Estimating Ionospheric TEC Using Single-Frequency Wideband Low-Elevation GNSS Signals

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Abstract
Accurate estimation of ionospheric total electron content (TEC) is crucial for mitigating GNSS ranging errors and ensuring the reliability of navigation and positioning systems. TEC is also a fundamental parameter that describes the state of the ionosphere for space science research. This study investigates the ability to expand TEC measurement capability by the reduction of multipath and measurement noise by utilizing single-frequency wideband GNSS signals. Narrowband GNSS signals are characterized by increased multipath errors and higher measurement noise, especially for low-elevation satellites. For this reason, most ground-based GNSS monitoring stations impose a masking angle to eliminate low-elevation measurements. The purpose of this study is to make use of these low-elevation satellite signals for TEC estimation. Our results show that the utilization of the wideband signals can reduce measurement noise by a factor of approx. 3–5 at high satellite elevation, and 3–7 at elevation below 30 degrees when compared to dual-frequency methods. The technique presented here could enable wideband single-frequency receivers to produce better TEC estimates than standard dual-frequency methods.

Background and Motivation
Most ground-based GNSS monitoring stations impose a masking angle to eliminate measurements from low satellite elevation angles, removing noisy signals and signals corrupted by multipath errors. However, low-elevation signals are abundant, especially at high and mid latitudes. These signals carry rich environmental information, as they travel longer distances through the ionosphere’s active layers. Utilizing low-elevation signals would greatly increase the number of available TEC observations while offering more diverse signal geometries for 3-D TEC mapping algorithms.

Results: Single-Track TEC Estimation
Currently, the estimation of ionospheric TEC is most-commonly achieved using dual-frequency narrowband GNSS signals. Figures 4 and 5 illustrate TEC estimate noise quality improvements using our wideband signal-frequency method. As satellite elevation angle decreases, dual-frequency TEC noise greatly increases, as single-frequency wideband TEC noise remains more consistent.

Benefits
• Usage of L5 signals reduced multipath and pseudorange error
• Dual frequency TEC estimates dominated by L1/L2 noise at low elevation angles, washing out signals
• Low-elevation measurements enable more diverse signal geometry
• Better for advanced tomography TEC mapping techniques

Challenges
• Difficult to calibrate Rx clock/hardware bias
• Currently found using high-elevation L1/L2 signals as an intermediate computation
• Single-frequency methodology is more computationally intensive
• Multipath errors are not completely eliminated by using wideband signals

Results: Single-Frequency TEC Elevation Analysis
Our single-frequency methodology is used to estimate relative sTEC with one-week datasets of L1/C/A, L2C, and L5C signals collected by receivers stationed in HI and AK. Figure 5 shows the TEC estimate noise-quality improvements using the wideband signal-frequency method binned by elevation angle. Number of samples is also plotted below, showing the frequency of received signals by elevation angle. Notably, the high-latitude station has more numerous received signals at low satellite elevation angles.

Conclusion
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References