Available online at www.sciencedirect.com
ScienceDirect
Advances in Space Research 38 (2006) 2478–2484
ADVANCES IN SPACE RESEARCH
(a COSPAR publication)
www.elsevier.com/locate/asr

Ionospheric effects on GPS positioning

Smita Dubey *, Rashmi Wahi, A.K. Gwal

Space Science Laboratory, Department of Physics, Barkatullah University, Bhopal, MP 462026, India

Received 1 November 2004; received in revised form 3 July 2005; accepted 8 July 2005

Abstract

Ionospheric scintillation results from a single frequency global positioning system (GPS) receiver have been presented in this paper. Ionospheric scintillation is rapid variation in the amplitude and phase of radio signals caused by irregularities in the ionosphere. Ionosphere contains large amplitude variations over spatial scales from few cm to 100s of km. It is observed that VHF–UHF communications as well as automated navigation and precision positioning via GPS are affected by scintillations.

Scintillations do not have major effects on mid latitude regions, but low latitude scintillations are the greatest cause of GPS position errors. In the present work, we study the effect of ionospheric scintillations on GPS signal at low latitude station, Chiang Rai, Thailand. The data were analyzed from January 2001 to December 2001. Results show that scintillation has a significant problem at this latitude and position error increases during active scintillation condition, which causes loss of lock on several satellites.

Keywords: Ionospheric scintillation; Irregularities; GPS

0. Introduction

In the absence of the international degradation of the global positioning system (GPS), standard positioning service known as selective ability (SA), the ionosphere represents the largest source of positioning error for the users of the GPS. The main constraint on the use of space based system like GPS arises from the medium of propagation, particularly the ionosphere. Transionospheric signals from GPS are perturbed in two ways: (a) introduction of an error in the estimated range by group delay of the signal and (b) fluctuations in the signal characteristics caused by irregularities in the electron density distribution of the ionosphere.

The irregularities cause severe fluctuations known as scintillation in the signal strength. The positioning accuracy capability of GPS has been degraded by the presence of ionospheric scintillation caused by small-scale irregularities. Since fluctuations present additional stresses to the GPS receiver tracking loop and can induce cycle slips or even complete loss of lock, so this phenomenon becomes a major issue for navigational applications.

The scintillation at low latitude is primarily controlled by the generation and growth of irregularities over the magnetic equator. After sunset when the eastward electric field is enhanced, the equatorial F-region irregularities are generated by Rayleigh–Taylor instability mechanism (Dungey, 1956; Basu et al., 1978; Tsunoda, 1981; Kelley, 1989). Ionospheric scintillation, the most significant manifestation of such disturbances, often takes place in equatorial and auroral region.

It is well known that ionospheric scintillation has the potential to affect all types of GPS receivers. When a radio wave propagates through a medium containing plasma structures, the signal suffers amplitude and phase fluctuations from VHF to L-band mainly near the geomagnetic equator (Aarons, 1982; Basu et al., 1988). These fluctuations of the radio signals are known as

* Corresponding author. Tel.: +91 0755 2677722.
E-mail address: smitadubey@yahoo.com (S. Dubey).

0273-1177/$30 © 2005 COSPAR. Published by Elsevier Ltd. All rights reserved.
doi:10.1016/j.asr.2005.07.030

scintillations. The strongest L-band scintillation with signal fades of about 20 dB occurs during solar maximum years, at ±15° dip latitude, i.e., in the equatorial anomaly regions during post sunset period (Aarons, 1982; Basu et al., 1988). Weak or strong levels of scintillation can produce disruptions of the communication and navigation links that use low or high altitude orbiting satellites. The impact of scintillation on GPS navigation has generated a new impetus in view of the increasing reliance on satellite-based positioning systems in critical application (Kinter et al., 2001).

Woodman and LaHoz (1976) were the first who detected this plume-like structure in electron density distribution at Jicamarca. These structures give rise to intense scintillations at VHF and UHF (Basu et al., 1977). The plumes development, predominantly showing backscatter irregularities up to 800 km, produce amplitude scintillations. Within ±5° of the magnetic equator 6–7 dB peak-to-peak fluctuations at 1.5 GHz occur (Aarons, 1993). Several workers have studied the formation and dynamics of these ionospheric bubbles and plumes (Aarons et al., 1980; Basu et al., 1983).

Radio scintillations due to the presence of moving irregularities in the ionosphere is a major problem in Navigation applications using GPS and in satellite communication, SATCOM, especially at low latitudes, the problem being particularly acute around equatorial anomaly peak region. The resulting amplitude and phase distortions of the wavefront may cause degradation performance in GPS receivers. The decrease in amplitude and the stress due to phase fluctuations may degrade the performance of various tracking loops. Ionospheric scintillation affects positioning, communication, space tracking and surveillance system at low latitude.

This paper presents the study of ionospheric scintillation and its effects on GPS positioning.

1. Ionospheric scintillation monitoring and methodology

Using an ionospheric scintillation monitor (ISM) single frequency receiver, scintillation activity was monitored at Chiang Rai (lat. 19.57°N, lon. 99.52°E), Thailand. The ISMs are based on Novatel GPS single frequency ($L1$) receiver, which has been modified to process raw data, sampled at 50 Hz and calculate various parameters, which characterize the observed scintillation. This receiver is configured to measure amplitude and phase scintillation at the $L1$=1.57542 GHz from January 2001 to December 2001. The ISMs record processed data automatically at 1-min intervals throughout the day. The measured parameters are the amplitude scintillation index ($S4$), phase scintillation index ($\sigma_{\Delta\phi}$), latitude and longitude in degree. Amplitude scintillation monitoring is traditionally accomplished by monitoring the index $S4$. The $S4$ index is derived from detrended signal intensity of signals received from satellites. Signal intensity is actually received signal power, which is measured in a way that its value does not fluctuate with noise power. Thus, it cannot be based upon signal-to-noise density or ratio.

$S4$ measured at L-band needs to have the effects due to ambient noise being removed, since the ambient noise at the L1 frequency translates to a relatively high $S4$ at lower frequency VHF and UHP frequencies. The $S4$ values are normally computed over 60-s intervals. In the ISM, values are stored on a file and displayed for each satellite along with the storage and display of the phase data as described earlier. This is referred to as the Total $S4$ (or $S_{4\mathrm{T}}$). The normalized $S4$ index, including the effects of ambient noise, is defined as follows (Van Dierendonck et al., 1993):

$$S_{4\mathrm{T}} = \sqrt{\frac{\langle P^2\rangle - \langle P\rangle^2}{\langle P\rangle^2}}. \tag{1.1}$$

Unfortunately, the total $S4$ defined in Eq. (1.1) can have significant values simply due to ambient noise. The amplitude measurements are filtered using a low pass filter (LPF) and the effects of ambient noise removed from the $S_{4\mathrm{T}}$. Since this index would be used in practice by scaling to predict amplitude scintillation at lower frequencies, such as VHF and UHF, any value due to noise at $L1$ can swamp out low amplitude scintillation that scales to significant levels at VHF and UHF. Thus, it is desirable to remove, as well as one can, the effects of ambient noise. This can be done by estimating the average signal-to-noise density over the entire evaluation interval (60 s), and using that estimate to determine the expected $S4$ due to ambient noise. This is legitimate since the amplitude scintillation fades do not significantly alter the average signal-to-noise density over a 60-s time interval. Note from Eq. (1.1) that $S4$ is simply the square root of the normalized variance of signal power. If the signal-to-noise density (S/N) is known, then the predicted $S4$ due to ambient noise is

$$S_{4N_0} = \sqrt{\frac{100}{S/N_0}\left[1 + \frac{500}{19S/N_0}\right]}. \tag{1.2}$$

Thus, by replacing the S/N_0 with the 60 s, we obtain an estimate of the $S4$ due to noise S_{4N_0}. Subtracting the square of this value from the square of Eq. (1.1) yields the revised value of $S4$.

$$S_4 = \sqrt{\frac{(P^2) - (P)^2}{(P)^2} - \frac{100}{S/N_0}\left[1 + \frac{500}{19S/N_0}\right]}. \tag{1.3}$$

When there is no scintillation the value under the radical may go slightly negative.

Phase scintillation monitoring is traditionally accomplished by monitoring the standard deviation, $\sigma_{\Delta\phi}$, and