Mid-latitude field-aligned ionospheric irregularities and its impact on GPS

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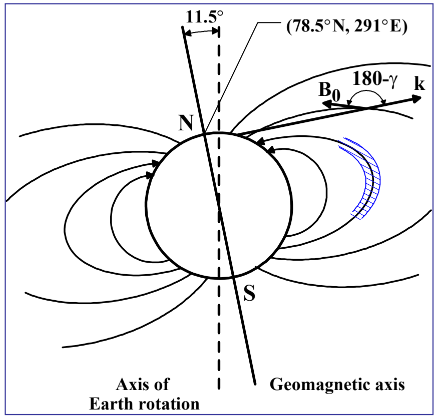
Introduction

Strong scintillations of amplitude and phase of transionospheric radio signals occur due to signal scattering on intensive small scale irregularities. Scintillation can have an adverse effect on GPS signals and cause a GPS receiver to lose lock on the signal in some extreme cases. Although the plasma bubble is a common phenomenon and it has been studied for years, precise observed data of ionospheric scintillations and loss of lock to GPS receivers due to plasma bubble at mid-latitude are still limited. In most papers there are no data regarding the space geometry of field-aligned irregularities. For the first time, we propose a GPS method to detect mid-latitude field-aligned irregularities (FAIs) by line-of-sight angular scanning regarding the local magnetic field vector. We show that total GPS L2 phase slips over Japan during the recovery phase of the 12 February, 2000 geomagnetic storm (Ma and Maruyama, 2006, doi:10.1029/2006GL027512) were caused by GPS signal scattering on FAIs for the line-of-sight of both aligned to magnetic field line (the region of aligned scattering, FALS), and across it (the region of across scattering, FACS). Our FALS results confirm well with data of investigation of magnetic field orientation control of GPS occultation observations of equatorial scintillation during detailed LEO CHAMP, SAC-C and PICOSat measurements, realized by Anderson and Strauss (2005, doi:10.1029/2005GL023781).

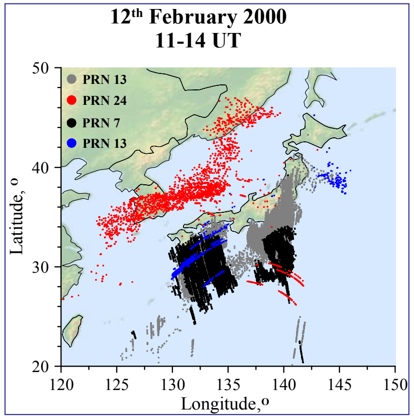
Technique

We carried out our analysis for all the GEONET GPS receivers (~1200). The data we used are available in the standard RINEX format with 30 sec sampling intervals. The standard GPS technology allows to detect L2 slips by analyzing Loss-of-lock indicator and presence of L2 measurements in RINEX files. Also, we determined the azimuth α_s and the line-of-sight (LOS) elevation θ_s between a GPS site and a satellite for all L2 slips.

On the first leg, for all slips we determine the coordinates of the subionospheric point at an altitude ***hmax*** in the geographical coordinate system. Then we calculate the magnetic field line direction at the altitude ***hmax*** over the subionospheric point ***Si*** by using the International Geomagnetic Reference Field model IGRF-10 and determine the angle γ between the vectors "satellite-receiver" and ***B*** . Then, we calculate the histograms N(γ) of L2 phase slips dependent on the angle γ value.

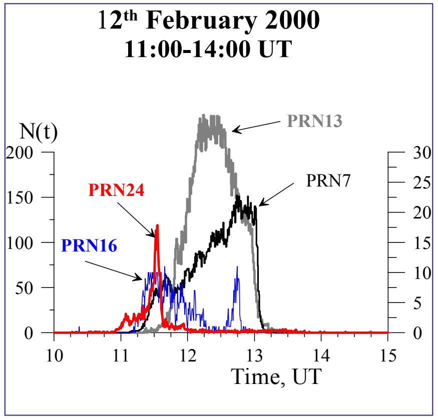


Scheme of calculating the angle γ between ray "satellite GPS – receiver" and magnetic field vector. For calculations we chose 350 km as ionosphere altitude and calculated local magnetic field vector using IGRF-10.

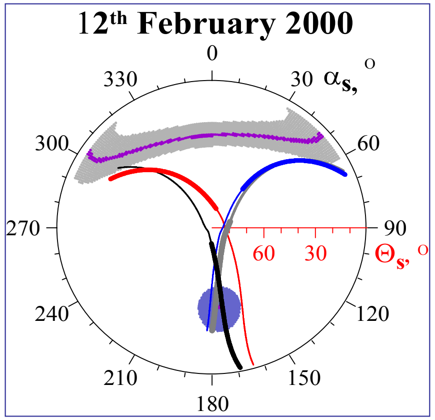


Map of subionospheric points corresponding to registered L2 phase slips. We show data for 4 satellites (PRN13, 24, 7, 13) during 11:00 - 14:00 UT.

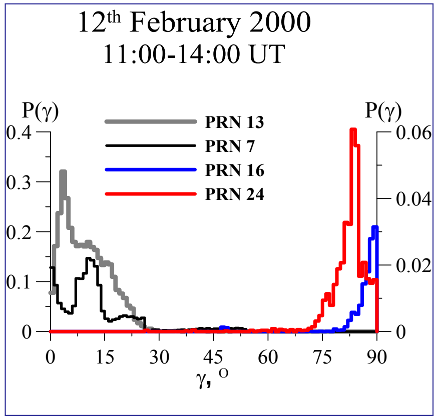
Analysis of the data from GPS satellites with maximal number of L2 phase slips



Time dependence of the number of receivers registered L2 phase slips. The number of slips ***N(t)*** increases abruptly (up to 230 receivers for PRN 13) in ten minutes. The total number of receivers is ~1200.

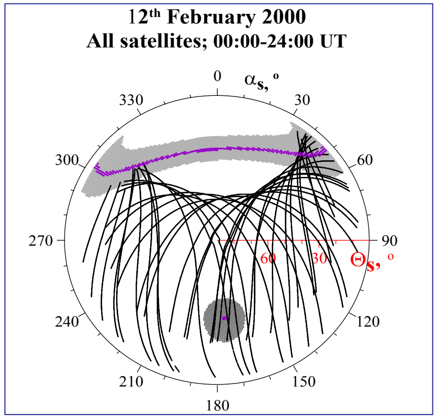


Trajectories of subionospheric points in the coordinate system «elevation-azimuth». Bold lines mark time interval 11-14 UT when maximal amounts of slips were registered. Blue field is the magnetic zenith region. Grey field is the magnetic normal region.

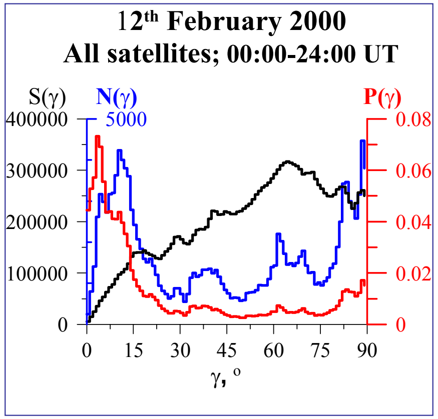


Normalized numbers of slips for satellites PRN7, 13, 16, 24. For satellite PRN13 the number of slips reached 33 %. One can see increasing number of slips in the regions of magnetic zenith and magnetic normal.

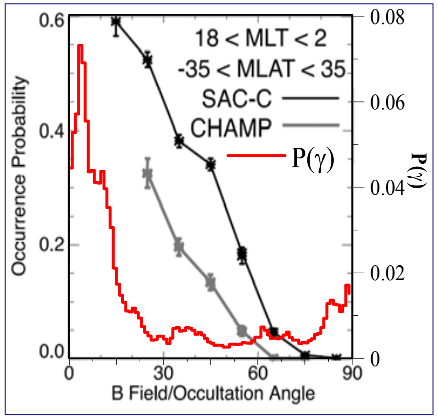
Total slips statistics



Trajectories of all satellites observed in the middle of Japan 12 February 2000. Small part of them went through regions of magnetic zenith or magnetic normal. Nevertheless most of slips corresponded to these very regions.



Total number of measurements ***S(γ)***, number of slips ***N(γ)***, normalized number of slips P(γ) against to γ. When GPS signal propagate across magnetic field line the number of slips increase up to 1.5% (background level is 0.5%), and when along magnetic field line P(γ) increases up to 7%.



Comparison between our normalized distribution **P(γ)** obtained from GEONET data, with the occurrence frequency of oscillations with maximum S4 greater than 0.09 versus the angle between the occultation ray path and the magnetic field from CHAMP measurements (from Anderson and Straus, 2005)

Conclusion

1. For the first time, we suggest a GPS method to detect mid-latitude field-aligned irregularities by line-of-sight angular scanning relative to the local magnetic field vector. We show that the total GPS L2 phase slips over Japan during the recovery phase of the 12 February 2000 geomagnetic storm (Ma and Maruyama, 2006) were caused by GPS signal scattering on FAIs both for the line-of-sight aligned to the magnetic field line and across the magnetic field line.

2. It was shown that there is increasing of numbers of slips in both the magnetic zenith region and magnetic normal region. The number of receivers registered L2 phase slips is about 6-7%, but for some satellites it is up to 30 %. Our results for magnetic zenith region are in good agreement with the data on investigation of magnetic field orientation control of GPS oscillations. For explanation of the results in magnetic normal region special investigation are necessary.

Acknowledgments

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