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ScienceDirect

Advances in Space Research 56 (2015) 2552–2562

ADVANCES IN SPACE RESEARCH (a COSPAR publication)

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GNSS data filtering optimization for ionospheric observation

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Received 28 May 2015; received in revised form 29 September 2015; accepted 1 October 2015
Available online 8 October 2015

Abstract

In the last years, the use of GNSS (Global Navigation Satellite Systems) data has been gradually increasing, for both scientific studies and technological applications. High-rate GNSS data, able to generate and output 50-Hz phase and amplitude samples, are commonly used to study electron density irregularities within the ionosphere. Ionospheric irregularities may cause scintillations, which are rapid and random fluctuations of the phase and the amplitude of the received GNSS signals.

For scintillation analysis, usually, GNSS signals observed at an elevation angle lower than an arbitrary threshold (usually 15°, 20° or 30°) are filtered out, to remove the possible error sources due to the local environment where the receiver is deployed. Indeed, the signal scattered by the environment surrounding the receiver could mimic ionospheric scintillation, because buildings, trees, etc. might create diffusion, diffraction and reflection.

Although widely adopted, the elevation angle threshold has some downsides, as it may under or overestimate the actual impact of multipath due to local environment. Certainly, an incorrect selection of the field of view spanned by the GNSS antenna may lead to the misidentification of scintillation events at low elevation angles.

With the aim to tackle the non-ionospheric effects induced by multipath at ground, in this paper we introduce a filtering technique, termed SOLIDIFY (Standalone OutLiers IDentIfication Filtering analYsis technique), aiming at excluding the multipath sources of non-ionospheric origin to improve the quality of the information obtained by the GNSS signal in a given site. SOLIDIFY is a statistical filtering technique based on the signal quality parameters measured by scintillation receivers. The technique is applied and optimized on the data acquired by a scintillation receiver located at the Istituto Nazionale di Geofisica e Vulcanologia, in Rome. The results of the exercise show that, in the considered case of a noisy site under quiet ionospheric conditions, the SOLIDIFY optimization maximizes the quality, instead of the quantity, of the data.

Keywords: Ionospheric scintillations; Multipath; GNSS; Filtering technique

1. Introduction

In the last two decades, the interest in ionospheric scintillation on L-band signals is growing fast, as it can seriously affect many technological systems and services relying on GNSS signal accuracy. Scintillations are rapid and random fluctuations of the phase and amplitude of trans-ionospheric radio signals. This effect occurs when radio waves encounter electron density irregularities in the ionosphere that act as wave scatterers as a result of the fluctuations of the refractive index.

Scintillation is most intense around ±15°/20° of magnetic latitude, and in the auroral and polar cap regions of both hemispheres (see, e.g. Basu et al., 1988; Kintner et al., 2009). In these ionospheric areas electron density

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http://dx.doi.org/10.1016/j.asr.2015.10.002
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irregularities often form, because of the intense solar irradiation and of the solar wind-magnetosphere coupling (see, e.g. Kelley, 1989).

The investigation of fast small-scale irregularities causing radio scintillation can be carried out with special GNSS receivers outputting signal amplitude and phase at a high rate, such as 50 Hz (see, e.g. De Franceschi et al., 2006; Van Dierendonck, 2001). Although this sampling frequency is useful to investigate transient ionospheric effects, it cannot distinguish the scintillations caused by ionospheric irregularities from multipath due to physical obstacles (buildings, trees, etc.) that may be present in the environment surrounding the receiver antenna, causing diffusion, diffraction and reflection in the signals.

A Procedures able to remove short and long term effects due to environmental multipath are challenging to be implemented, because no quantities directly measured by the receiver can separate ionospheric from environmental effects on the signal.

To overcome this issue, it is commonly adopted in the literature to filter out the observations below an arbitrary threshold on the elevation angle (α_{elev}), typically 15°, 20° or 30°. Such cut off is arbitrary, not physical, site independent and not standard. Moreover, this selection is often made at data acquisition level and not at data analysis level, leading to a definitive loss of scintillation data.

Therefore, in order to improve the quality of a GNSS site, it is necessary to identify and remove the contribution of the local environment that contaminates the scintillation measurements or, at least, to mitigate its effects, by wisely filtering the data sample.

We start from the first step towards a new filtering technique proposed by Spogli et al. (2014), which we then test and refine while analyzing the data collected by a GNSS receiver located at the headquarters of the Istituto Nazionale di Geofisica e Vulcanologia in Rome.

The site has been chosen because it is weakly affected by the ionosphere (on average quiet at mid-latitudes), but located in an urban context, where many sources of environmental multipath are present.

Hence, to optimize the previous filtering technique and to pinpoint the non ionospheric effects induced by multipath at ground, we implemented the SOLIDIFY (Standalone OutLiers IDentIfication Filtering analYsis) technique.

Thanks to an incisive discussion about outliers definition, to an extensive test of the signal quality parameters measured, and to a photographic and telemetric analysis of the Rome receiver antenna location, SOLIDIFY is able to give data-driven indications to efficiently remove measurements affected by multipath. In agreement with the general theory of statistical data analysis (see, e.g. Barnett and Lewis, 1995), here we consider as outliers the values of the signal quality parameters that are distant from the bulk of the distribution, i.e. values that lie in the tail(s) of the considered distributions.

SOLIDIFY is based upon the Ground Based Scintillation Climatology (GBSC) and upon a site characterisation technique inspirited by the work reported by Romano et al. (2013). The GBSC is a data analysis technique that was introduced to map ionospheric irregularities producing scintillations over long-term periods and on selected areas (Spogli et al., 2009; Alfonsi et al., 2011).

This paper is organized as follows: Section 2 introduces the data analyzed in the study, Section 3 describes the method adopted to implement SOLIDIFY, optimizing and testing different signal quality parameters by using the statistical filtering technique; Section 4 presents the results of the investigation; whereas, summary and concluding remarks are given in Section 5.

2. Data

The data analyzed in this study have been acquired by a GISTM (GPS Ionospheric Scintillation and TEC Monitor) receiver located in Rome, Italy (receiver ID NSF01, geographic coordinates: 41°49′N, 12°30′E) from January 2013 to December 2014. The GISTM consists of a NovAtel GSV4004 dual frequency receiver owned by the University of Nottingham and hosted by Istituto Nazionale di Geofisica e Vulcanologia. The GISTM generates phase and amplitude at 50 Hz and code/carrier divergence at 1 Hz for each satellite being tracked on the GPS L1 frequency. The receiver provides the following parameters measured on GPS signals:

- Phase scintillation index (σ_Φ), calculated on the L1 over time intervals of 1, 3, 10, 30 and 60 s;
- Amplitude scintillation index ($S4$), calculated on the L1 over 60 s;
- TEC (Total Electron Content) and ROT (Rate of TEC change) every 15 s from L1 and L2;
- Code to Carrier Divergence (CC) and its standard deviation (CCSTDDEV), calculated on the L1 over 60 s;
- Carrier to noise ratio (CN) on L1 and L2, every 60 s;

Since its deployment in 2012, the Rome GISTM receiver is set to acquire data only for observations made at $\alpha_{elev} > 5°$. In this paper, we have selected two years of data to propose a filtering method able to identify long-term effects based on a large statistics. During the selected period, the data are available for 50% of the days. Despite this limitation in the data availability, we decided to use such sample because the receiver is located in a quiet ionospheric environment and characterized by the easiness in accessing the antenna for the photographic and telemetric analysis. The data availability is described in Fig. 1, which presents the monthly percentage of available data in 2013 (blue histogram) and in 2014 (red histogram).

Fig. 2 shows the percentage of the spatial data coverage considering the full dataset 2013–2014, obtained applying no threshold on the elevation angle (a) and with a