The possibility of using GNSS quality control parameters to assess ionospheric scintillation errors

Craig Matthew HANCOCK, China, Huib DE LIGT, China, and Xu TANG, China.

Key words: GNSS, Ionosphere, Quality Control, Multipath, Scintillation

SUMMARY

Global Navigation Satellite Systems are affected by a variety of errors that can influence the quality and reliability of the position information calculated using their signals. One of the major sources of error experienced by GNSS signals is caused by the atmospheric effects of the ionosphere. The ionospheric error on GNSS signals is particularly degrading to the quality and integrity of GNSS positions by a phenomena known as ionospheric scintillation. This phenomena is more prevalent at areas close to the magnetic equator as well as close to the Polar Regions. Currently, these effects are primarily studied using specialised ionospheric scintillation GNSS receivers that calculate the effects on the phase and amplitude of the GNSS signals by 2 parameters: S4 and σ_{ϕ}. However, these specialised receivers are more expensive than normal GNSS receiver and the networks that contain these are sparser than existing GNSS networks. The study of this phenomena would therefore be aided if scintillation effects could be investigated both in the past (from archived data sets) and in the future by utilising the huge number of Continuously Operating Reference Stations (CORS) found around the world. In previous studies a possible correlation between quality control parameters that can be calculated using any GNSS receiver and the scintillation parameters S4 and σ_{ϕ} has been noted. This paper uses dedicated scintillation monitoring receivers and normal CORS GNSS network receivers in Hong Kong to investigate the usefulness of using the quality control parameters calculated using TEQC as a method of evaluating the effects of ionospheric scintillation. The results show that there is some agreement between the scintillation and the quality control parameters and that it may be possible to use quality control parameters as a means of assessing ionospheric scintillation effects.

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1. INTRODUCTION

GNSS is the positioning tool of choice for many surveying and navigation based applications. However even though the number of GNSS satellites is increasing and the technology on the satellites is improving there are still many error sources that mean that using GNSS for applications that require high availability and reliability of positions is still difficult (Hancock et al., 2009, Hancock et al., 2016). Ionospheric delay is the largest error source for GNSS systems. This error can often be mitigated through double differencing when using base stations or through modelling techniques when using other methods of processing. One of the most problematic errors caused by the ionosphere is the phenomena known as “ionospheric scintillation”. This phenomena is much more difficult to predict than more common ionosphere related errors and therefore more difficult to mitigate. It occurs more frequently in areas close to the equator and close to the poles than in does at mid-latitudes. In some areas ionospheric scintillation is a serious problem and causes significant and frequent errors on GNSS positions.

Currently Ionospheric scintillations are monitored by networks of specialized receivers that are owned and operated by different organizations around the world. These networks provide scintillation parameters that can be used in mitigation algorithms and to some extent, prediction algorithms to aid in error mitigation. However these specialized receivers are relatively expensive and not currently widely available, particularly in countries with emerging economies. If more standard GNSS receivers could be used to detect and monitor scintillation effects then existing, much denser GNSS networks could be used for monitoring and mitigation of these effects and also possibly used by atmospheric scientists to learn more about the physics of the ionosphere.

The purpose of this paper is to investigate the effects of the ionosphere and in particular ionospheric scintillation on multipath parameters that are produced by the quality control software “TEQC”. The paper shows that there is good agreement between known scintillation events and higher multipath, MP1 and MP2 values. This gives evidence that TEQC parameters (Estey and Meertens, 1999) maybe used within normal GNSS receivers for the detection and mitigation of errors caused by ionospheric scintillation.

2. BACKGROUND

The Ionosphere is one of the largest contributors to GNSS errors. The phenomena known as “Ionospheric Scintillation” has the potential not only to degrade satellite signals, and therefore lead to the degradation of the quality of satellite positioning systems, but also can lead to complete loss of lock on tracked satellites. Over the past few decades this phenomena has been studied extensively. In more recent times investigations of small scale fast irregularities have been carried out using GPS (De Franceschi et al., 2006, Van Dierendonck and Arbesser-Rastburg, 2001) and even more recently GNSS receivers (Sreeja et al., 2011). Ionospheric scintillations can occur anywhere in the world but are much more likely to occur at certain geographic locations. Scintillations are most likely in the Polar Regions at what is known as the auroral zones or close to the Earth's Magnetic equator (±15 magnetic latitude). Ionospheric scintillation can be described using 2 parameters. These parameters are called S4 and σ_ϕ (Van Dierendonck and Arbesser-Rastburg, 2001). σ_ϕ can be written as:

$$\sigma_\phi = \sqrt{E(\delta\phi^2)} \tag{1.1}$$

Where E is the nominal received signal without scintillations and $\delta\phi^2$ represents the scintillation phase. In addition S4 can be written as:

$$S4 = \sqrt{S4_{4T}^2 - S4_{N0}^2}$$

$$= \sqrt{\frac{E(SI^2) - E(SI)^2}{E(SI)^2} - \frac{100}{S/N_0}\left[1 + \frac{500}{19S/N_0}\right]} \tag{1.2}$$

In equation 1.2 S4 is the corrected S4 and $S4_T$ and $S4_0$ are the total S4 and the predicted S4 due to ambient noise. S/N_0 IS THE Signal to Noise Ratio which can be calculated by a GNSS receiver (Van Dierendonck and Arbesser-Rastburg, 2001). From Van Dierendonck and Arbesser-Rastburg (2001) SI is the Signal Intensity and can be calculated from the Narrow Band Power (NBP) and the Wide Band power (WBP) and is shown below:

$$SI = \frac{(NBP - WBP)}{(NBP - WBP)_{lpf}} \tag{1.3}$$

$$NBP \left(\sum_{k=1}^{N} i_k\right)^2 + \left(\sum_{k=1}^{N} q_k\right)^2 \tag{1.4}$$

$$WBP = \sum_{k=1}^{N} (i_k^2 + q_k^2)$$

In this study it is proposed to evaluate the effect of ionospheric scintillation on parameters obtained from the quality control software package TEQC (Estey and Meertens, 1999). The parameters being examined are the multipath values MP1 and MP2. MP1 and MP2 can be represented by the following equations according to Estey and Meertens (1999):

$$MP1 \equiv P_1 - \left(1 + \frac{2}{\alpha - 1}\right) L_1 + \left(\frac{2}{\alpha - 1}\right) L_2$$
$$= M_1 + B_1 - \left(1 + \frac{2}{\alpha - 1}\right) m_1 + \left(\frac{2}{\alpha - 1}\right) m_2 \quad (1.5)$$

$$MP2 \equiv P_2 - \left(1 + \frac{2}{\alpha - 1}\right) L_1 + \left(\frac{2}{\alpha - 1}\right) L_2$$
$$= M_2 + B_2 - \left(1 + \frac{2}{\alpha - 1}\right) m_1 + \left(\frac{2}{\alpha - 1}\right) m_2 \quad (1.6)$$

Where

L_i = phase observable for frequency *i*
P_i = pseudorange observable for frequency *i*
m_i = phase multipath for frequency *i*
$\alpha = \frac{f_1^2}{f_2^2}$

and the bias terms are defined as:

$$B_1 \equiv -\left(1 + \frac{2}{\alpha - 1}\right) n_1 \lambda_1 + \left(\frac{2}{\alpha - 1}\right) n_2 \lambda_2 \quad (1.7)$$

$$B_2 \equiv -\left(\frac{2}{\alpha - 1}\right) n_1 \lambda_1 + \left(\frac{2\alpha}{\alpha - 1} - 1\right) n_2 \lambda_2 \quad (1.8)$$

Romano et al. (2013b) studied GNSS station characterization using data from the University of Nottingham scintillation network (some of the data from the network is available to the public, access is described in Romano et al. (2013a)) with regard to the ionospheric parameters S4 and σ_ϕ as well as the Standard Deviation of the Code Carrier Divergence, that is a known measure of multipath. It was shown in this paper that multipath caused by the surrounding environment, such as buildings and trees close by to the GNSS station have an effect on both S4 and σ_ϕ and therefore multipath has a detrimental effect on one's ability to map ionospheric scintillation. The paper also shows that there is a link between the ionospheric scintillation parameters and multipath. If a link between these parameters can be found then it is possible that MP1 and MP2 values can be used to derive satellite specific weights in the least squares process to mitigate ionospheric errors. Initial analysis of this possibility is presented in Hancock and Zhang (2016) and some promising results were obtained showing agreement between the MP1 and MP2 values from stations in Hong Kong compared with known periods of ionospheric scintillation.

This paper extends that research by directly comparing MP1 and MP2 with ionospheric scintillation parameters also collected in Hong Kong.

3. METHODOLOGY

Hong Kong is located at geographic latitude 22.3°N and longitude 114.2°E approximately. This puts Hong Kong in one of the parts of the world that is most likely to be affected by Ionospheric scintillation. Hong Kong also has a relatively dense GNSS network that is freely accessible through the Geodetic Survey of Hong Kong. The network consists of 15 continuously operating GNSS reference stations (Figure 1).

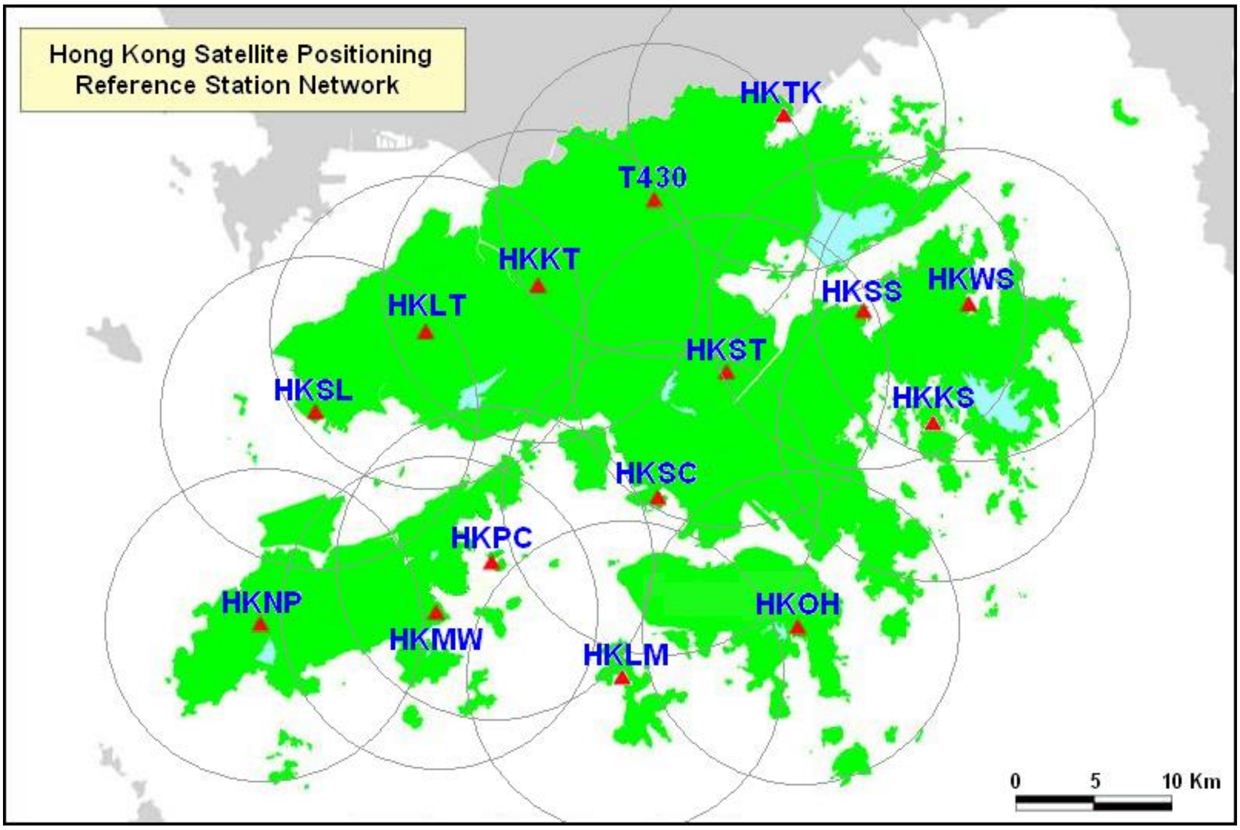

Figure 1 Map showing the CORS network of the Geodetic Survey of Hong Kong

Data from this network has been downloaded for 1 day in 2012 when it is known that scintillation occurred. This day has been chosen using a paper written by Xu et al. (2012) who presented the scintillation events on this days in their paper. The day chosen was the 31st of August 2012. 2 Stations from the Geodetic Survey of Hong Kong have been chosen for this study. Station HKSC and station HKWS.

The RINEX file for both days were processed using the TEQC software using the +qc to produce values of MP1 and MP2 for all epochs and satellites contained within the RINEX files. These values have then been analysed to see if there is a significant increase in the average MP1 and MP2 values during the scintillation events on the specified days.

Level	MP1 or MP2
1	>0.4 – 0.8
2	0.8 – 1.2
3	1.2 – 1.6
4	1.6 – 2.0
5	2.0 – 2.4

Table 1 Definition of Levels for MP1 and MP2 values

In addition to the data from the Geodetic Survey of Hong Kong data from Hong Kong Polytechnic University's ionospheric scintillation monitoring receiver (PolaRxS) has been used to directly compare the ionospheric scintillation parameters with the MP1 and MP2 values from all three stations. This station is named HKHT.

Following the convention in Xu et al. (2012) levels from 0 – 5 have been set for the scintillation parameters to allow the counting of the number of occurrences over a certain time period. Table 2 shows the definition of each level.

Level	S4 and σ_ϕ
1	>0.2 – 0.4
2	0.4 – 0.6
3	0.6 – 0.8
4	0.8 – 1.0
5	>1

Table 2 Definition of Levels for S4 and σ_ϕ values

4. RESULTS AND ANALYSIS

Using the levels defined in Table 1 and Table 2 a comparison has been made between the MP2 values and the σ_ϕ recorded at the station HKHT with a Septentrio PolaRxS GNSS receiver. Both the MP2 and the σ_ϕ values have been divided into 1 hour blocks of data over a 24 hour period on the 31st August 2012. The data has been filtered using a 30 degree cutoff angle to remove the majority of the noise caused directly by multipath. What is noticeable from Figure 2 is that although the σ_ϕ values are noisier (although the levels or MP2 and σ_ϕ are different) the peak in the number of high values (higher levels) is close to 15:00 UTC for both MP2 and for σ_ϕ.

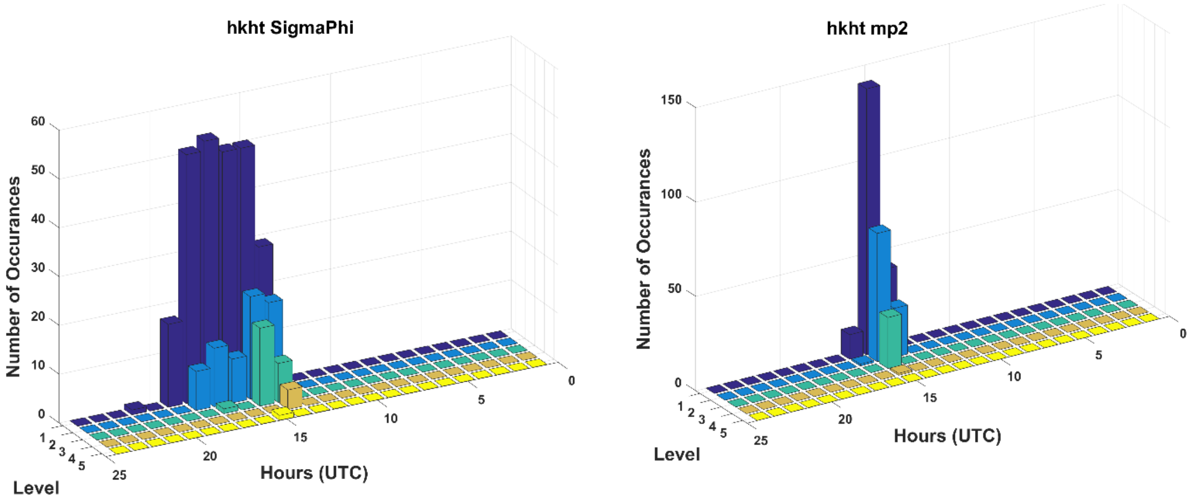

Figure 2 Hourly occurance of different levels (1-5 defined in table 1 and table 2) of σ_ϕ (left) and MP2 (right) at the scintillation monitoring station HKHT in Hong Kong on the 31st August 2012.

It is further noticeable that the vast majority of MP2 and σ_ϕ values during the 31st of August don't get high enough to register as Level 1 apart from during the time that scintillation is occurring.

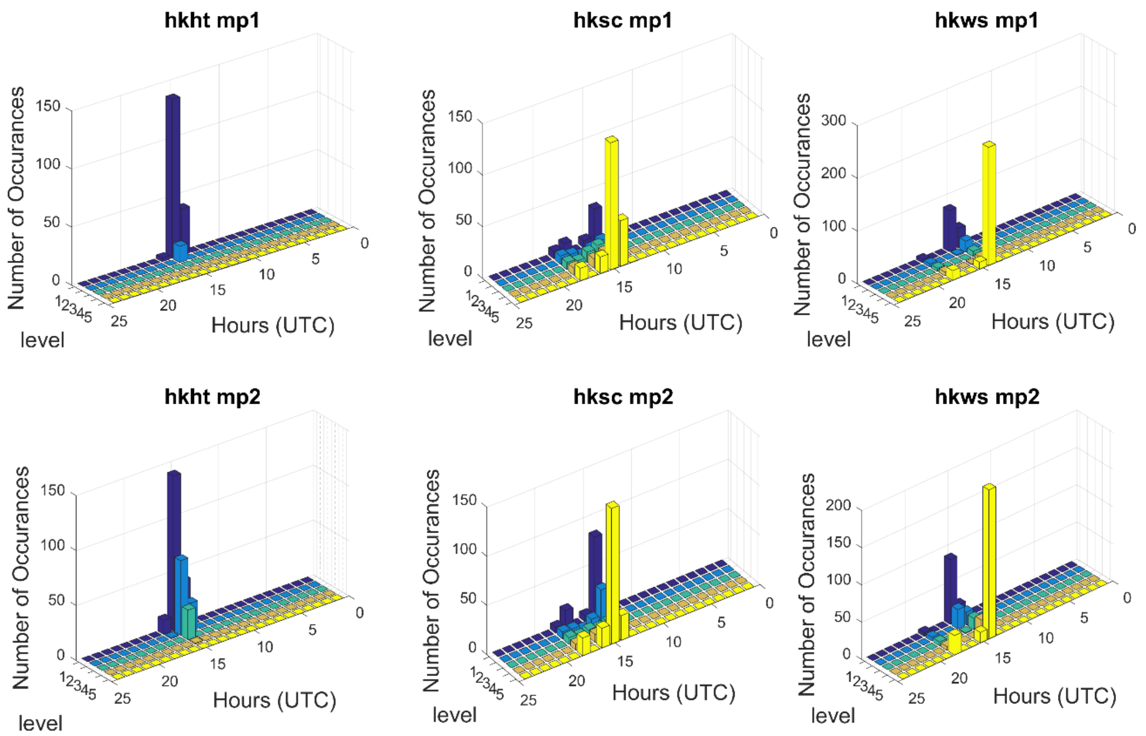

Figure 3 Hourly occurance of different levels (1-5 defined in table 1) of MP1 (top) and MP2 (bottom) at the stations HKHT (left), HKSC (centre) and HKWS (right) in Hong Kong on the 31st August 2012.

To further investigate the possible relationship between MP1 and MP2 with scintillation 2 other stations from the Hong Kong Geodetic network were used to calculate MP1 and MP2 to compare with the MP1 and MP2 values calculated from the scintillation monitoring station (which have already been shown to have some agreement with MP2 values at HKHT). The data was again divided into blocks of 1 hour and then into levels described in table 1 and table 2. It is noticeable that the hour from 14:00 UTC to 15:00 UTC contains the highest values of MP1 and MP2 on all 3 stations. Before 13:00 UTC none of the hour blocks show any data higher than level 0. Also after 19:00 UTC none of the blocks show values higher than level 0. Only during the time that scintillation is known to be occurring are the MP1 and MP2 values at all 3 stations higher than level 0.

Figure 4 shows a more detailed comparison of MP1 and σ_ϕ from the station HKHT for one satellite (PRN15) from approximately 12:00 UTC to 17:00 UTC. Figure 4 shows that PRN15 begins to be effected by scintillation at the start of the time series (evidenced by the relatively higher values of σ_ϕ when comapred to values after approximately 14:30). It can be seen that there is good agreemnet between MP1 and σ_ϕ, particularly around the peak σ_ϕ error around 14:00 UTC. It is also noticelable that after 15:00 UTC the average values of both MP1 and σ_ϕ are lower than from 12:00 – 15:00.

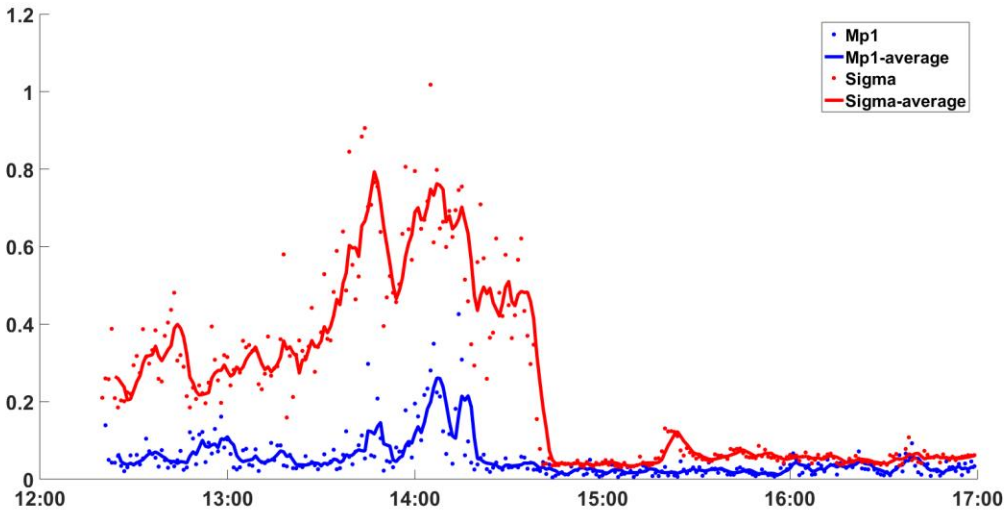

Figure 4 A comparision of σ_ϕ (left) and MP1 on satellite PRN 15 at HKHT on 31st August 2012

5. CONCLUSION

This investigation of the agreement between quality control parameters from TEQC and the ionospheric scintillation parameter σ_ϕ shows some promising results. The results show that during times of ionospheric scintillation (measured by an ionospheric monitoring scintillation receiver a PolaRxS) that the MP1 and MP2 values measured using normal Geodetic GNSS CORS stations in Hong Kong also show an increase. A direct comparison of the MP1 and σ_ϕ on PRN 15 shows good agreement on an epoch by epoch basis. Due to these preliminary results may be possible with further research to utilize MP values from dense GNSS networks to monitor and mitigate ionospheric scintillation in areas susceptible to this phenomena.

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