Positioning performance of the NTCM ionospheric model driven by Galileo Az coefficients

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Abstract

The interaction of GNSS signals with the ionosphere may cause link related errors of up to 100 m at GNSS frequencies in the L-band. To aid single frequency applications, the Neustrelitz Total Electron Content Model driven by Galileo ionization coefficients (NTCM-GlAzpar) has been proposed as an adequate solution to mitigate propagation errors. For the first time, we present a global statistical validation of the NTCM-GlAzpar model in the position domain by comparing its results with the results of the Galileo NeQuick and GPS Klobuchar models. For this purpose, we used the GNSS analysis tool gLAB in the Standard Point Positioning (SPP) technique. The used GNSS data corresponds to a one-month period of perturbed solar activity (December 2014) and one-month period of quiet conditions (December 2019). We achieved a worldwide coverage with up to 73 IGS stations.
The statistical analysis of the hourly mean 3D position error shows that NTCM-GlAzpar outperforms the Klobuchar model. Also, the results achieved with NTCM-GlAzpar are slightly better or comparable to the results obtained with NeQuickG. The performance of NTCM-GlAzpar decreases slightly for conditions of reduced solar activity – at night time, higher latitudes and low perturbations. Nevertheless, simple software adaptations and a low computational time make NTCM-GlAzpar an alternative practicable algorithm to improve the accuracy of positioning applications.

Keywords: GNSS – ionospheric correction – NTCM – gLAB tool – single frequency positioning

The Neustrelitz Total Electron Content Model (NTCM)

- NTCM is a two-dimensional empirical ionospheric correction model of the vertical total electron content (VTEC) defined by five subfunctions (local time, season, geomagnetic field, latitude anomaly and solar activity)

$$VTEC_{\mathrm{NTCM}} = F_1 \times F_2 \times F_3 \times F_4 \times F_5$$

NTCM driven by the Galileo ionization coefficients

$$F_5 = k_1 + k_2\, GlAzpar$$

$$GlAzpar = \left|\sqrt{a_{i0}^2 + 1633.33\, a_{i1}^2 + 4802000\, a_{i2}^2 + 3266.67\, a_{i0} a_{i2}}\right|$$

where: $GlAzpar$ – driver of solar activity analogous to F10.7
$k_{1,2}$ – model coefficients
$a_{i,1-3}$ – broadcast Galileo ionization coefficients

- $GlAzpar$ is independent of geomagnetic inclination and geographic latitude, therefore simplifying its applicability
- In the TEC domain, NTCM-GlAzpar performs equal to or better than the NeQuickG model
- Its computation time has been found to be 65 times faster than NeQuickG

Data sources

- The used data corresponds to 2 different solar activity periods:
  - perturbed – December 2014 (F10.7 ~ 150 sfu)
  - quiet – December 2019 (F10.7 ~ 70 sfu)
- In total, GNSS data from up to 73 International GNSS Stations (IGS) distributed worldwide were used

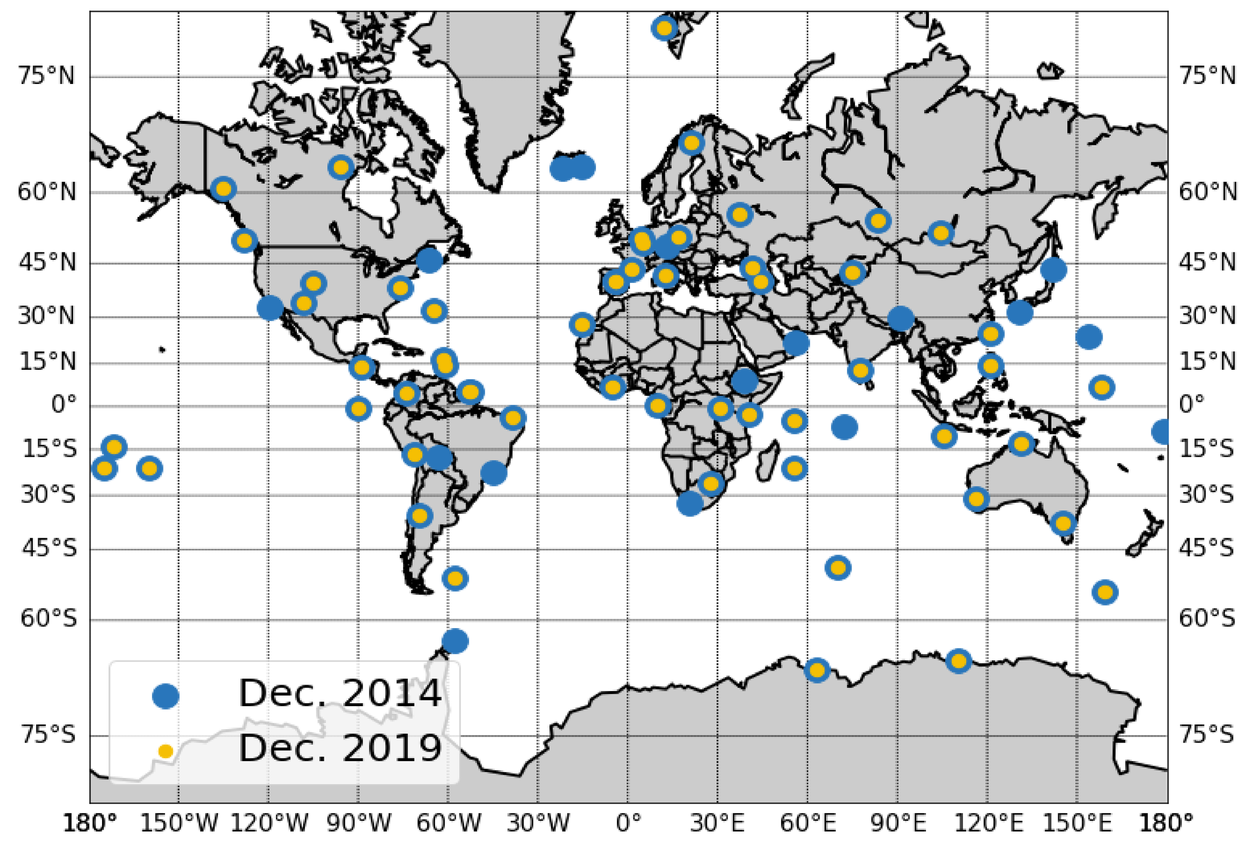

Fig. 1 Worldwide coverage achieved with the GNSS data

Methodology

- ESA's analysis tool gLAB was used for data processing and estimation of position in the single point positioning (SPP) mode
- gLAB is capable of achieving a 3D position accuracy better than 5 cm for precise point positioning (PPP) experiments
- The processing with gLAB required the RINEX observation and navigation files, as well as the weekly SINEX a priori position of the considered IGS stations
- The Galileo broadcast ionization coefficients (Az) were used for driving the NTCM-GlAzpar and NeQuickG models
- gLAB's customization capability allowed to compare the positioning performance under four modelling approaches:
  1. no application of ionospheric correction
  2. GPS Klobuchar model correction
  3. Galileo NeQuick model correction
  4. NTCM-GlAzpar model correction

Analysis

- To compare the four modelling approaches, the hourly mean 3D position over the two periods of time was determined (**Fig. 2**)
- For statistically comparison of the results, the data was arranged based on sectors of geographical latitude (φ) and local time (**Fig. 3**):

i. $\varphi \in [-90°, 90°]$, LT $\in$ [0,24] h
ii. $\varphi \in [-90°, 90°]$, LT $\in$ [6,18] h
iii. $\varphi \in [-90°, 90°]$, LT $\in$ [18,6] h
iv. $\varphi \in [-30°, 30°]$, LT $\in$ [0,24] h
v. $\varphi \in [\pm 30°, \pm 60°]$, LT $\in$ [0,24] h
vi. $\varphi \in [\pm 60°, \pm 90°]$, LT $\in$ [0,24] h

	RMS (m) - 3D position error overall sample		
period	Klobuchar	NeQuickG	NTCM-GlAzpar
December 2014 (perturbed)	6.71	4.61	**4.36**
December 2019 (quiet)	2.75	2.35	**2.32**

Table 1 RMS values of the models for the overall data sample for perturbed and quiet conditions

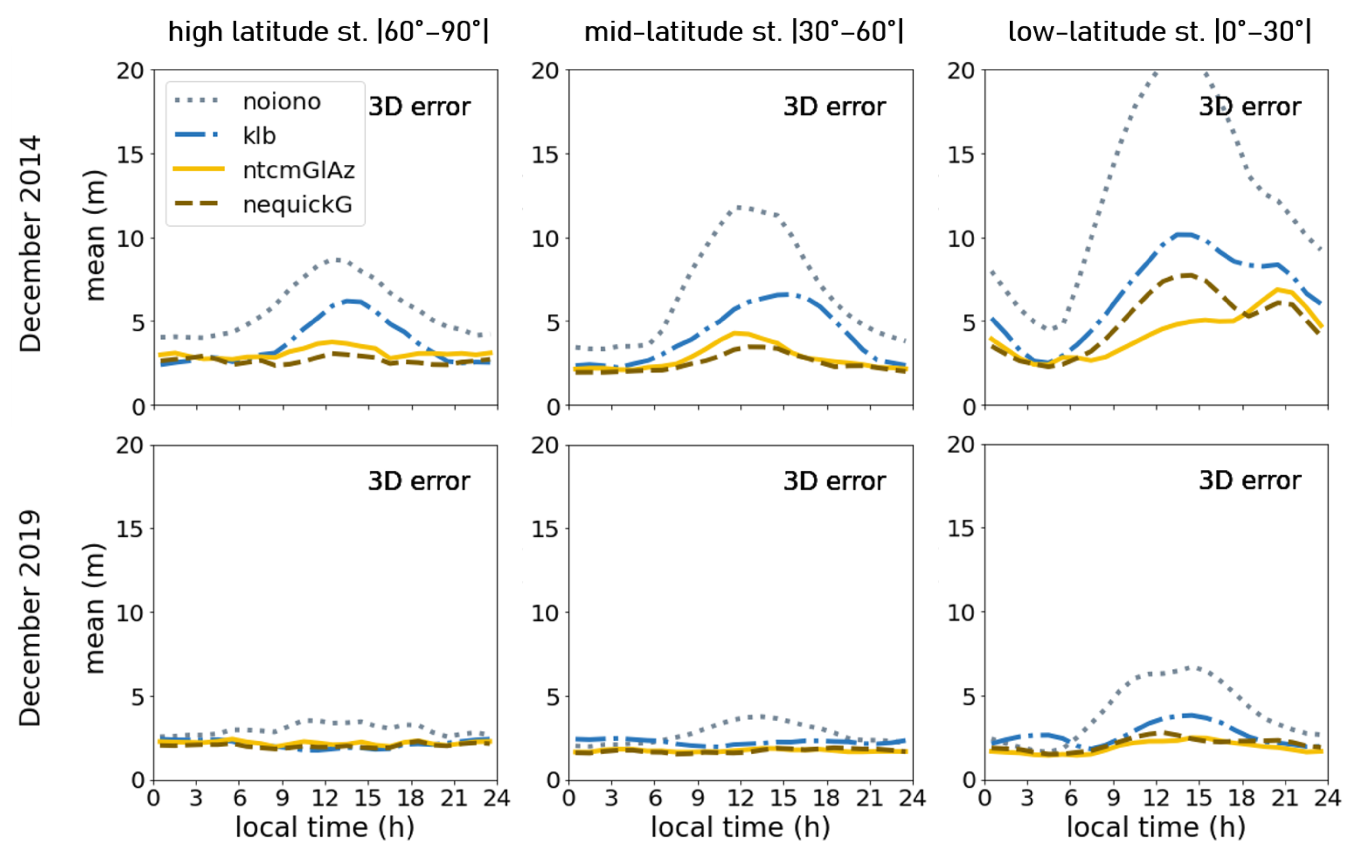

Fig. 2 Comparison of resulting 3D position errors versus local time of the four modelling approaches per latitude range. The results for the perturbed period (Dec. 2014) are shown in the top panels and the results for the quiet conditions (Dec. 2019) are in the bottom panels

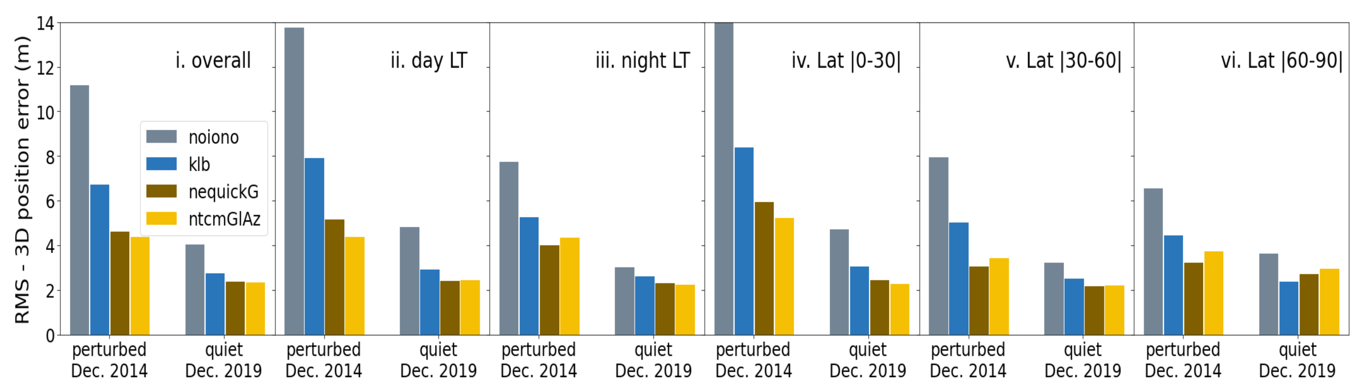

Fig. 3 Comparison of RMS values achieved with each model for perturbed and quiet conditions and for sectors of latitude and local time

Conclusions

- The performace of NTCM-GlAzpar in the position domain is better than the GPS Klobuchar and Galileo NeQuick models in the overall comparison
- NTCM-GlAzpar's performance degrades with reduced solar activity – at night time, higher latitudes and quiet conditions
- Although NTCM-GlAzpar and Galileo NeQuickG achieve comparable positioning accuracy, simple software adaptations and a lower computational cost make NTCM-GlAzpar an alternative practicable algorithm to improve the accuracy of GNSS single frequency applications

References

Data sources: https://cddis.nasa.gov/archive/; https://omniweb.gsfc.nasa.gov/
gLAB: Ibañez et al. 2018
Klobuchar model: Klobuchar 1987
NeQuick model: European Comission 2016
NTCM model: Hoque et al. 2015, 2017, 2018, 2019; Jakowski et al. 2011

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