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Session 1B Paper 3

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The Impact of the Ionosphere on WAAS at Low Latitude

Radio signals emitted from satellites in a global navigation satellite system (GNSS) experience delay as they propagate through the ionosphere. This delay affects the accuracy of position estimates derived from measurements of these signals. The ionosphere is, in fact, the largest source of GNSS positioning error.

To enable the use of GNSS signals for aircraft navigation, satellite-based augmentation systems (SBAS) have been implemented to enhance the accuracy, availability, continuity, and integrity of user position estimates based upon GNSS signals. Over North America, the augmentation of the Global Positioning System (GPS) for aircraft navigation is provided by the Federal Aviation Administration's Wide Area Augmentation System (WAAS).

WAAS measures the delay encountered by signals propagating from GPS satellites to multiple, dual frequency receivers distributed in a network of thirty-eight reference stations. WAAS derives from these measurements an estimate of the vertical delay, designated the ionospheric grid delay (IGD), at each point on an ionospheric grid covering North America, where grid points are generally spaced at 5˚ intervals. Perhaps more important, WAAS also calculates at each IGP a safety-critical integrity bound called the grid ionospheric vertical error (GIVE). In the derivation of the GIVE, the formal estimation error of the vertical delay is inflated to protect the user from the influence of well-sampled ionospheric irregularities as well as from the consequences of undersampling. By using geostationary satellites to broadcast the values of IGDs and GIVEs derived at regular intervals, WAAS allows the user to correct the error in his or her position estimate due to ionospheric delay and to bound the remaining estimation error with a high degree of confidence.

The broadcast IGDs and GIVEs are calculated from fits of slant delay measurements converted to estimates of vertical delay using the standard thin-shell model of the ionosphere. The fit at each ionospheric grid point (IGP) incorporates those measurements whose ionospheric pierce points (the points where the signal raypaths each cross a shell height of 350 km) lie nearest the IGP in question. The vertical delay estimate at the IGP is derived assuming a local planar model. At mid-latitude, the planar model has generally been found to provide accurate delay estimates except under storm conditions. At low latitude (e.g., within 20˚ of the geomagnetic equator), however, the presence of the equatorial anomaly can render the assumed planar model highly inaccurate. The WAAS user is protected from the influence of the equatorial anomaly by the imposition of a relatively large floor on the values that the GIVE may assume at various low-latitude IGPs.

The next upgrade of the WAAS ionospheric threat model, i.e., the tables of numbers from which the GIVEs are derived, will be based upon an improved set of historical measurements. In particular, it will include data from solar cycle 24 that were not available when the current threat model was generated. Preliminary analysis has concluded that these new data will cause a degradation in WAAS availability unless the algorithm used to define the threat model is modified. It has been proposed to use the GIVE floor at each IGP to exclude threats from the threat model that are covered by the GIVE floor. (Currently the user is protected from such threats both by the GIVE floor and by the threat model.) Such an algorithm is expected to restore and possibly improve the level of availability currently achieved by WAAS. To implement this algorithm, it is necessary to examine carefully where the planar fit model fails to represent accurately the variation of the local vertical delay near an IGP.

This paper presents a quantitative discussion of the geographic distribution of error in vertical ionospheric delay calculated over North America, that is incurred by assuming a local planar model at all latitudes. It then examines the implications of these results for the construction of the next WAAS ionospheric threat model.

Acknowledgements

The research of Lawrence Sparks was performed at the Jet Propulsion Laboratory/California Institute of Technology under contract to the National Aeronautics and Space Administration and the Federal Aviation Administration. The research of Eric Altshuler was performed at the Sequoia Research Corporation under contract to Zeta Associates Incorporated and the Federal Aviation Administration.