

# **Ionospheric Research Issues for SBAS – Summary of A White Paper**

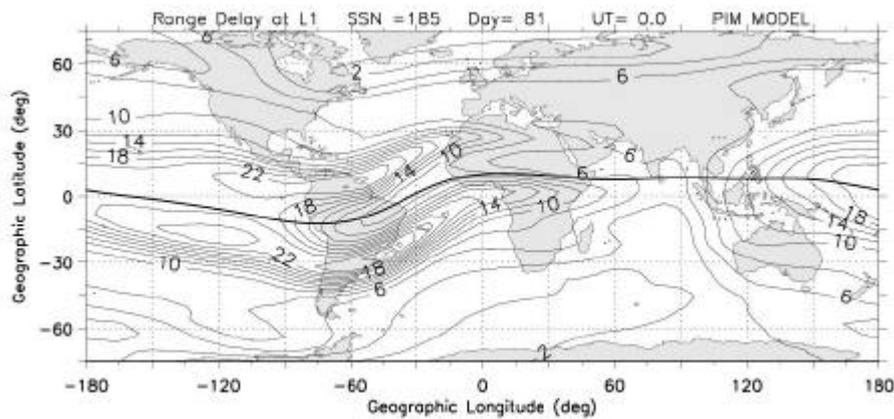
**SBAS Ionospheric Working Group  
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**Introduction:** SBAS precision approach services require correction for ionospheric range delay, and mitigation against scintillation fading effects. The uncertainties on these corrections and potential scintillation effects are the primary limiting factors for availability of currently planned systems. The ionosphere over mid-latitude regions (e.g., CONUS and most of Europe) normally has small spatial range delay gradients, with a resulting high range delay correction capability, and a very low occurrence of significant amplitude fading. Infrequent instances of uncorrected large, non-planar ionospheric spatial gradients may be observed during major geomagnetic storms that occur less than 0.5% of the time, with smaller non-planar gradients occurring during moderate geomagnetic storms that can occur up to approximately 7% of the time. On the other hand the near-equatorial ionosphere normally has large non-planar ionospheric range delays and a significant occurrence of deep amplitude scintillation fading, both of which occur during quiet geomagnetic conditions during years of high solar activity.

## **SBAS ionospheric corrections work well in the CONUS WAAS ionosphere:**

Experience with WAAS over the last two years of solar maximum activity has shown only a few infrequent periods of time when there were significantly increased GIVES (Grid Ionospheric Vertical Errors) in portions of the CONUS WAAS coverage region. Based on this experience with WAAS the ionosphere in the mid-latitudes should permit a high availability of precision approach services (APV-I). Further investigation is necessary to allow increased availability for better levels of service (lower decision heights), such as APV-II. Figure 1 illustrates the relatively smooth spatial gradients in the mid-latitude ionosphere and the large absolute range delay values, and potentially large non-planar ionosphere in the equatorial regions. Note that the large vertical uncorrected ionospheric range delay values exceed 22 meters.

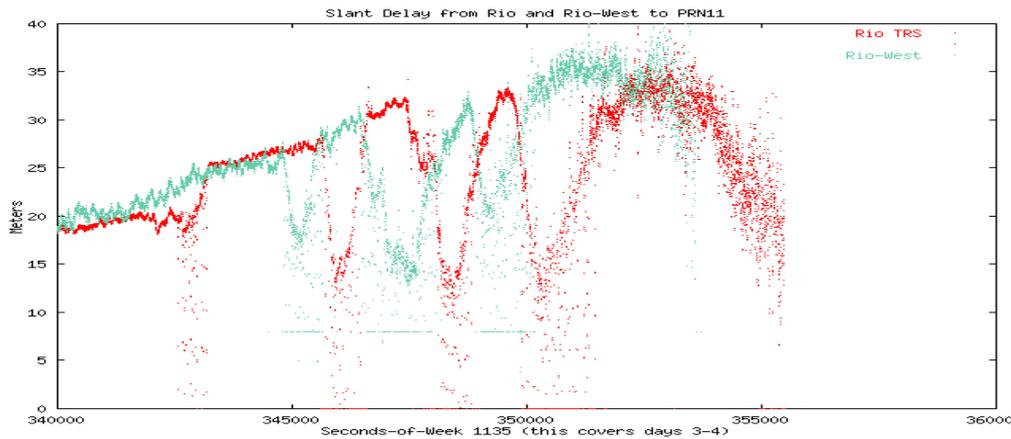
**Large, non-planar, range delay values in the equatorial ionosphere:** Note from Figure 1, that in the near-equatorial region the absolute values of ionospheric range delay are significantly higher than in the mid-latitudes, and the spatial gradients are also much higher, as indicated by the relative closeness of the contours of equal values in the equatorial latitudes. To first order, the ionospheric range delay contours seen in Figure 1 move in the magnetically westward direction as the earth rotates under the ionosphere. These large, non-planar gradients exist during normal geomagnetically quiet conditions, and are a regular feature of the near-equatorial ionosphere. The existing SBAS 5° x 5° ionospheric correction grid likely will NOT be able to correct for these very high absolute range delays under these normal conditions of large spatial and temporal non-planar gradients. Additionally, there are large, rapid drops in range delay, associated with deep amplitude scintillation fading, observed during the post-sunset hours in the equatorial region.



**Figure 1. Contours of ionospheric range delay, in meters at L1, for typical solar maximum equinox conditions at 00 UT. (This map was produced from the Parameterized Ionospheric Model, PIM.)**

Two large, rapid drops in range delay due to such depletions are illustrated in Figure 2 with observations of relative changes in range delay observed from two stations located 95 kilometers apart in an East-West direction near Rio de Janeiro, Brazil, (Dehel, private communication, May 2002). These changes in slant ionospheric range delay, of the order of 20 meters, cannot be accounted for with any reasonably sized network of reference stations, nor can the size of the depletions, and their locations, be determined by any reasonably sized grid. Thus, large depletions in TEC could severely limit SBAS precise ionospheric correction during those hours when they could occur, with a potentially large impact on precision approach service availability.

Techniques that work well in mid-latitude regions such as the planar fit approach to estimating vertical grid delays (Walter, et al., 2001), and the simple obliquity factor which converts from slant to vertical delays, then back from vertical to slant delays, (ICAO SARPs) may not perform adequately in the equatorial region. New techniques that are more tolerant of the large spatial and temporal variations in TEC could perhaps be developed. However, the deep equatorial depletions will remain a problem no matter what estimation technique is used because the spatial density of measurements will, in all likelihood, remain insufficient to ensure 100% detection of narrow depletion structures.



**Figure 2. Slant ionospheric range delay on a night in October 2001, from two stations located near Rio de Janeiro, Brazil. Note the nearly identical depletions observed in ionospheric range delay occurring later along the eastward path, clearly indicating the eastward direction of motion of the depletions. (Dehel, SBAS Iono Meeting No. 5, McLean, VA, May 10-11, 2002.)**

**Dual frequency SBAS:** When a full constellation of dual frequency civilian GNSS satellites becomes available all ionospheric range delay issues will be eliminated, except for those times when the user loses access to one or more frequencies. This could happen during severe scintillation periods or in a RF interference environment. During these times, the user must revert to the SBAS ionospheric corrections.

**Amplitude scintillation effects on the SBAS user signals:** Amplitude fading due to scintillation can cause intermittent loss of one, or more GNSS satellite signals, with a continually changing “mix” of satellites used in the navigation solution as various satellites momentarily lose, and regain, lock during periods of deep fading. Since there are expected to be two complete constellations of GNSS satellites, GPS and Galileo, with a total of approximately 50 satellites in orbit, a user should have nearly 20 satellites visible in the equatorial region from which to compute a position; thus the momentary loss of signal from one, or even several, satellites at once, should not be a significant problem. However, there will be only two geostationary satellites transmitting the SBAS augmentation signals, and the simultaneous loss of both signals due to deep amplitude fading could result in loss of continuity. To improve system continuity and to insure that the SBAS GEO correction message is received by SBAS users, an SBAS could transmit the SBAS correction message on both the L1 and the L5 frequencies, with a time difference in the coded message of approximately one second on the two frequencies, to provide a combination of 1) spatial, 2) frequency and 3) time redundancy.

**Summary:**

- WAAS ionospheric corrections have been shown to work well in the mid-latitude CONUS ionosphere. Similar results are expected for the EGNOS European mid-latitude region.
- An SBAS likely will have unacceptable GIVEs in the equatorial region, that extends from  $\approx \pm 20^\circ - 25^\circ$  geomagnetic latitude, due to the non-planarity of the range delay spatial gradients in this large region of the world.
- Amplitude scintillation effects on GNSS satellite signals can be mitigated by increasing the number of GNSS satellites available (GPS, Galileo, GLONAS).
- Amplitude scintillation effects on the SBAS geostationary satellite correction message can be mitigated by having two satellites spaced at least as far apart as  $45^\circ$  in longitude. The correction message should be transmitted on both the L1 and the L5 frequencies, with an approximate one-second time difference in the message content on the two frequencies, thus providing the necessary spatial, frequency and temporal diversities.
- Precision approach capability should be feasible for all regions when a dual frequency GNSS constellation is available.

**Recommendations:**

- TEC depletions in the near-equatorial regions should be characterized in terms of their geographic size, their severity, and how long they persist. A set of reference station prototype receivers that can gather TEC data continuously should be installed in the equatorial coverage regions of interest. This will provide an early assessment of system performance in that region to assist in demonstrating the integrity of the system.
- Spatial TEC curvatures in the equatorial regions should be evaluated against the  $5^\circ$  by  $5^\circ$  grid for its impact to user interpolation accuracy using any available actual TEC data, plus realistic ionospheric model data, where necessary. Temporal TEC gradients should be evaluated against the GIS broadcast schedule.
- Studies of the errors in the slant to vertical and vertical to slant conversion processes should be made for the regions where large non-planar ionospheric range delay exist to determine how to improve upon the present method of providing range delay corrections to users.
- The impact on ground station and airborne receivers, in terms of signal and message data reception should be studied in detail, in both equatorial and auroral regions, using currently available amplitude scintillation data. The impact on future dual frequency users should be considered.
- Appropriate measurements of scintillation effects on both SBAS and geostationary satellite correction message data should be made in order to specify the severity, and the spatial, temporal, seasonal and solar cycle characteristics, of scintillation effects on airborne and SRS receivers. Additional potential methods to mitigate these scintillation effects should be proposed.

A full “white paper” describing all the potential ionospheric effects on SBAS in detail for the various ionospheric regions of the world is available upon request.