# Techniques for improved measurement of TEC with GPS

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Improved absolute TEC measurement accuracy is demanded by many global ionospheric characterization schemes, where small errors can be magnified in 3D tomographic profile reconstructions. We will present techniques and analyses of ionospheric GPS data that demonstrate an improved characterization of ionospheric TEC. Some of these include collecting TEC at 50 Hz, others include mitigating biases such as receiver differential code bias. We present research demonstrating that three biases typically result from characterizing TEC with GPS receiver data.

These biases are:

1) Estimation, instead of measurement of receiver differential code bias (DCB)
2) Ionospheric divergence of pseudorange code derived TEC resulting from code smoothing
3) Delay of pseudorange TEC as a result of code smoothing

We will present a technique that uses this internal calibrator to measure receiver DCB to sub-centimeter level or less then 0.1 TECU. Demonstrations of data collected with multiple receivers and other techniques will be presented that verify the effectiveness of this calibrated receiver DCB. We will also present comparisons of determining GPS receiver bias using the CRS calibrator and the NASA/JPL GAIM model.

To mitigate inherent fluctuations in pseudorange due to bandwidth limited precision, receiver noise, and multipath, typical GPS receivers generally employ so-called phase smoothing or leveling of code. A standard method for phase smoothing is the Hatch filter, and we will show that employing a Hatch filter delays the code TEC from the true code TEC by approximately 1/3 of the smoothing time (typically 200-1000 seconds). We will present comparisons demonstrating that a standard GPS receiver employed for ionospheric monitoring possess a code TEC that is delayed by approximately 30 seconds. Therefore if the ionospheric delay is changing, the code estimate of TEC will be biased by an amount equal to the change in delay over that 30 second or longer period, which is often as large as 0.5-3 TEC (depending on filter time and ionospheric conditions). A Hatch filter also imposes a bias on the code derived TEC during ionospheric changes due to what is known as ionospheric divergence (phase advance versus group delay). We will derive and demonstrate using GPS measurements, that this bias is equal and magnitude and opposite in direction to the change in ionospheric delay over the course of a smoothing time, and presents between a 1 TECU and 20 TECU bias for normal to storm-time conditions.