omagnetic Activity and GPS Anomalies at High Latitud

Adam Jacobs (Millersville University), Robert Steenburgh (NOAA SWPC)

Abstract

Many government, commercial, and public interests rely on accurate Global Positioning System (GPS) coordinates. Errors in GPS coordinates originate from a variety of sources including geophysical phenomena. These error sources, particularly ionospheric scintillation, have been studied in detail at low latitudes. This study explored the relationship between high latitude geomagnetic activity and signal degradation. Eight Alaskan National Geodetic Survey (NGS) Continuously Operating Reference Stations (CORS) of varying latitudes were selected. We focused on two types of GPS anomalies: cycle slips and positioning errors. These data sets were generated from RINEX formatted files using a software collection called GPS Toolkit (GPSTk). Planetary geomagnetic index data and geomagnetic index data from the College International Geophysical Observatory near Fairbanks, AK was obtained for this work. A strong correlation between GPS cycle slips and the daily College A-index data emerged. Neither the daily A-indices, nor the three hourly College K-index, exhibited an obvious direct or lagged correlation with three hourly median GPS position errors. Future work will be directed towards examining the data with finer temporal granularity

Introduction

The GPS signal is vulnerable to solar and geomagnetic activity. High speed streamers in the solar wind and Coronal Mass Ejections (CMEs) cause perturbations in the Earth's magnetic field. Depending on whether the plasma has a southward Bz, a substantial amount of energy can be released through reconnection, causing an increase in particle precipitation and ionospheric structure. This ionospheric structure will be composed of plasma bubbles and blobs, which contain large gradients in total electron content (TEC). A good indication of where ionospheric structure and GPS errors will occur is the location of the auroral oval. These discontinuities cause diffraction and refraction of electromagnetic waves, which in turn cause phase shifts and amplitude variation in the GPS signal. These rapid shifts in phase and amplitude are called scintillation. GPS cycle slips occur when the phase shift exceeds the bandwidth of a receiver's phase lock loop (PLL) the receiver loses lock . Positioning errors can occur as a result of scintillation as well (Fig 1).

Figure 1: (*Left*) A coronal mass ejection from the sun meets the Earth's magnetopause. (Center) A schematic diagram showing the network of GPS satellites. (*Right*) A depiction of scintillation and group (psuedorange) delay due to passage of the GPS signal through a plasma bubble in the ionosphere.

Data Used

Data was obtained from eight Alaskan GPS reference stations. Geomagnetic data was obtained from the College International Geophysical Observatory near Fairbanks Alaska (Fig. 2). We used the GPStk software package developed at the University of Texas, Austin to process the raw RINEX files from the GPS stations. Daily and 3-hourly median error and daily cycle slip data were processed from the software output. We used daily A-index and 3-hourly K-index data from College. The K-index represents the maximum fluctuations in the horizontal magnetic field components relative to a quiet day, during a three hour interval. The A-index is the daily average of the eight "equivalent three hourly" (a-index) values which have been converted nonlinearly from the K-index values. We collected these data types for 2003 and 2008 (active and quiet years).

Figure 2: (Left) Aerial view of the College International Geophysical Observatory. (Right) Locations of the eight Alaska GPS reference stations where data was obtained and analyzed from, including the location of College.

Results

We started by comparing the GPS cycle slip data with the daily College A-index data. A strong correlation was found between the two data sets. The strongest correlation was found at the Fairbanks station. The likely cause for this is the proximity between College and Fairbanks. The best separation between 2003 and 2008 data occurred with the PUO1 GPS data. The worst correlation and separation between years occurred with the TSEA station. One possible cause of this is that this station is one of the southern most stations. Most of the station at higher latitudes showed better correlations. Looking at the daily median error and daily A-index time series, the peaks in errors seemed to agree well with the geomagnetic events (Fig. 3).

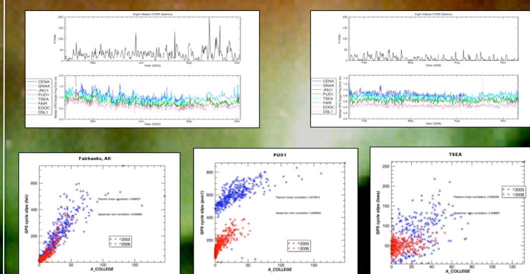

Figure 3: (Top Left) Time series plots of the daily A-index and daily median positioning error for all eight stations in 2003. (Top Right) Time series plots of the daily A-index and daily median positioning error for all eight stations in 2008. (Bottom Left) Plot of Fairbanks daily cycle slip number vs. the College daily A-index. (Bottom Center) Plot of PUO1 daily cycle slip number vs. the College daily A-index. (Bottom Right) Plot of TSEA daily cycle slip number vs. the College daily A-index.

After finding the strong correlation in cycle slip data we moved on to analyzing positioning error data. It was here that we increased the granularity to 3-hourly. For the daily max error, daily median error, and 3-hourly median error, we calculated the Pearson and Spearman correlation coefficients. These data sets were extremely less correlated with the geomagnetic data (Fig. 4). The 3-hourly median error data set had almost no correlation.

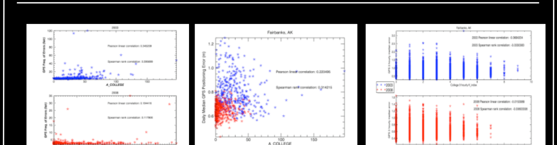

Figure 4: (Left) Plots of the College daily A-index vs. the daily max GPS position error. (Center) Plot of the College daily A-index vs. the daily median GPS position error. (Right) Plots of the College 3-hourly K-index vs. the 3-hourly Fairbanks median GPS position error. Pearson and Spearman correlation coefficients are included.

Due to the loss of correlation strength going from cycle slip data to positioning error data, we pursued the possibility that there was noise overshadowing the relationship between GPS positioning errors and geomagnetic activity. We planned to plot several histograms to analyze the distribution of errors. If there happened to be an outer ring of higher frequency we would have taken the values just from this ring and done more correlations. This outer ring did not show up, and the noise that we saw in the data ended up not being separable using this method (Fig. 5). Zooming in on the 3-hourly median error plot we also saw there was no consistent lag present during a sequence of substantial geomagnetic ev

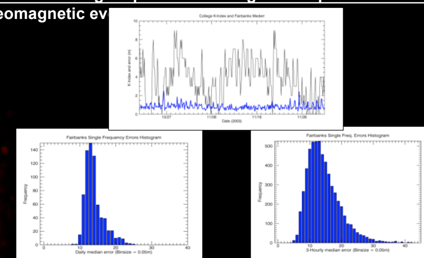

Figure 5: (Top) Zoom in of the 2003 Fairbanks 3-hourly median error vs. 3-hourly K-index from College plot. (Bottom Left) Histogram using the daily median error data at Fairbanks. (Bottom Right) Histogram using the 3-hourly median error data at Fairbanks.

Future Work

Further work can be done with the current data sets. Since the ionosphere takes time to respond to geomagnetic activity, better results may be found using running and weighted averages of the K-index data. There is also a hint of seasonal variability in the daily median position error time series. This possible seasonal cycle should be pursued. Isolation and analysis of elevated error periods can also be done. Incorporation of auroral oval location and intensity data can then be done. The data sets of choice would most likely be POES data and subsequent hemispheric power data (Fig. 6). This could then be compared to the GPS error data and checked for a stronger correlation. Whether or not a stronger correlation is found the GPStk software package provides many possibilities for generating different data sets to compare to either ionospheric or geomagnetic index data. One of these possibilities is an elevation mask which would exclude the use of satellite data below a certain elevation angle on the horizon.

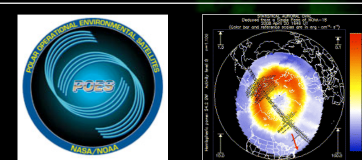

Figure 6: (Left) The POES project logo. (Right) Plot of POES data using the FROTO software package and IDL.

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