Eye on the Ionosphere: Correction Methods for GPS Ionospheric Range Delay

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INTRODUCTION

Selective Availability (SA), the intentional degradation of the accuracy of the single-frequency GPS position by the DoD, ended over one year ago, on 2 May 2000. Now the major source of potential range delay for single frequency GPS users is the ionosphere, as described by Kunches and Klobuchar (2001). The ionospheric range delay on GPS can be corrected in several different ways. This column discusses these various methods and their approximate levels of correction capability.

CORRECTING FOR IONOSPHERIC RANGE DELAY

Left uncorrected, GPS *slant* pseudorange errors due to TEC can be on the order of 20–30 meters. In fact, the *vertical* ionospheric range delay in the southwestern CONUS reached over 40 meters during two recent large geomagnetic storms, a region where monthly average *vertical* range delay values are typically of the order of only 10 meters.

There are five different methods of correcting for the effects of ionospheric range delay. Each of these methods will be discussed, along with the relative difficulty in implementing the correction. The methods yield the following approximate corrections:

0%: No attempt to correct for ionospheric range delay. This is a trivial case, but is included for the sake of completeness. Even a "constant" correction for each "season" and location, with no diurnal dependence, would be a considerable improvement over this "do nothing" case.

50%: Use the Ionospheric Correction Algorithm (ICA) designed to correct for approximately 50%, (r.m.s.), of the ionospheric range delay. This is the standard correction used by virtually all single frequency GPS receivers. The coefficients for the ICA are transmitted as part of the satellite message and are updated at least once each ten days by the GPS Master Control Facility, or more often if there are significant changes in the five-day running mean solar radio flux during the ten-day period. The ICA is limited to only 8 coefficients due to GPS message length limitations (Klobuchar, 1987).

75%: Use a state-of-the-art ionospheric model, requiring hundreds of coefficients, but which will fit the monthly average behavior of ionospheric range delay to within a residual bias of approximately 10%. Typical models are the International Reference Ionosphere, (IRI) and the Bent model. Both models are available over the Internet. Use of such models still leaves the GPS user to contend with the remaining day-to-day variability of approximately 20–25%, and the consequent approximate 22–27%, one σ error when the bias in knowledge of the monthly mean is included. Note that this level of correction still does not use any near-real-time inputs, but relies only on a state-of-the-art model to more accurately describe the monthly average ionospheric behavior than the ICA that only uses 8 coefficients. Thus, by increasing the number of coefficients from 8 to several hundred, the improvement goes from approximately 50% to approximately 75%, r.m.s.

90%: Use the WAAS ionospheric corrections that are transmitted as part of the WAAS augmentation message. This greatly improved correction provides near-real-time ionospheric range delay data obtained from a network of WAAS Reference Stations that are used to generate a grid of equivalent ionospheric range delay corrections at 5° by 5° latitude and longitude grid points over the coverage region. The improvement by using actual near-real-time ionospheric data comes at a cost of requiring a single-frequency GPS receiver that is also capable of receiving the WAAS message. The estimated correction of only 90%, even with using near-real-time range delay data, is due to the need to interpolate from the 5° by 5° grid values of vertical ionospheric range delay provided by WAAS to the equivalent slant range delays along the line of sight to each GPS satellite being monitored by the user.

99%: Use a dual-frequency receiver to remove essentially all the ionospheric range delay along the path to each GPS satellite being monitored. This method

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directly measures the line of sight slant ionospheric range delay along each GPS satellite path, and involves no model computations, and no interpolation from range delay values measured along another path. It is by far the best correction technique to use, and should become the standard for all civilian GPS users when the new L5 frequency is fully implemented on future GPS satellites, likely by sometime in the second decade of the 21st century.

Each of the above percentage correction levels comes with a penalty of some sort, the zero correction, of course, has the penalty of having the largest errors, and the 99% correction has the obvious higher cost of requiring a dual frequency GPS receiver. Using the ICA to correct for approximately 50% r.m.s. of the ionospheric range delay error has only a small penalty as the equations for its implementation are given in the Interface Control Document ICD-200, and it is the standard procedure used in single-frequency GPS user receivers.

CONCLUSIONS

Now that selective availability has been turned off, the ionosphere is the largest potential error source for single-frequency GPS users. The best method of automatically correcting for ionospheric range delay is to use a dual-frequency GPS receiver to directly measure the ionospheric range delay along the path to each GPS satellite. Using the near-real-time range delay measurements provided by WAAS yields an approximate correction of 90%, while the use of any non-updated model is limited to how well the monthly mean ionosphere can be modeled, which is an approximate 75% correction, r.m.s.

The specification of the term "r.m.s." doesn't take into account that there will be occasional large departures from the monthly mean conditions produced by large geomagnetic storms. Models that are not updated with an actual measured range delay, nearby both in time and in space, cannot reasonably expect to correct for these large departures from average conditions, but there are various prediction services, the NOAA, Space Environment Center for example, that provide predictions of times when large departures from monthly average ionospheric range delay conditions are likely to occur.

REFERENCES

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