International Beacon Satellite Symposium BSS-2016
Trieste, Italy

A new approach for LEO receiver bias estimation and TEC calibration for LEO-GNSS paths

M. M. Hoque, N. Jakowski and J. Berdermann

Institute of Communications and Navigation, German Aerospace Center, Kalkhorstweg 53, 17235 Neustrelitz, GERMANY.
(E-mail: Mainul.Hoque@dlr.de, Norbert.Jakowski@dlr.de, Jens.Berdermann@dlr.de)

ABSTRACT

Many Low Earth Orbiting (LEO) satellites have been/will be launched with Global Navigation Satellite System (GNSS) receivers aboard, especially for precise orbit determination (POD) purpose and occasionally also for radio occultation measurements (e.g., CHAMP/GRACE/COSMIC-1,-2/SAC-C/TerraSAR-X/Metop- A/Jason1, 2 ...). Space based TEC (total electron content) observations, especially ionospheric radio occultation (IRO) observations have shown a great potential in ionospheric data assimilation [3] for better nowcast, forecast, and ionospheric driver estimation because of global coverage and high vertical resolution. Having a large number of POD related slant TEC observations makes the 3-D imaging of ionosphere/plasmasphere attractive [4]. However, big TEC errors will make the data useless. Therefore, it is important to know the quality of TEC data used in data assimilation. One of the main sources of TEC error is the inter-frequency LEO receiver bias (e.g., Differential Code Bias DCB) estimation.

We applied a new approach for bias estimation of GPS receivers installed on board the COSMIC satellites and calibration of ionospheric radio occultation measurements, i.e., TEC estimation for LEO-GPS paths. For doing this, we used the daily estimates of differential GPS satellite biases that are publicly available from the CODE (Center for Orbit Determination System). Additionally, high quality CODE post processed vertical TEC maps are used together with a multi-layer mapping function approach [1] to initialize TEC at the highest elevation angle ray-path in the LEO-GPS phase-connected arc. Moreover, an exponential decay of electron density with altitude is used to model the plasmaspheric electron content above the LEO satellite height.

To get low-noise absolute TEC we used the cycle slip corrected low-noise carrier phase derived relative TEC to smooth the code-derived absolute TEC [2]. Now the TEC observations can be simplified as

$$\mathrm{TEC}_{\mathrm{i}}^{\mathrm{slnt}} = \mathrm{TEC}_{\mathrm{model}}^{\mathrm{slnt}} + \mathrm{b}_{\mathrm{RX}} + \mathrm{b}_{\mathrm{SAT}} + \varepsilon_{\mathrm{N}} \qquad (1)$$

where b_{SAT} and b_{RX} are the satellite and receiver DCBs, respectively. As already mentioned, the satellite DCBs are removed first using the daily estimates of satellite biases from CODE. Then, we only considered the highest elevation angle (also > 45°) ray-path in the phase-connected arc for receiver DCB estimation. The quantity TEC_{model}^{slnt} is the modelled slant TEC for the highest elevation ray-path. It is obtained by integrating CODE vertical TEC along the ray-path using a multi-layer mapping function approach based on Chapman layer profile [1]. To take into account the plasmaspheric electron content a superposed exponential decay function describing the plasmaspheric electron density distribution is used. The unknown receiver bias b_{RX} is then estimated by fitting the DCBs to numerous high elevation TEC observations from 24 hours data in a least squares sense. Figure 1 compares the DCBs estimated by the UCAR/CDAAC (COSMIC Data Analysis and Archival Center) and by our/DLR (German Aerospace Center) approach for the COSMIC C001 POD2 receiver during a selected quiet (day of year DOY 8-32) and a perturbed (DOY 285-306) period in 2011.

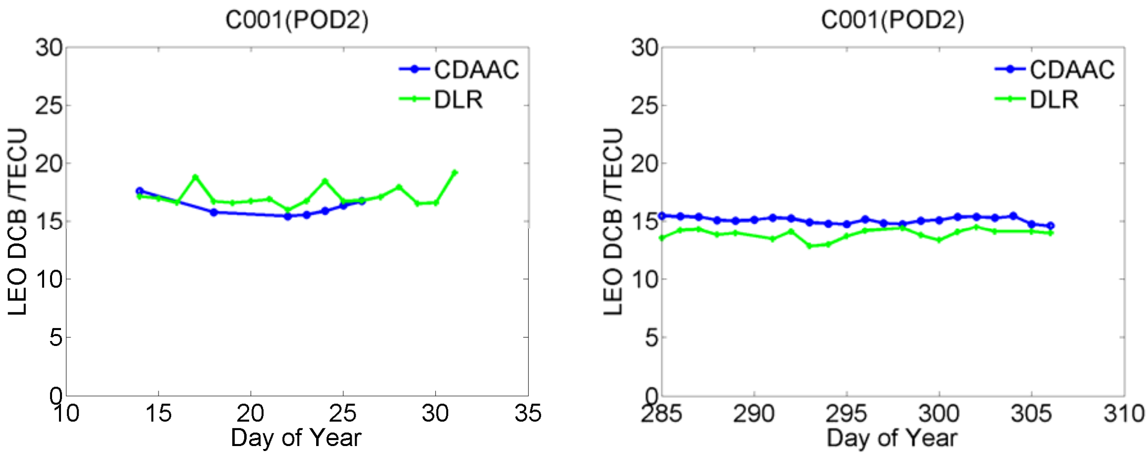

Figure 1. Comparison of LEO DCBs estimated by two approaches for a COSMIC C001 POD2 receiver during a selected quiet (left plot) and a perturbed (right plot) period.

We have found that the differences between the two DCB estimates do not vary by more than 3 TECU. In Figure 2 slant TECs estimated by the UCAR/CDAAC and by the DLR approach are compared for the COSMIC C001 POD2 receiver during a selected quiet day (DOY 14, 2011) and a perturbed day (DOY 285, 2011). The corresponding TEC differences (TEC_{DLR} - TEC_{UCAR}) are computed providing the mean and standard deviation (STD) values at about 0.24 and 1.72 TECU, respectively for the quiet day. For the perturbed day the corresponding mean and STD values are 1.45 and 1.38 TECU, respectively.

We have found that during a quiet as well as a perturbed day the estimated mean and STD of IRO TEC differences do not exceed the 2 TECU level. The accuracy of the LEO slant TEC is assumed to be within 1-3 TECU depending on the satellite mission [5].

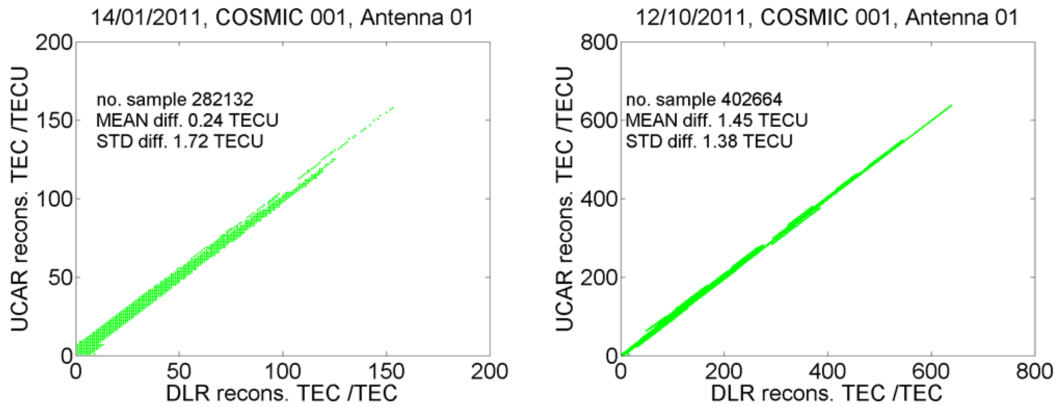

Figure 2. Scatter plot of UCAR-reconstructed IRO derived TEC versus DLR-constructed IRO derived TEC for the COSMIC 001 satellite during a quiet (left plot) and a perturbed (right plot) ionospheric day.

We successfully tested and validated the method for estimating the biases of GPS receivers from COSMIC satellites (~700 - 800km). Our limited investigation using data from SWARM satellites (~460 - 530km) shows that the method can also be applied for receiver onboard satellites with even a lower orbit height. This is due to the usage of actual vertical TEC maps and an advanced mapping function approach.

Acknowledgements:

The authors are grateful to sponsors and operators of the FORMOSAT-3/COSMIC mission; Taiwan's National Science Council and National Space Organization (NSPO), the US National Science Foundation (NSF), National Aeronautics and Space Administration (NASA), National Oceanic and Atmospheric Administration (NOAA) and the University Corporation for Atmospheric Research (UCAR) for publishing COSMIC data.

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