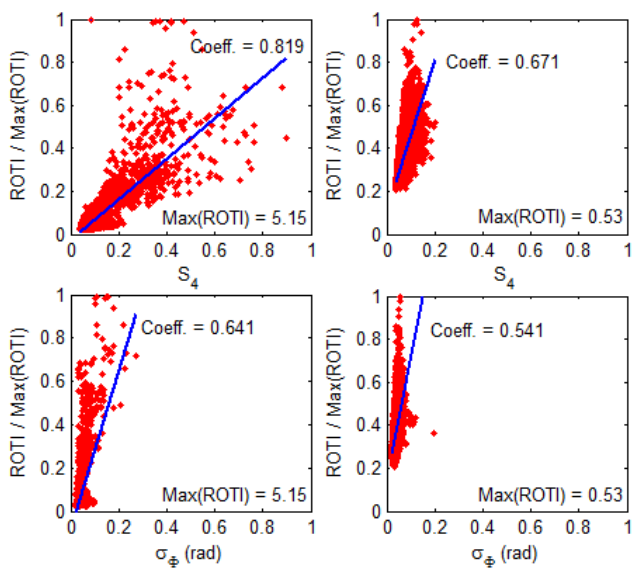

Fig. 2 Scatter plots of ROTI and 5-min averaged S_4 and σ_Φ indices on 17 June 2012 (left) and on 15 August 2012 (right). The solid lines are obtained from the linear regression.

While Fig. 2 shows the correlation between ROTI and S_4/σ_Φ derived from all the satellites observed on 17 June and 15 August 2012, Fig. 3 illustrates the correlation coefficients derived from each individual GPS satellite observed on those two days. It shows that for most satellites, the correlation coefficient between ROTI and S_4 and σ_Φ is higher than 0.6. Additionally, it is found that when there is a strong scintillation event (S_4 or σ_Φ is large), the correlation coefficient between ROTI and S_4 (or σ_Φ) also shows a large value. For example on 17 June 2012, there are enhanced structures of S_4 for the satellites PRN 5, 8, 10, 17 and 28 (Fig. 1a). The correlation coefficients between ROTI and S_4 corresponding to these satellites (Fig. 3) are 0.935, 0.877, 0.879, 0.905 and 0.880, respectively. On 15 August 2012, the correlation coefficients for those same satellites are 0.707, 0.697, 0.721, 0.541 and 0.684, respectively. This indicates that the correlation between ROTI and scintillation indices become stronger when there exists strong scintillation activity. In Fig. 3, the correlation coefficients corresponding to PRN 12 and 32 are very small. It may be caused by the fact that these satellites have very low elevation angle (below 40°). Compared with other satellites, the relatively higher noise in their measurements may lead to weaker correlation between ROTI and scintillation indices.

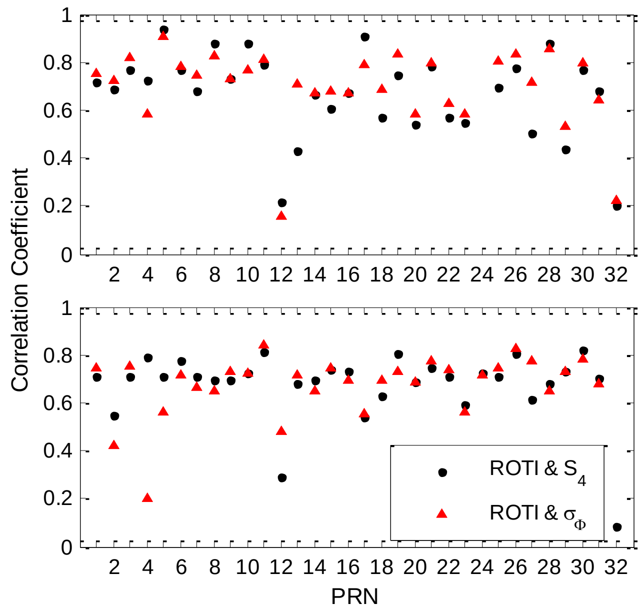

Fig. 3 Correlation coefficients between ROTI and S_4/σ_Φ indices derived from GPS observations corresponding to each satellite on 17 June 2012 (top) and on 15 August 2012 (bottom)

Analysis of daily correlation between ROTI and S_4/σ_Φ collected from all satellites

Fig. 4 illustrates the daily correlation coefficients between ROTI and S_4 for all satellites over the period June to August 2012 and May to December 2013. It clearly shows that the correlation between ROTI and S_4 is strong, with coefficients larger than 0.6 most of the time. During the whole observation period, the coefficients are very stable and consistent. Occasionally, the correlation between ROTI and S_4 becomes very strong and has a value higher than usual. By analyzing the geomagnetic Kp index, it is found that ROTI has a high correlation relationship with S_4 on geomagnetically disturbed days. For instance on 17 June and 26 August of 2012, 16 August and 24 September and 7 November of 2013, which are specified as disturbed days by the Geomagnetic Data Service Center (http://wdc.kugi.kyoto-u.ac.jp/qddays/index.html), the correlation coefficient values have a sharp increase (Fig. 4).

Here, it should be noted that the Kp index monitors the geomagnetic activity on a worldwide scale (Menvielle and Berthelier 1991), so it may not exactly reflect the geomagnetic activity at small-scale regions. In Fig. 4, in order to study the relationship between scintillation activities and the correlation coefficient of ROTI and S_4, the number of S_4 greater than 0.2 in each day is also plotted in the right ordinate. Previous studies show that $S_4 > 0.2$ always indicates non-ignorable scintillation activity (Muella et al. 2008; Zou and Wang 2009). It can be seen that the correlation coefficient increases with the number of $S_4 > 0.2$, indicating that strong scintillation activity may occur with the TEC fluctuations and at the same time they are strongly correlated with each other. In addition, the variation of the number of $S_4 > 0.2$ also shows the dependence of scintillations on geomagnetic activity. As discussed above, on disturbed days scintillation activities become active and ROTI has strong correlation with scintillation indices. These abovementioned results further provide evidence of the dependence of the correlation between ROTI and scintillation indices on geomagnetic activity.

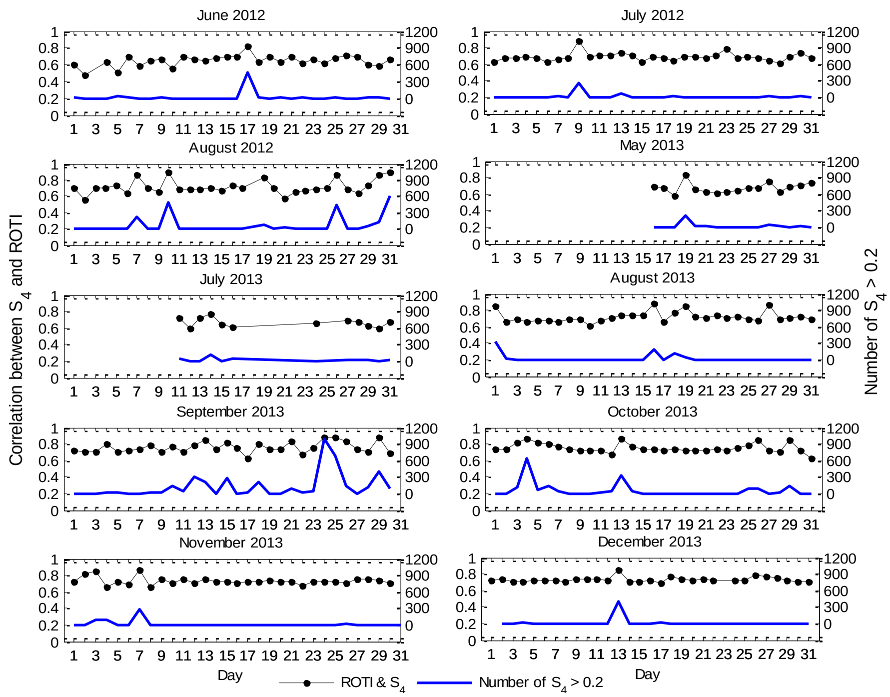

Fig. 4 Daily correlation coefficients between ROTI and S_4 derived from all GPS satellites collected at Hok Tsui station in each month. The number of daily amplitude scintillations with S_4>0.2 is shown in the right ordinate.

Fig. 5 shows the correlation coefficients between ROTI and σ_Φ derived from daily GPS data recorded by all satellites during June to August 2012 and May 2013. The GPS carrier phase data after May 2013 have a low sampling rate, thus they are not suitable for phase scintillation calculation and not used in the data analysis. The number of phase scintillations in each day with σ_Φ greater than 0.1 radian is also displayed in the right ordinate of Fig. 5. Previous study suggests that $\sigma_\Phi > 0.1$ rad (or 6°) could be used to detect scintillation events (Jiao et al. 2013). It can be found that for all satellites, the correlation coefficient between ROTI and σ_Φ is about 0.6. In addition, it is observed that the coefficient becomes larger when the number of events with $\sigma_\Phi > 0.1$ rad increases, especially for August 2012. In the other words, for stronger phase scintillation activities, the ROTI and σ_Φ have higher correlation. Compared to the amplitude scintillations, the correlation between ROTI and σ_Φ is not as strong as that between ROTI and S_4. This may be explained by the observations that phase scintillations are weaker than amplitude scintillations in equatorial regions (Doherty et al. 2003; Gwal et al. 2006). The amplitude and phase scintillation are biased to different irregularity scale sizes from a few kilometers down to a few hundred meters (Prikryl et al. 2015). The amplitude scintillations on GNSS signals are caused by ionospheric irregularities of scale size smaller than the Fresnel radius, which is of the order of hundreds of meters for GPS signals, while the phase scintillations are likely caused by irregularities of scale size of hundreds of meters to few kilometers (Spogli et al. 2009). At equatorial latitudes, the amplitude scintillations are stronger with respect to other latitudes (Basu et al. 2002).

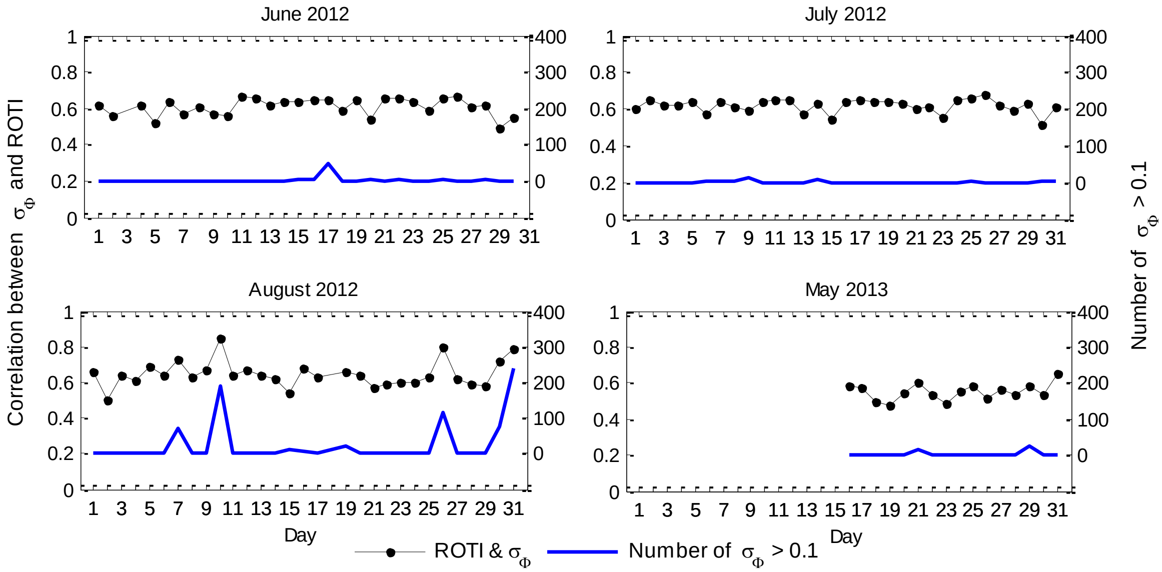

Fig. 5 Daily correlation coefficients between ROTI and σ_{Φ} derived from all GPS satellites collected at Hok Tsui station in each month The number of daily phase scintillations with σ_{Φ}>0.1 is exhibited in the right ordinate.

Analysis of correlation of ROTI and S_4/σ_{Φ} for each individual satellite

In order to analyze the correlation between ROTI and scintillation indices corresponding to each individual satellite, **Fig. 6** shows the correlation coefficients between ROTI and S_4/σ_{Φ} derived from observations of each satellite in each day. The amplitude scintillation data covering the 10-month period are shown in the left panel. The phase scintillation data in the period June-August 2012 and May 2013 are shown in the right panel. From the figure it can be seen that ROTI is highly correlated with scintillation indices. The maximum coefficient even can be up to 0.972. For some satellites such as PRN 2, 12, 13, 29 and 32, the correlation between ROTI and S_4/σ_{Φ} is very weak and the coefficients corresponding to these satellites are below 0.5 most of the time, especially for PRN 12 and 32. As shown in **Fig. 3**, the low correlation between ROTI and scintillation indices of these satellites is attributed to the fact that these satellites are observed at low elevation angles.

In order to further analyze this issue, Fig. 7 shows the maximum elevation angle of each satellite (top panel) and the averages of correlation coefficients between ROTI and S_4/σ_{Φ} derived from each satellite (bottom panel). It should be mentioned that GPS data with elevation angle below 30° have not been used for scintillation analysis. As presented in the figure, it is found that satellites with lower maximum elevation angles have smaller correlation coefficients. For example, the average correlation coefficient between ROTI and S_4 is only 0.257 for PRN 12, and 0.465 for PRN 32. The maximum elevation angles for PRN 12 and 32 are 40.1° and 43.25°, respectively. Regarding the satellites (including PRN 2, 4, 13, 20, 23, 29, 31) with maximum elevation below 60°, their average coefficients are mostly below 0.6. It suggests that the data observed at low elevation angles have weak correlation between ROTI and scintillation indices. In the case of other satellites (maximum elevation above 60°), the average correlation coefficient is above 0.6 and can be as much as 0.8.

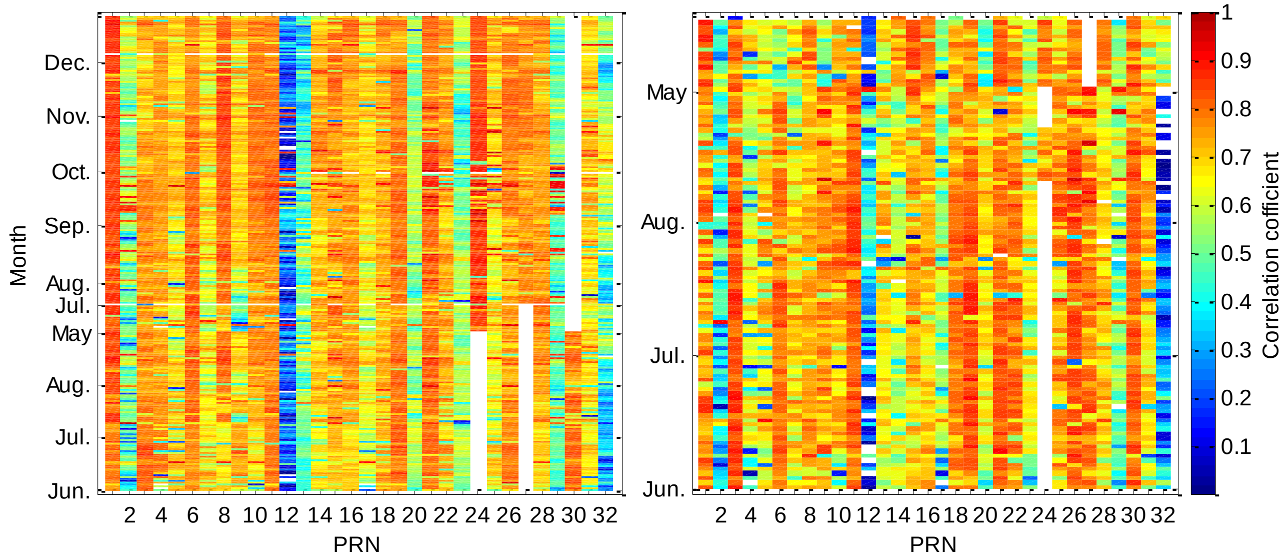

Fig. 6 Correlation coefficients between ROTI and scintillation indices (S_4/σ_Φ) derived from observations of each satellite. Left: ROTI & S_4 during the months of June to August 2012 and May to December 2013; Right: ROTI & σ_Φ during the months of June to August 2012 and May 2013.

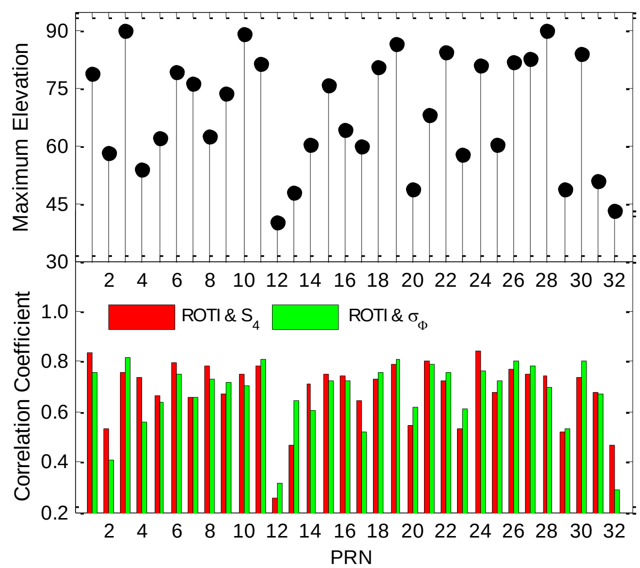

Fig. 7 The maximum elevation angle of each satellite and the average correlation coefficients between ROTI and scintillation indices (S_4/σ_Φ) derived from observations of each satellite.

As a quantitative estimate of ROTI and scintillation indices, the average ratios of ROTI/S_4 and ROTI/σ_Φ are shown in Fig. 8. It can be clearly seen that the ratio of ROTI/S_4 varies between 1 and 4. For ratio ROTI/σ_Φ, the value is about 2 to 9. It has been pointed out that it is difficult to accurately quantify the relationship between ROTI and scintillation indices (Basu et al. 1999; Bhattacharyya et al. 2000). The ratio of ROTI/scintillation indices is mainly controlled by the projected satellite velocity in the ionosphere and the irregularity drift. For different GPS satellites with varying satellite trajectories the projected satellite velocity is different. So even for the same drift speed of ionospheric irregularities, the scale-size of ROTI for different satellites will be different, leading to the difficulty in quantitatively estimating scintillation from an analysis of ROTI. Furthermore, it is found that the ratio ROTI/σ_Φ is larger than that of ROTI/S_4 for all the satellites. This may be related to the relatively weaker phase scintillations at low latitude region in Hong Kong, compared to amplitude scintillations. As discussed in the previous analysis (Doherty et al. 2003; Gwal et al. 2006), the level of phase scintillations in the equatorial region is lower than that of the amplitude scintillations.

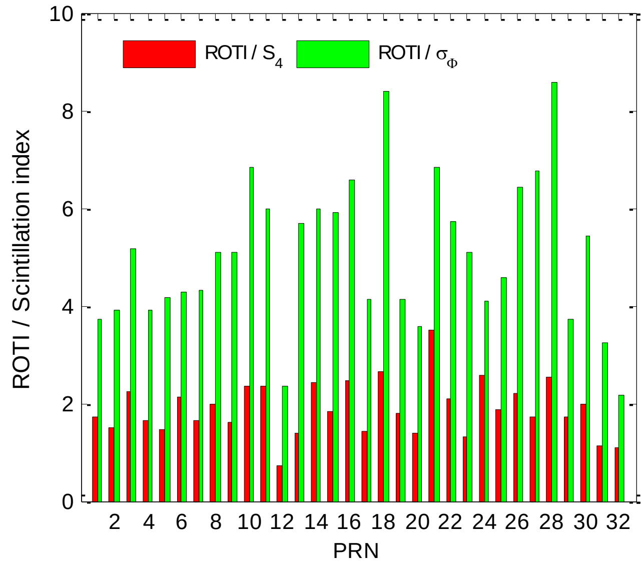

Fig. 8 Average ratios of ROTI/scintillation index (S_4 and σ_Φ**)** derived from observations of each individual satellite.

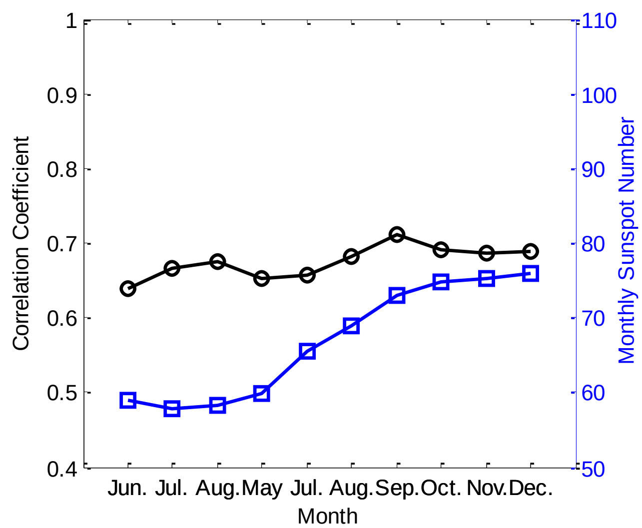

Fig. 9 Monthly mean correlation coefficient between ROTI and S_4 and smoothed monthly total sunspot number over the period June to August 2012 and May to December 2013.

As reported in some previous studies (Akala et al. 2011; Spogli et al. 2013), scintillation activity increases with the rise of solar activity. To examine the solar dependence of the correlation between ROTI and S_4, Fig. 9 shows the monthly mean correlation coefficients between ROTI and S_4 and the smoothed monthly total sunspot number. As there are only 4-month phase scintillation data in this study, the correlation between ROTI and σ_Φ with respect to scintillation activity is not considered here. The monthly mean coefficients are calculated by averaging the coefficients between ROTI and S_4 shown in **Fig. 6** (left panel). Fig. 9 shows that the monthly mean correlation coefficient between ROTI and S_4 is above 0.65 and displays a clear increase trend along the upward trend of solar activities during the 10-month period. It is also found that the correlation becomes stronger in the analyzed equinox month

(September). The mean coefficient reaches the peak of 0.71 in the month of September 2013. At low latitudes, scintillation activity is most pronounced during the equinox months and least during the solstice months (Adewale et al. 2012b; Huang et al. 2014). The largest mean correlation coefficient of September 2013 suggests that the correlation between ROTI and S_4 is strong in the solar active month that has a high level of scintillation activities.

Conclusion

This study investigates the relationship between ROTI and scintillation indices S_4 and σ_Φ by analyzing the ionospheric ROTI and scintillation data collected from a GPS scintillation monitoring receiver installed at the south of Hong Kong for the periods June-August of 2012 and May-December of 2013.

In the analysis of the correlation relationship of ROTI with scintillation indices, if all the GPS satellites data are analyzed together, the correlation between ROTI and S_4/σ_Φ is strong having a correlation coefficient of about 0.6. If each individual satellite is examined, the correlation coefficient between ROTI and S_4/σ_Φ is above 0.6 on average and sometimes they can be above 0.8. Our results also show that there is a good consistency between the temporal variations of ROTI with the scintillation activity under different geomagnetic conditions. The correlation coefficients are generally stable over time but the coefficients get high values in geomagnetically disturbed or active solar activity days. Moreover, our results indicate that low elevation angle satellites generally have a weak correlation between ROTI and S_4/σ_Φ. In addition to the correlation coefficients, the ratio of ROTI to S_4/σ_Φ has also been studied. The ratio of ROTI/S_4 varies between 1 and 4. For the ratio ROTI/σ_Φ, it varies between 2 and 9.

The findings obtained from this study enable us to take advantage of the large amount of GPS data recorded by common GPS receivers (not dedicated for scintillation monitoring) to study ionospheric scintillations. It is expected that the Hong Kong Satellite Positioning Reference Station Network (SatRef) will become a very valuable data source for ionosphere scintillation studies in Hong Kong and low-latitude regions.

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