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

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

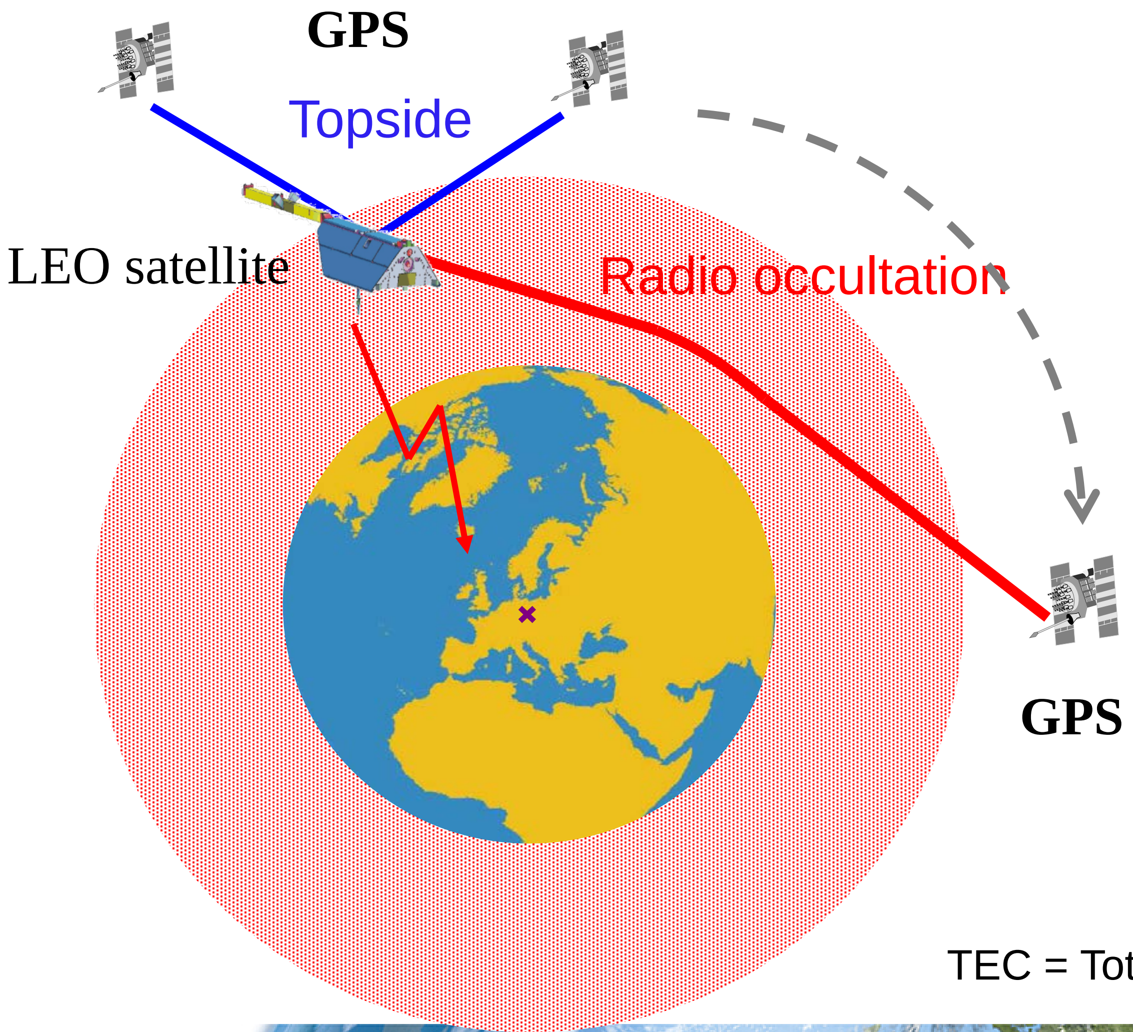
German Aerospace Center (DLR), Institute of Communications and Navigation, Germany

DLR

Outline

- Introduction to ionosphere radio occultation observations
- Motivation
- Our approach for LEO receiver bias estimation and TEC calibration
- Comparison of estimated COSMIC receiver biases during quiet and perturbed ionospheric days
- Comparison of estimated COSMIC IRO TECs during quiet and perturbed ionospheric days
- Estimates of SWARM receiver biases
- Conclusions

Space based GNSS ionosphere sounding



Measurement of the differential GPS Phase
→ **TEC(h, λ, ϕ)**

Radio occultation

TEC = Total Electron Content

DLR

Motivation

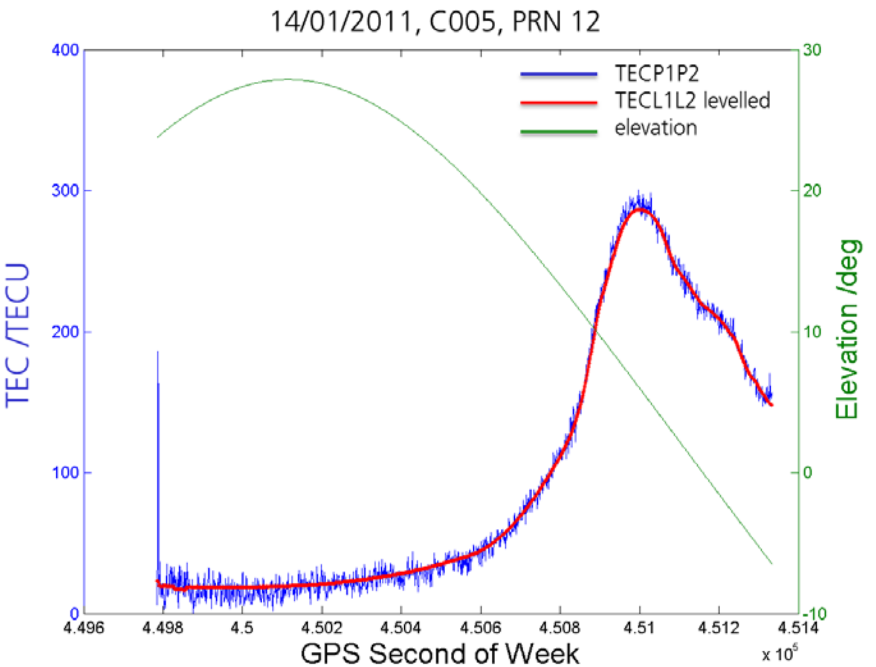
- Space based TEC observations, especially ionospheric radio occultation (IRO) observations have shown a great potential in ionospheric data assimilation for better nowcast, forecast, and ionospheric driver estimation because of **global coverage** and **high vertical resolution**.
- Having a large number of IRO slant TEC observations makes the 3-D imaging of ionosphere/plasmasphere attractive.
- 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.

LEO receiver bias estimation and TEC calibration- 1

$$TEC_{\Psi}^{slnt} = \frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}[\Psi_2 - \Psi_1] + b_{RX\Psi} - b_{TX\Psi} + \epsilon_{N\Psi}$$

$$TEC_{\Phi}^{slnt} = \frac{f_1^2 f_2^2}{40.3(f_1^2 - f_2^2)}[\Phi_1 - \Phi_2] + B_{ambiguity} + b_{RX\Phi} - b_{TX\Phi} + \epsilon_{N\Phi}$$

To get low-noise TEC we used the cycle slip corrected low-noise carrier phase derived relative TEC to smooth the code-derived relative TEC



Example of phase-to-pseudorange levelling

LEO receiver bias estimation and TEC calibration- 2

Now the relative TEC observations can be written as

$$TEC_i^{slnt} = TEC_{model}^{slnt} + b_{RX} - b_{SAT} + \varepsilon_N$$

where b_{SAT} and b_{RX} are the satellite and receiver DCBs, TEC_{model}^{slnt} is the modelled slant TEC for the highest elevation (> 45°) ray-path in the phase-connected arc.

1) The satellite DCBs are removed first using the daily estimates of satellite biases from CODE.
2) $\mathrm{TEC}_{\mathrm{model}}^{\mathrm{slnt}}$ is obtained by integrating CODE vertical TEC along the ray-path using a multi-layer mapping function approach based on Chapman layer profile.
3) To take into account the plasmaspheric content a superposed exponential decay function describing the plasmaspheric electron density distribution is used.
4) The unknown receiver bias b_{RX} is then estimated by fitting DCB to the numerous high elevation TEC observations from 24 hours data in a least squares sense.

Multi-layer mapping function approach based on Chapman layer profile

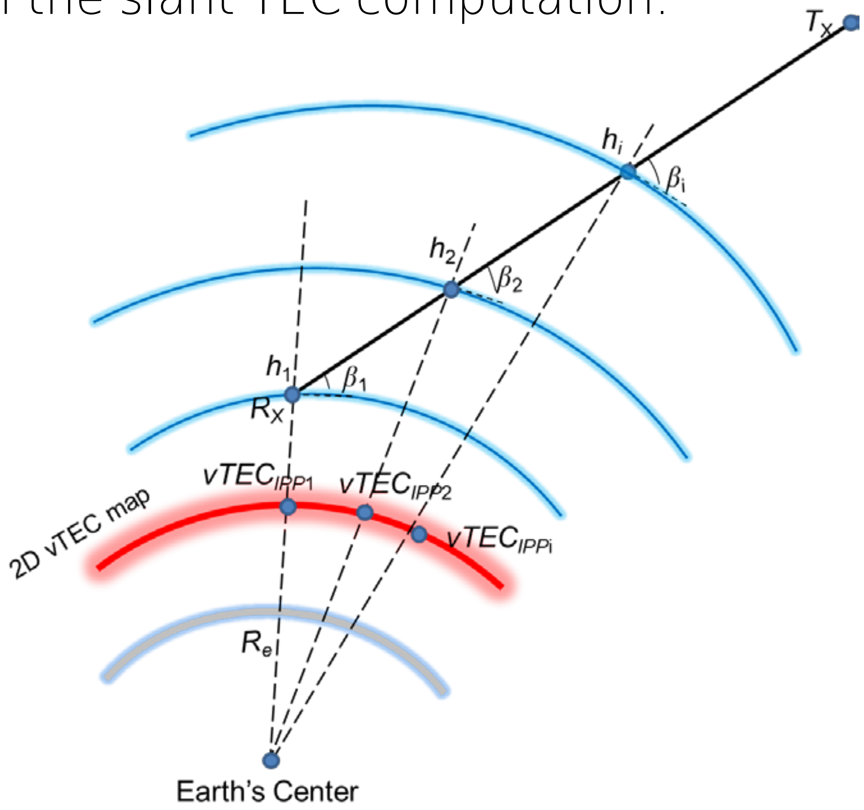
- Considering vertical TECs at different geographic locations along the ray path projected on the thin-shell at 350 km height, the approach incorporates the horizontal gradients in the slant TEC computation.

- We used the **Chapman layer** approach for describing the vertical electron density structure and derive the required obliquity factor.

$$n_e(h) = N_m.\exp\left(\frac{1}{2}(1 - z - \exp(-z))\right)$$

$$z = (h - h_m)/H$$

$$vTEC = \int_R^S n_e(h)dh \approx 4.13HN_m$$

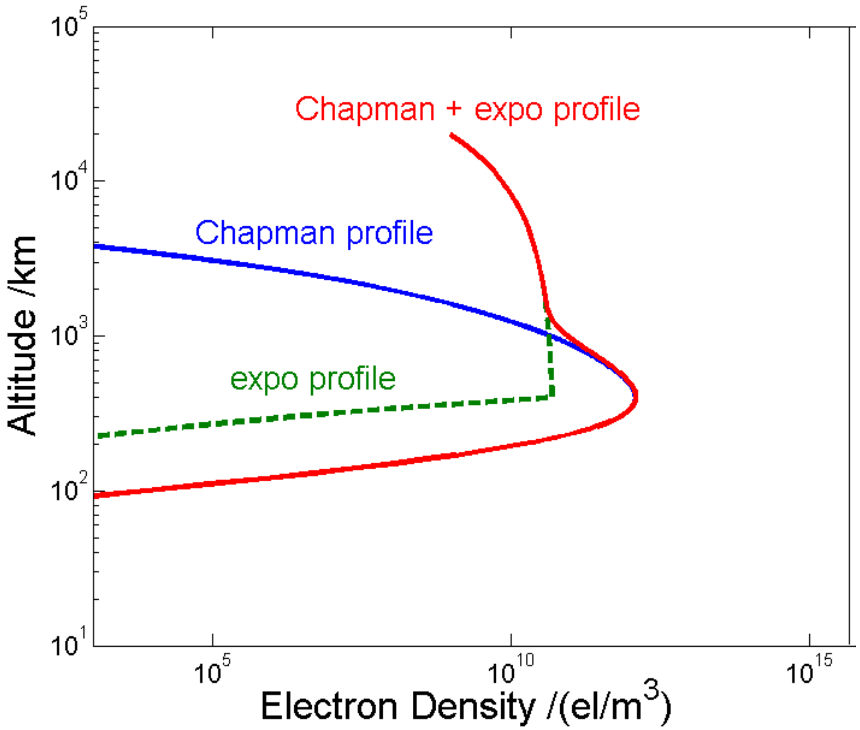


An exponential decay function describing the plasmaspheric electron density distribution

The plasmaspheric electron density is modelled by an exponentially decreasing function as

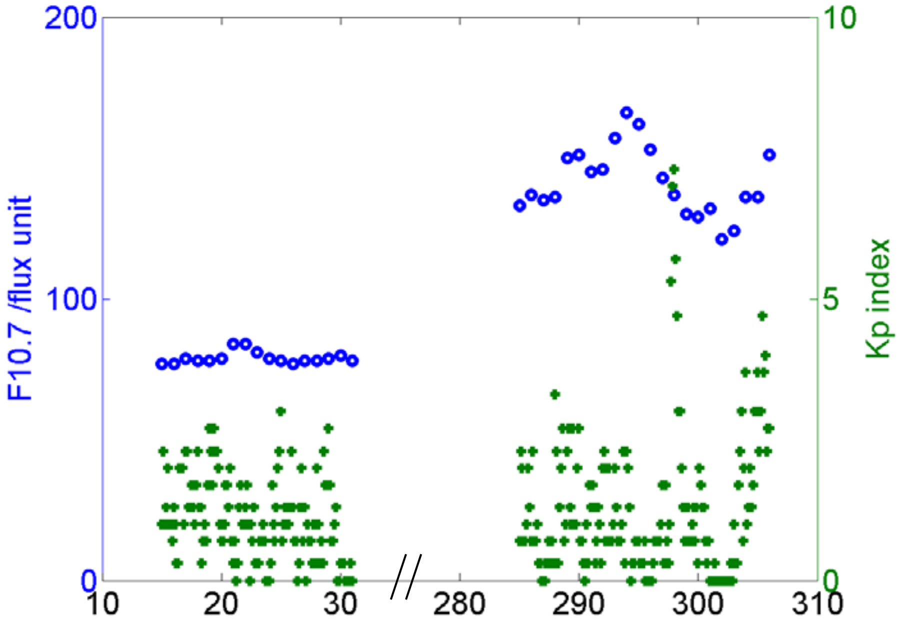
$$n_e^P(h) \approx n_p \exp\left(-\frac{h-h_0}{H^P}\right)$$

where n_p is the plasmaspheric basic density of electrons and H^p (≈ 10,000 km) is the mean scale height of the plasma density. The plasmaspheric density is maximum at the F2 layer peak ionization height (h_0) and exponentially decreases with the increase of height (h)



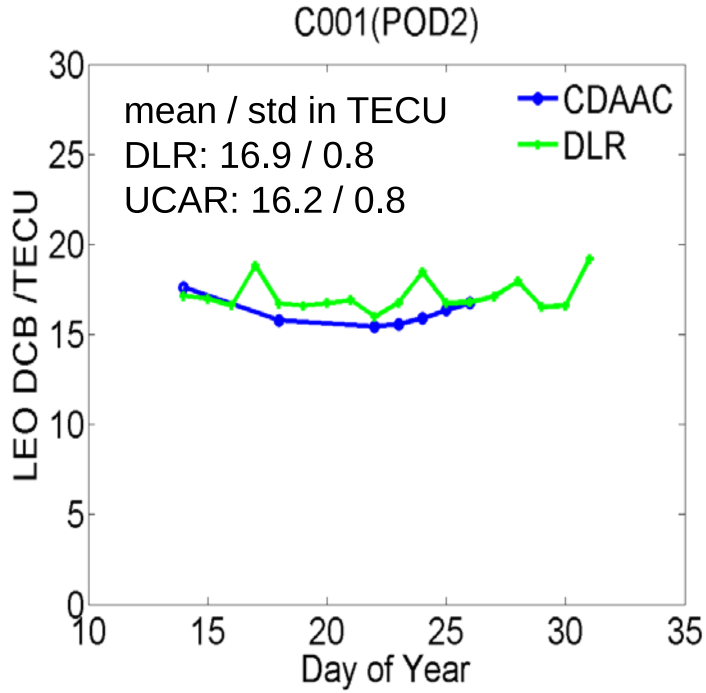
Database- quiet and perturbed ionospheric condition

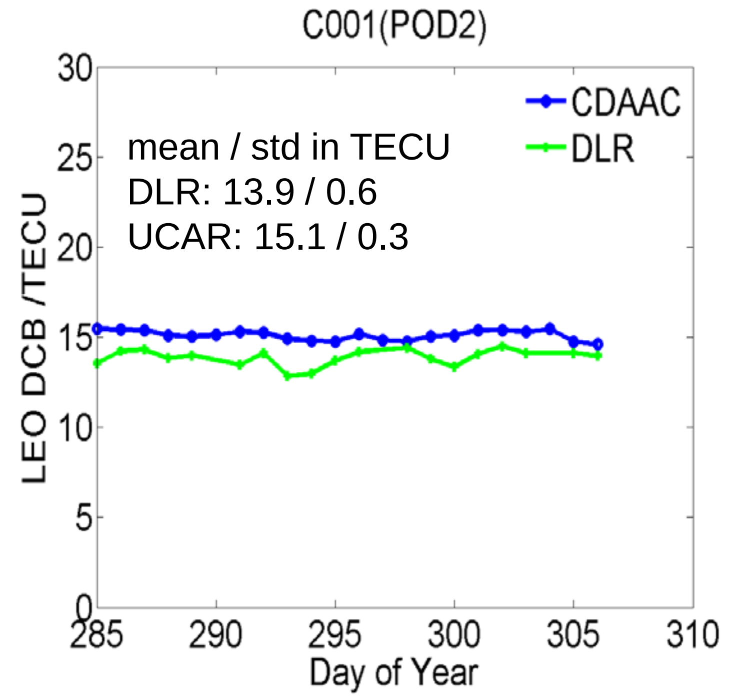
Quiet period: 14 – 31 Jan. 2011
Perturbed period: 12 Oct. – 2 Nov. 2011



Solar and magnetic activity proxy F10.7 and Kp variation during selected quiet and perturbed days

Comparisons of estimated LEO receiver biases

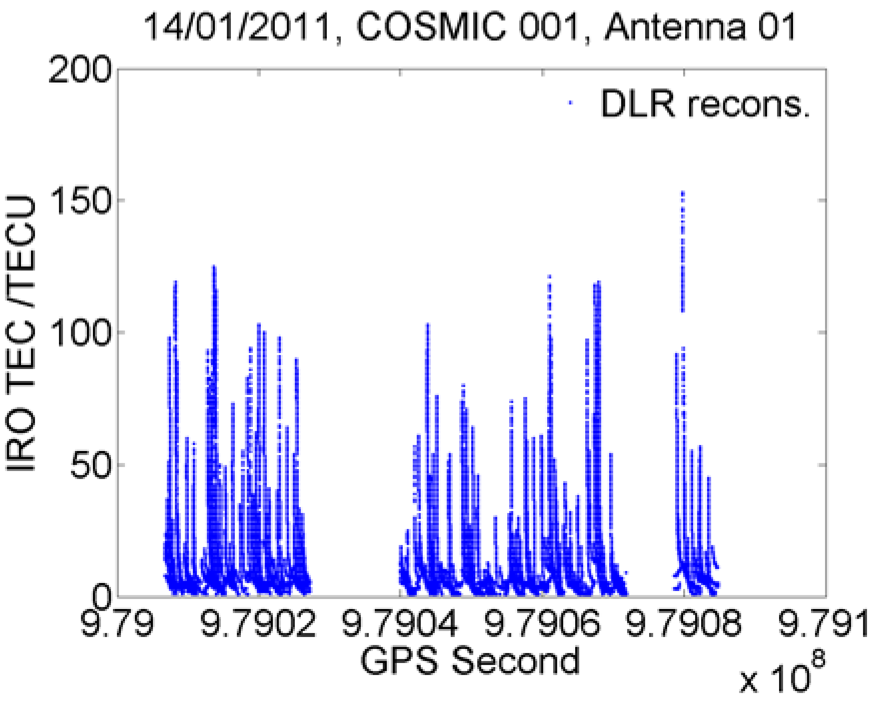


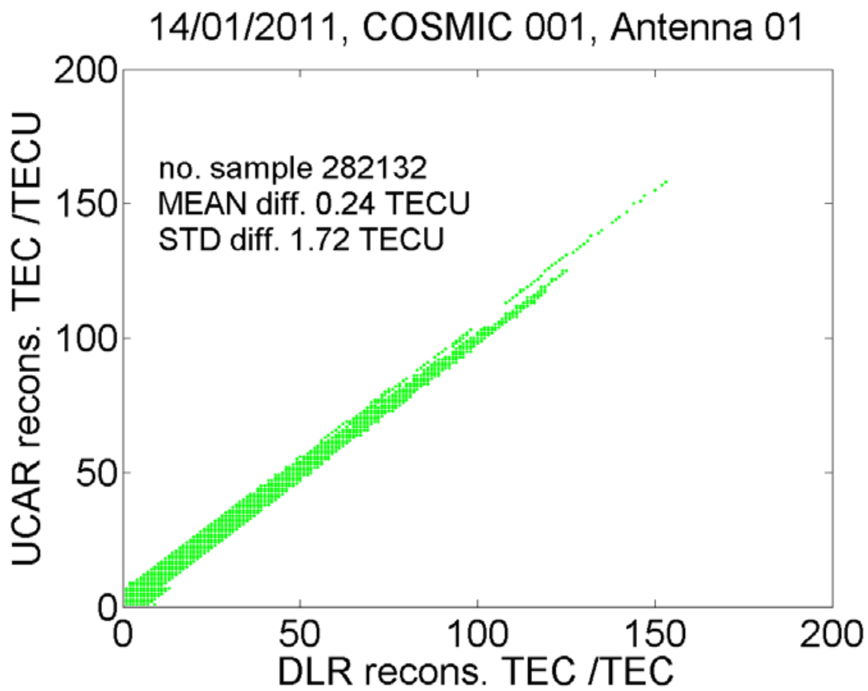


- Comparisons of LEO DCBs estimated by UCAR and DLR for COSMIC C001 POD2 receiver during the selected quiet (left plot) and perturbed (right plot) periods. We found that most of the cases the differences lie under the 3 TECU thresholds.

The levelling error and DCB estimation error are dependent on the satellite thermal status (e.g., receiver cpu temperature, environment temperature, solar radiation).

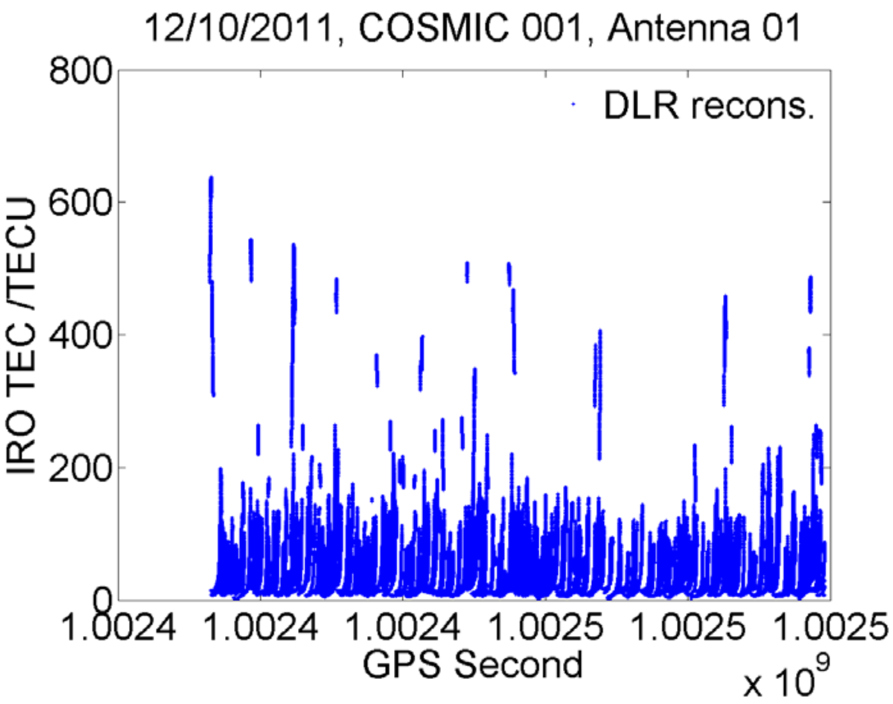
Comparisons of estimated IRO TECs- during a quiet ionospheric day

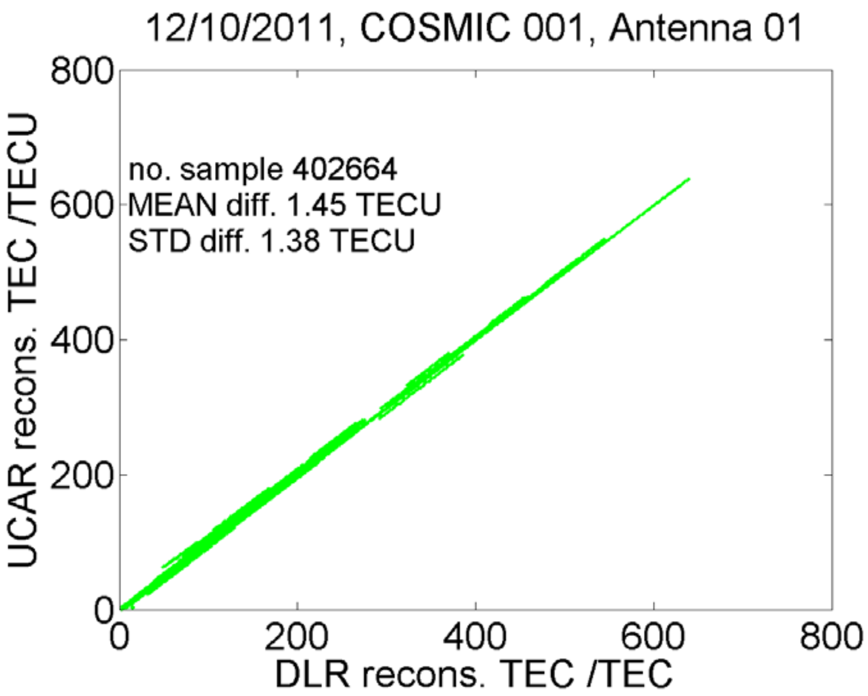




- DLR-reconstructed IRO TEC versus UCAR-constructed IRO TEC for COSMIC 001 satellite during a quiet ionospheric day.

Comparisons of estimated IRO TECs- during a perturbed ionospheric day

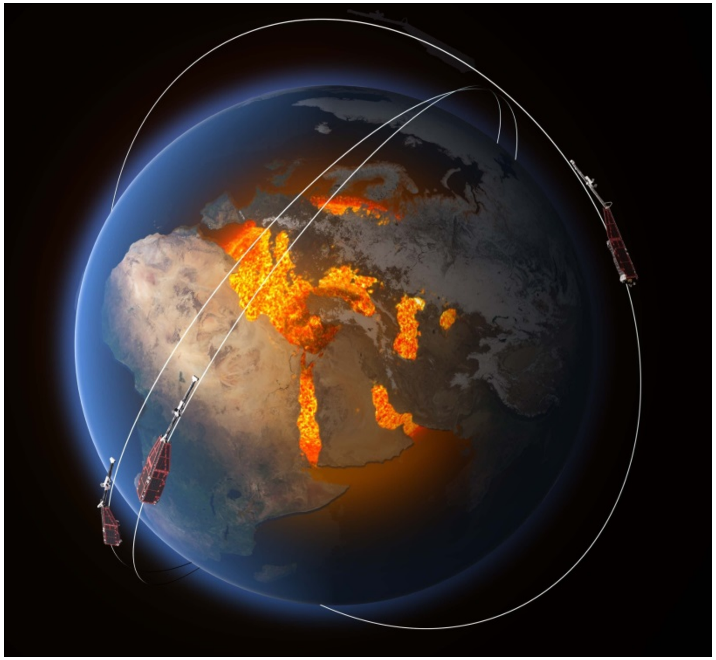




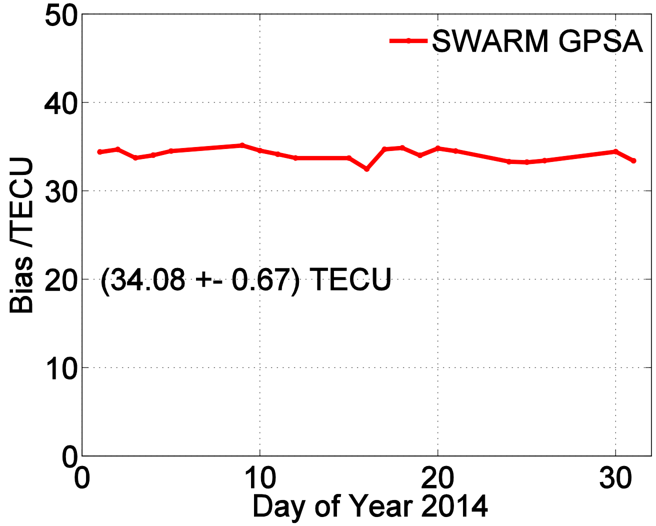
- DLR-reconstructed IRO TEC versus UCAR-constructed IRO TEC for COSMIC 001 satellite during a perturbed ionospheric day.

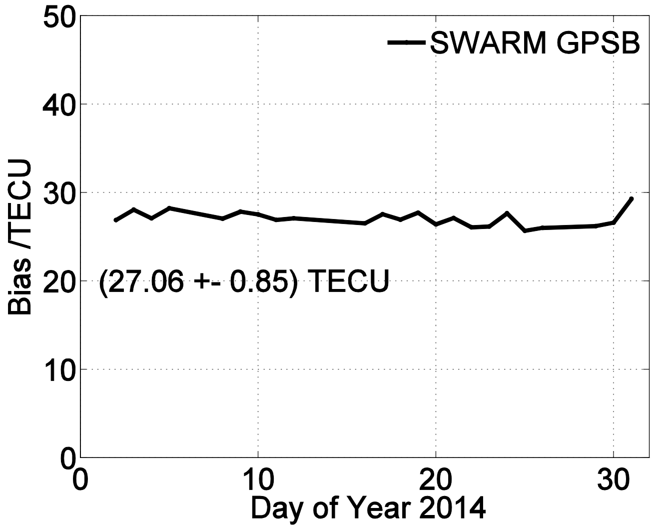
Receiver bias estimation and TEC calibration for SWARM-GPS paths- 1

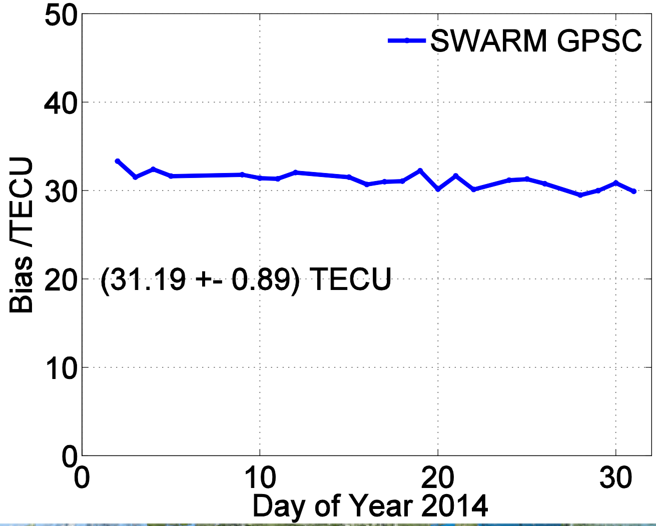
The GPS receivers on-board three identical SWARM satellites provide dual-frequency carrier-phase and code-pseudorange measurements primarily for orbit determination.



Receiver bias estimation and TEC calibration for SWARM-GPS paths- 2



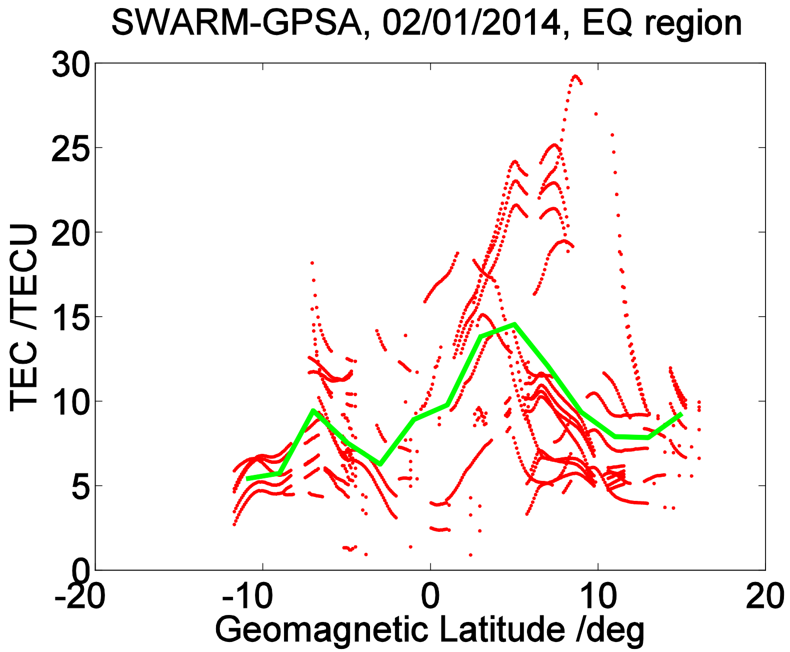


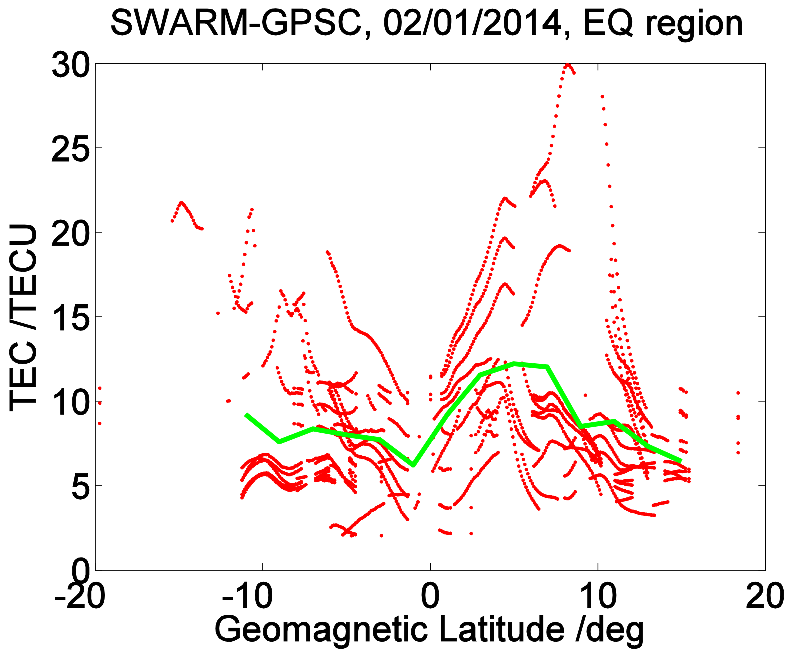


Investigation period: Jan 1 – 31, 2014

Although the SWARM satellites (~460 - 530km) fly far below of the orbit of the COSMIC satellites (~700 - 800km) our investigation shows that the method can also be applied for receivers onboard lower satellite orbit height.

Receiver bias estimation and TEC calibration for WARM-GPS paths- 3





Conclusions

- We have developed an approach for computing differential code bias for the GPS receiver onboard LEO satellites, e.g., COSMIC and SWARM satellites.
- The daily mean receiver bias is stable with a standard deviation below 1 TECU for GPS receivers on board COSMIC during both the selected quiet and perturbed periods.
- For all three SWARM satellites the daily mean GPS receiver bias is stable with a standard deviation below 1 TECU.
- We expect that the SWARM GPS observations will significantly contribute to the topside TEC reconstruction over the globe.

DLR

Thank You for Your Attention !

CDAAC LEO bias estimation and TEC calibration

$$(TEC_A + DCB)M(\theta_A) = (TEC_B + DCB)M(\theta_B)$$

Where $TEC_{A/B}$ are the link related slant TECs and *M* is the geometric mapping function for slant to vertical TEC conversion at LEO height. A least square fit is applied to the observations assuming that that the LEO DCB is constant during one day.