Good performance, less computation: A new ionospheric model for the Galileo Open Service

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Overview

- Ionosphere correction models for GNSS
- **N**eustrelitz **T**otal Electron **C**ontent **M**odel (NTCM) approaches
- Fast ionospheric correction using Galileo Az coefficients and the NTCM model
- Validation against GPS **V**ertical **T**otal **E**lectron **C**ontent (VTEC) data
- Validation against GPS **S**lant **T**otal **E**lectron **C**ontent (STEC) data
- Validation against 3D position data
- Summary

Ionosphere correction models for GNSS

Klobuchar / GPS ICA
- 8 broadcast coeffi.

GLONASS
- no ionos correction

NeQuick Galileo
- 3 Az coeffi.

mod. Klobuchar
- 8 broadcast coeffi.

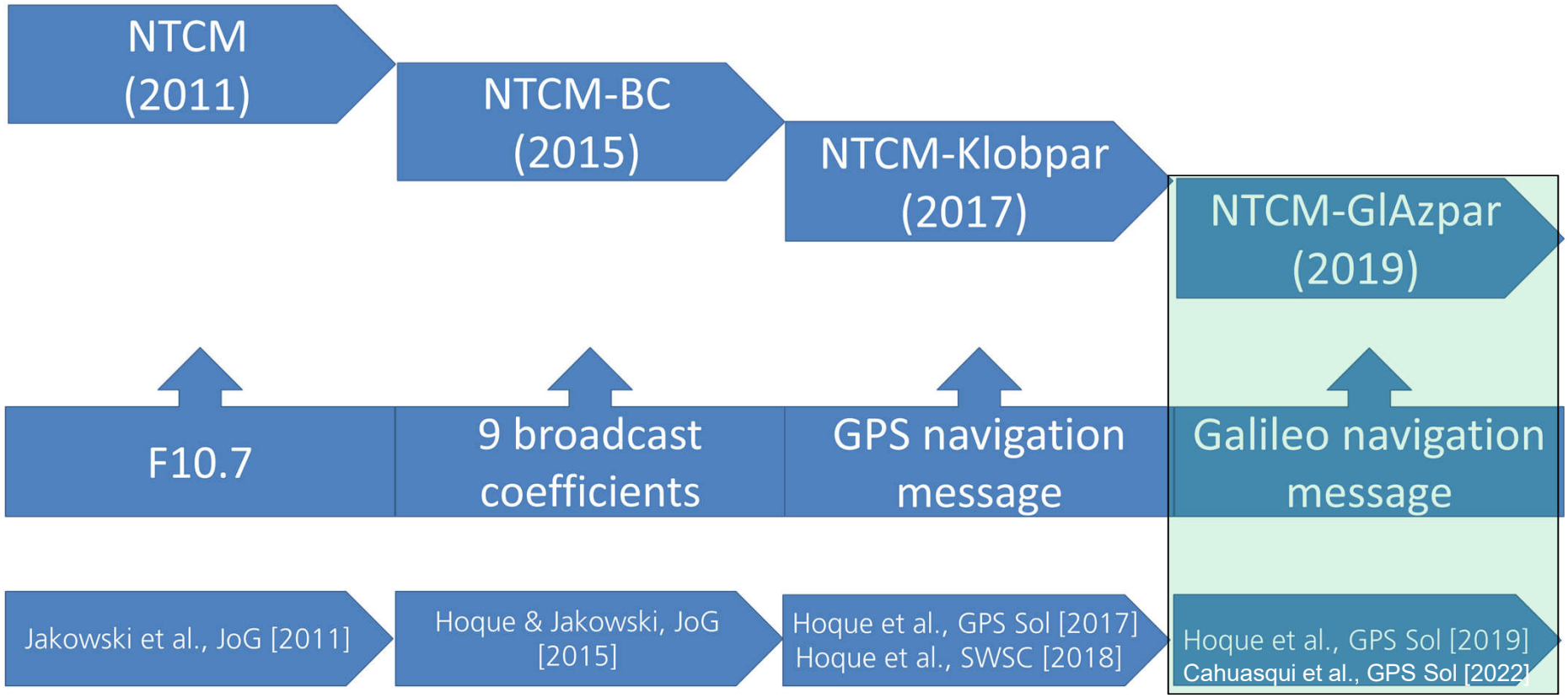
BDS-3, BDGIM
- 9 broadcast coeffi.

NTCM-BC
- 9 broadcast coeffi.

DLR has developed Neustrelitz TEC **B**road**C**ast Model **NTCM-BC** for next generation GPS, Galileo systems

BeiDou navigation satellite system (BDS-3), BDGIM: BeiDou global broadcast ionospheric delay correction model

Neustrelitz TEC Model (NTCM) approaches



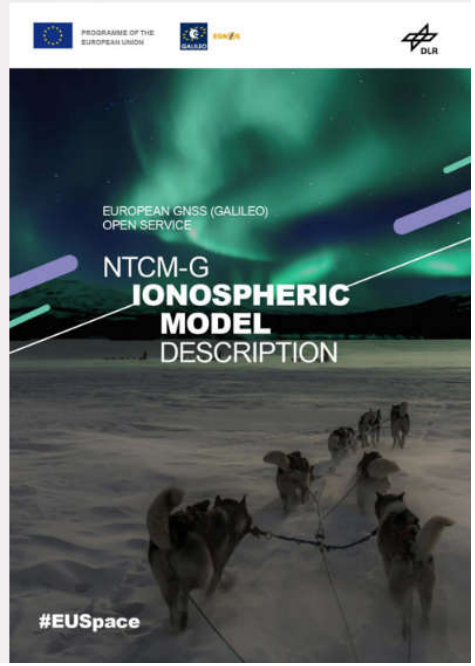
Neustrelitz TEC Model (NTCM) G

https://www.gsc-europa.eu/news/good-performance-less-computation-a-new-ionospheric-model-for-the-galileo-open-service, May 2022

- ✓ NTCM-G has been endorsed by EC as an alternative model to Nequick-G
- ✓ Nequick-G remains the official Galileo reference model for all OS users
- ✓ Due to its low computational load, NTCM-G can be exploited for particular user communities, in particular Aviation

NTCM G Source Code and Description

from F. Menzione, M. Sgammini, „NTCM G Software Package," May 2022.



EUSPA
European Union Agency for the Space Programme

European **GNSS** Service Centre

GALILEO | GNSS MARKET & APPLICATIONS | ELECTRONIC LIBRARY | SYSTEM & SERVICE STATUS | GSC PRODUCTS | SUPPORT TO DEVELOPERS

- OSNMA Public Observation Test Phase
- GNSS SIMULATION AND TESTING
- Galileo Satellite Metadata
- Galileo Compatible Devices
- Ionospheric Correction Algorithms
  - NeQuick G Source Code
  - NTCM G Source Code

NTCM G Source Code

Download NTCM G source code

An implementation of NTCM G algorithm, an alternative to Nequick G algorithm, is now available for users. The NTCM G source code provides a portable and validated C/C++ version of the NTCM G model that can be easily deployed in different GNSS application and simulation environments. The NTCM G source code package is composed of:

- The NTCM G source code repository, which includes the reference implementation of the NTCM G,
- The Model Based Design (MDB) repository, which contains all the results and auxiliary information relying on the NTCM G routine according to MBD.
- The Application repository, which includes examples of applications built on top of the source code.
- The NTCM G Software Package User Guide

The NTCM G algorithm implementation is **available for registered users** upon access request.

Request access

NTCM G model for single frequency users

The Neustrelitz Total Electron Content Model for Galileo (NTCM G) is an empirical model that provides a practical and cost-effective solution for the determination of the global ionosphere Total Electron Content (TEC).

NTCM G is an alternative to the reference ionospheric correction algorithm NeQuick G. The model is less computationally demanding than the reference Nequick G model, so, it represents a good option for applications in which computational resources are limited.

Users shall follow indications provided in the reference document "NTCM-G Ionospheric Model Description" in order to implement the NTCM G algorithm for Galileo single frequency receivers. The document contains definitions, step-by-step procedures and guidelines for implementation of NTCM G in the receivers.

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NTCM driven by GPS and Galileo ionospheric coefficients

GPS Klobuchar Model

delay at GPS L1 $T_{iono} =$

$$\begin{cases} F * \left[5.0 * 10^{-9} + AMP\left(1 - \frac{x^2}{2} + \frac{x^4}{24}\right)\right], & |x| < 1.57 \\ F * (5.0 * 10^{-9}) & |x| \geq 1.57 \end{cases}$$

$$AMP = \begin{cases} \sum_{n=0}^{3} \alpha_n \varphi_m^n, AMP \geq 0 \\ if\ AMP < 0, AMP = 0 \end{cases} (sec),$$

$$PER = \begin{cases} \sum_{n=0}^{3} \beta_n \varphi_m^n, PER \geq 72{,}000 \\ if\ PER < 72{,}000,\ PER = 72{,}000 \end{cases} (\text{sec})$$

$$x = \frac{2\pi(t - 50400)}{PER} \quad (radians)$$

Neustrelitz TEC Model (NTCM)

$$TEC_{NTCM} = F_1 \cdot F_2 \cdot F_3 \cdot F_4 \cdot F_5$$

$$F_1 = cos\chi^{***} + cos\chi^{**}(k_1 cosV_D + k_2 cosV_{SD} + k_3 sinV_{SD} + k_4 cosV_{TD} + k_5 sinV_{TD})$$

$$F_2 = 1 + k_6 cosV_A + c_7 cosV_{SA}$$

$$F_3 = 1 + k_8 cos\varphi_m$$

$$F_4 = 1 + k_9 exp(EC_1) + k_{10} exp(EC_2)$$

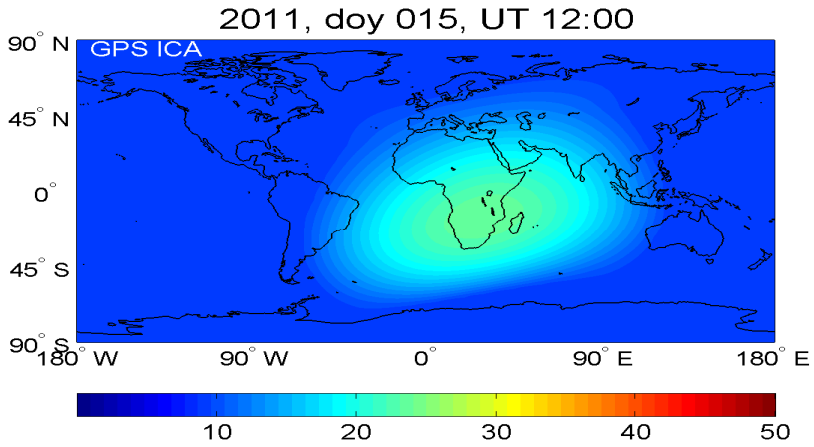
$$F_5 = k_{11} + k_{12}\boldsymbol{drivepar}$$

- ✓ ***F10.7***
- ✓ ***Klobpar***: drived from GPS navigation messages
- ✓ **GlAzpar**: derived from Galileo navigation messages

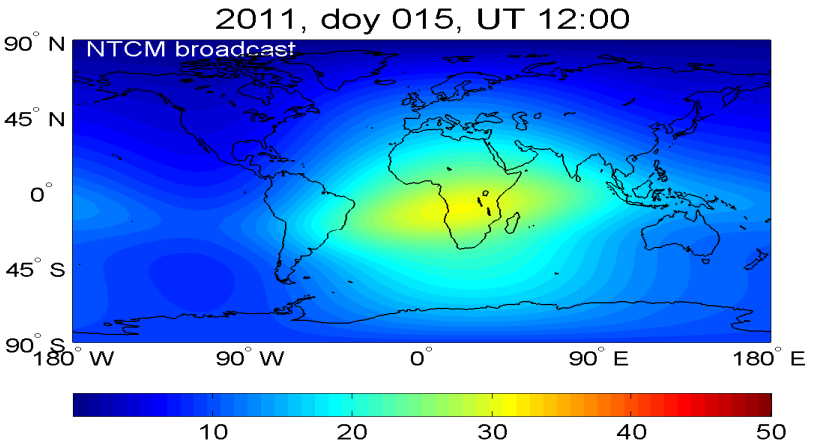
- ✓ **NTCM-Klobpar** model is proposed as an alternative to the **GPS Klobuchar** model.
- ✓ **NTCM-GlAzpar** model is proposed as an alternative to the **NeQuick Galileo** model.

GPS-Klobuchar versus NTCM

GPS Klobuchar Model



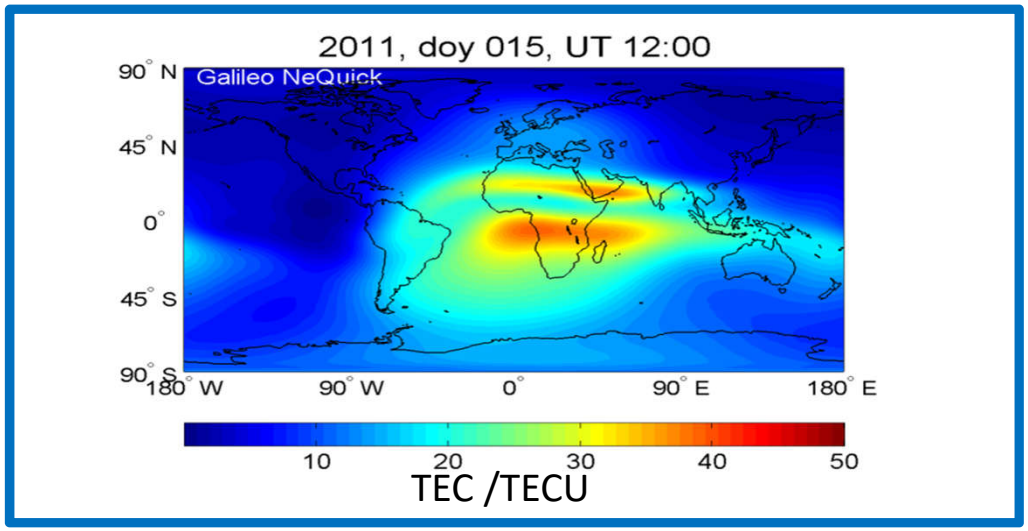
NTCM Model



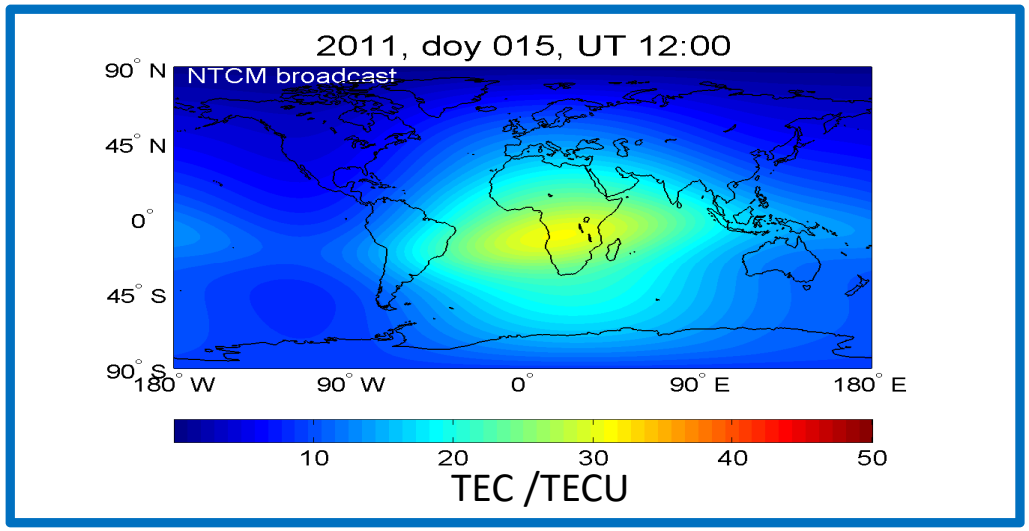
1 TECU is equivalent to16.3 cm range error at GPS L1 frequency

NeQuick-Galileo versus NTCM

NeQuick-Galileo Model



NTCM Model



parameter	model	# coefficients
peak ionization	24 maps	24 * 988 = 23,712
peak height	24 maps	24 * 441 = 10,584

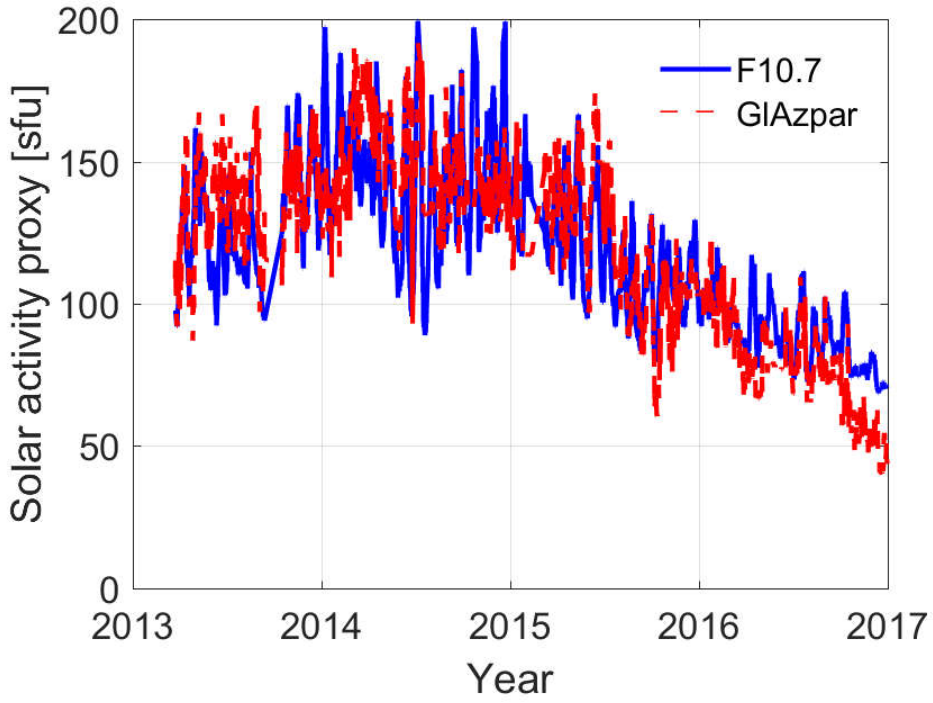
	NTCM	NTCM-BC	NTCM-Klobpar	NTCM-GIAzpar
# coeffi.	12	9	12	12

Fast ionospheric correction using Galileo Az coefficients and the NTCM model

GlAzpar is computed by

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

where a_{i0}, a_{i1}, a_{i2} are Galileo Az coefficients



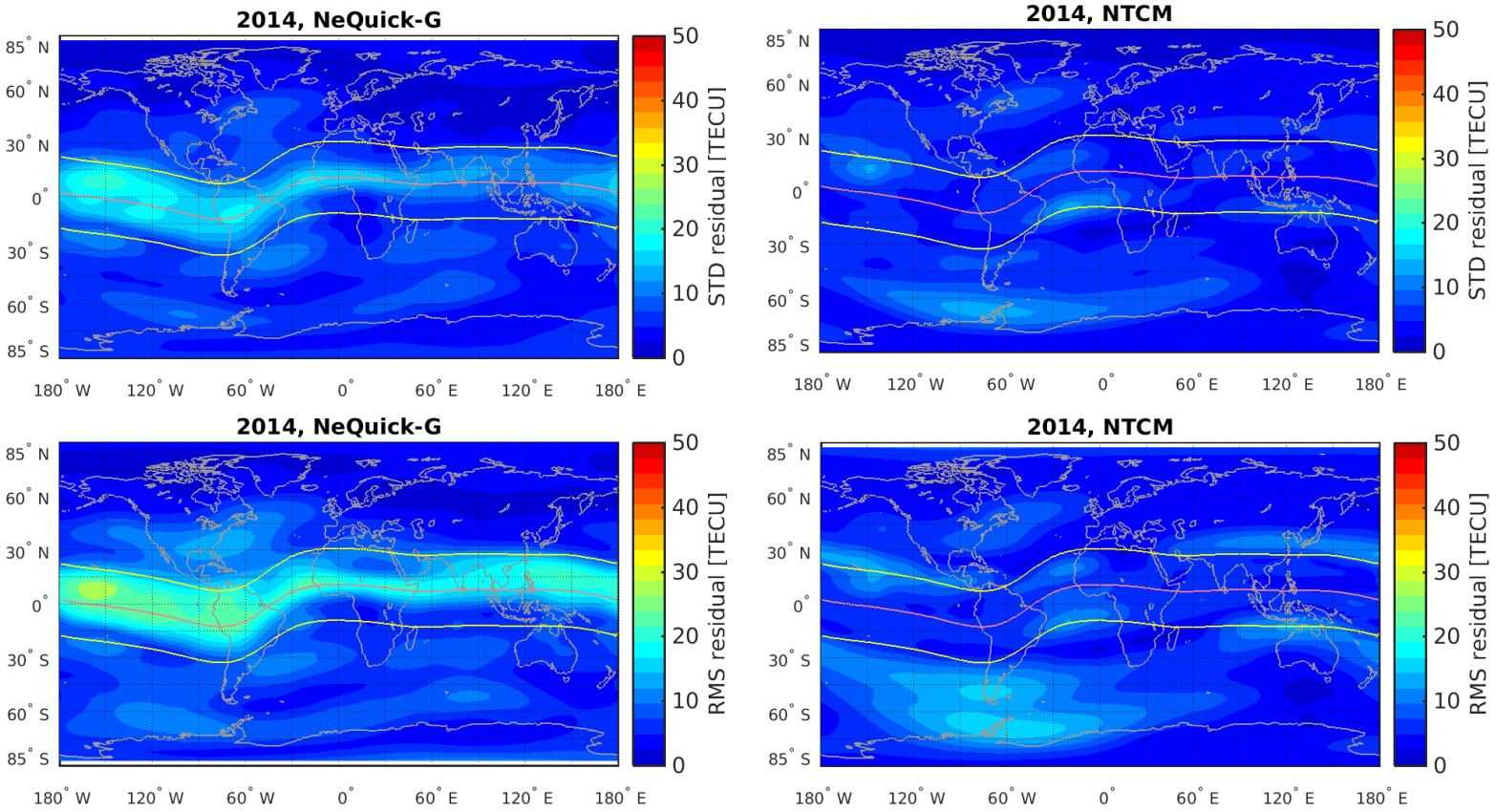
Comparisons of daily F10.7 and GlAzpar during 2013-2017. Special thanks to ESA for providing historical data of Az coefficients.

Hoque, M.M., Jakowski, N. & Orús-Pérez, R. GPS Solut (2019) 23: 41. https://doi.org/10.1007/s10291-019-0833-3

Vertical TEC performance- 1

VTEC residuals ($VTEC_{model}$ - $VTEC_{igsg}$) statistics considering **all local time**

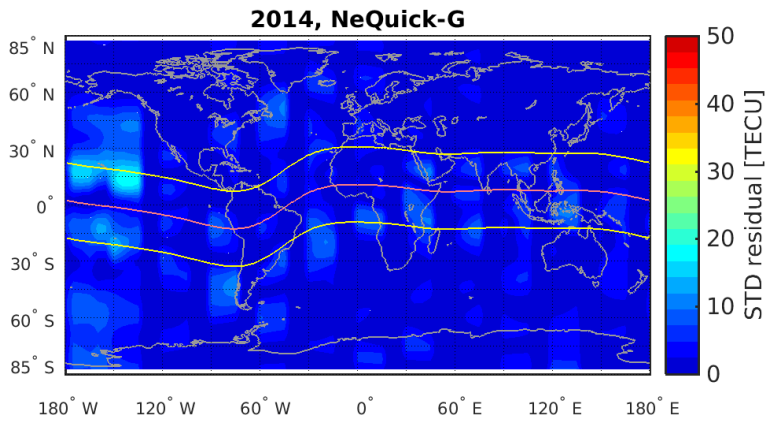
- Standard Deviation (STD)
- Root Mean Square (RMS)

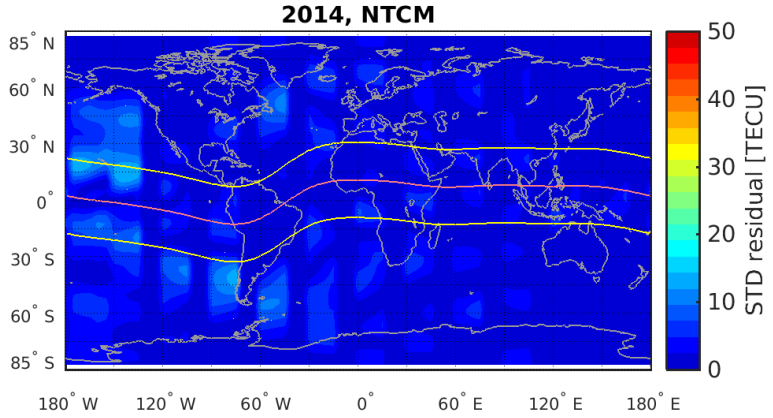


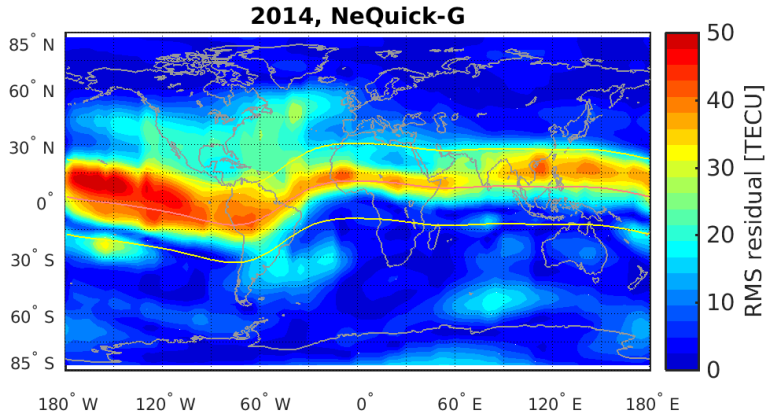
Vertical TEC performance- 2

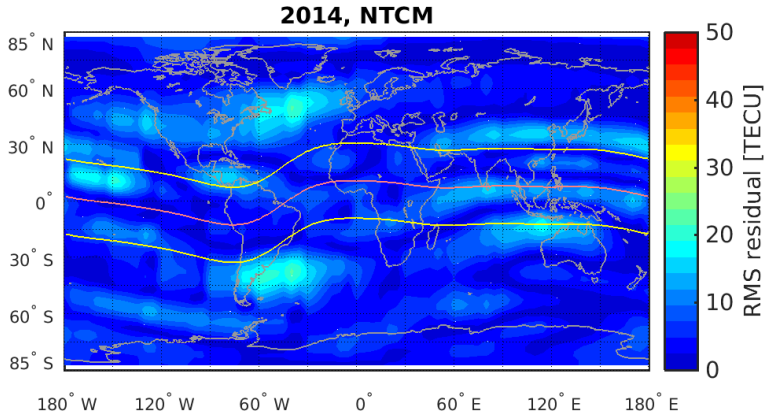
VTEC residuals statistics considering daytime hours **12-15 LT**

- Standard Deviation (STD)
- Root Mean Square (RMS)









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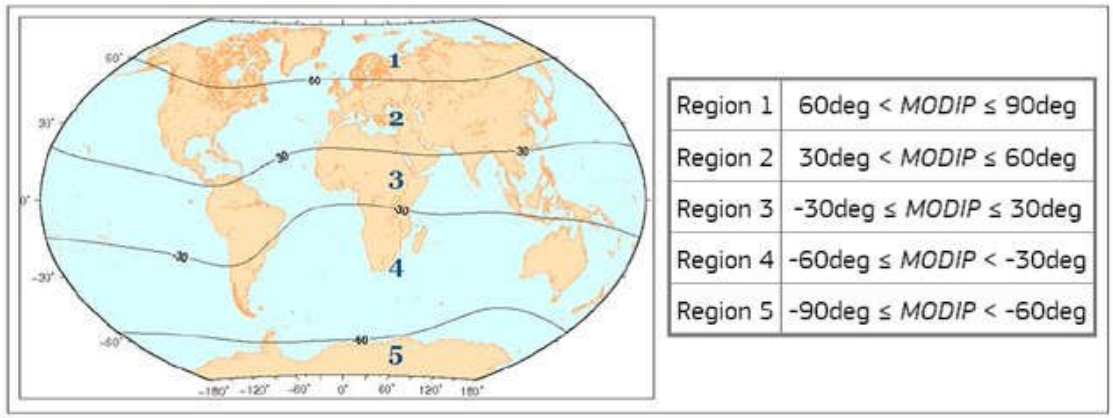
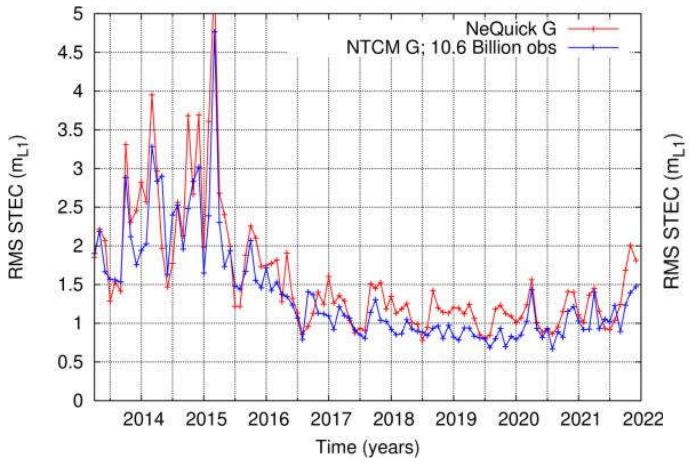
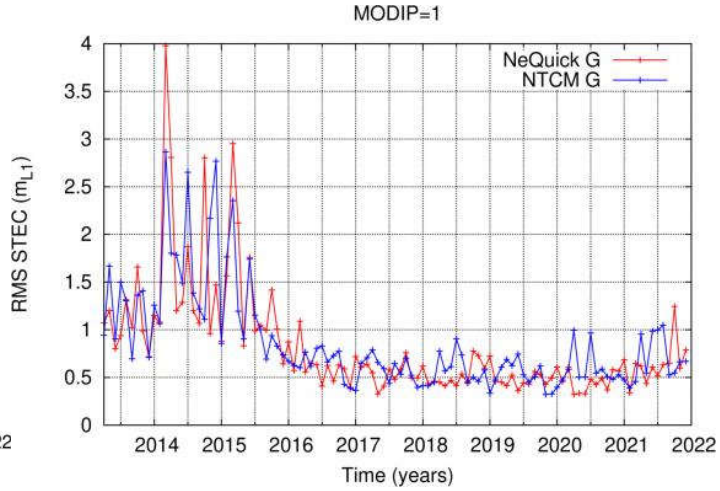
Slant TEC performance- 1

The performance of *NTCM G* and *NeQuick G* is assessed using independent Slant Total Electron Content (STEC) measurements computed at about 120 - 160 worldwide IGS ground stations for every day in the period March 2013 to December 2021



Region 1	60deg < *MODIP* ≤ 90deg
Region 2	30deg < *MODIP* ≤ 60deg
Region 3	-30deg ≤ *MODIP* ≤ 30deg
Region 4	-60deg ≤ *MODIP* < -30deg
Region 5	-90deg ≤ *MODIP* < -60deg

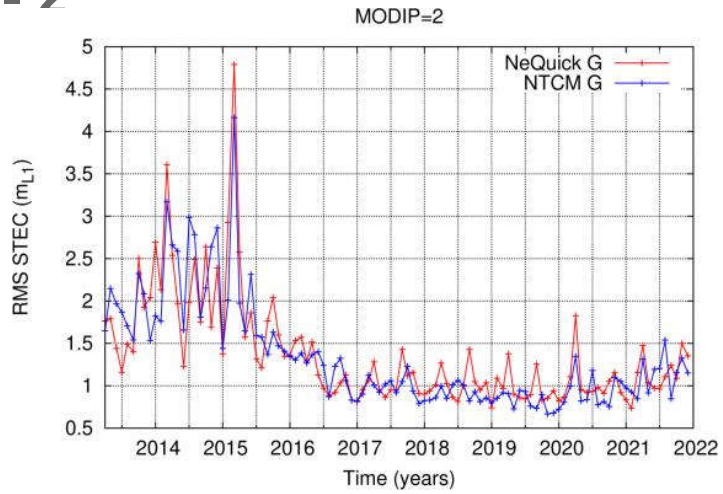


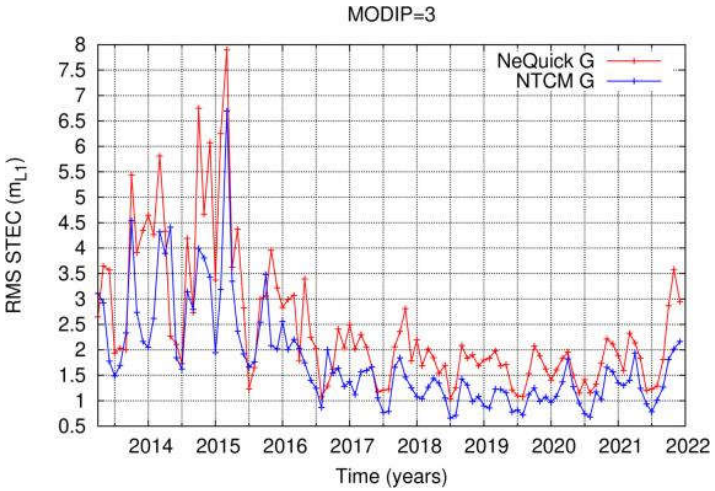


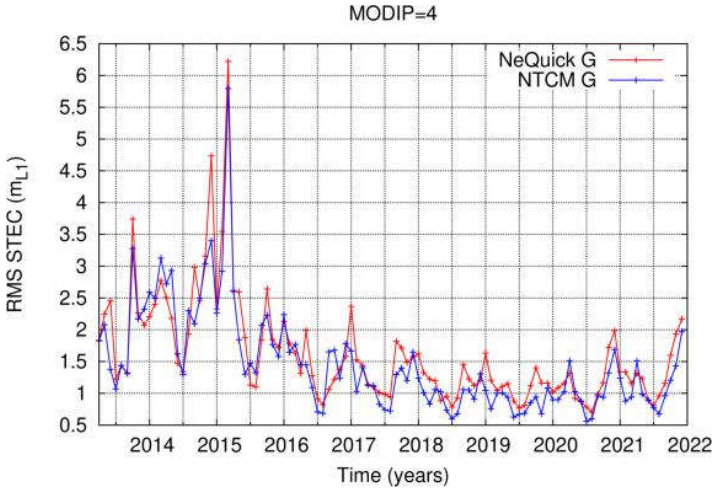
- Statistics of daily STEC residuals (monthly average) for the period March 2013 - December 2022 using NeQuick G and NTCM G

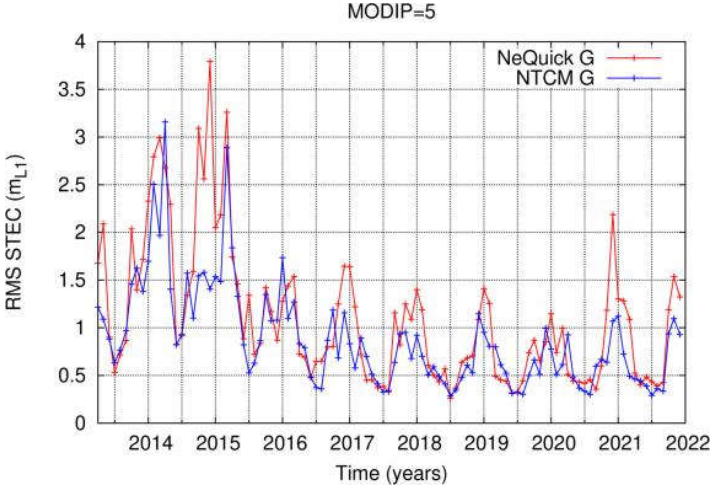
Slant TEC performance- 2

- Performance of both models is very similar and can be concluded that there is no significant difference in performance between NeQuick G and NTCM G



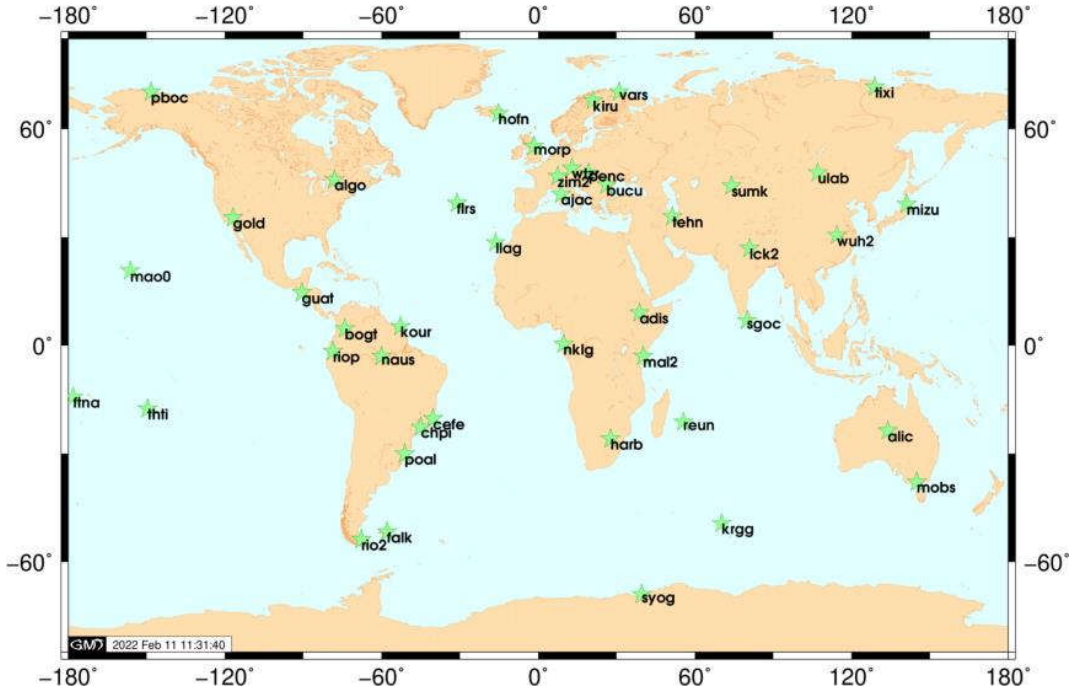






Global mean of 3D Position error- 1

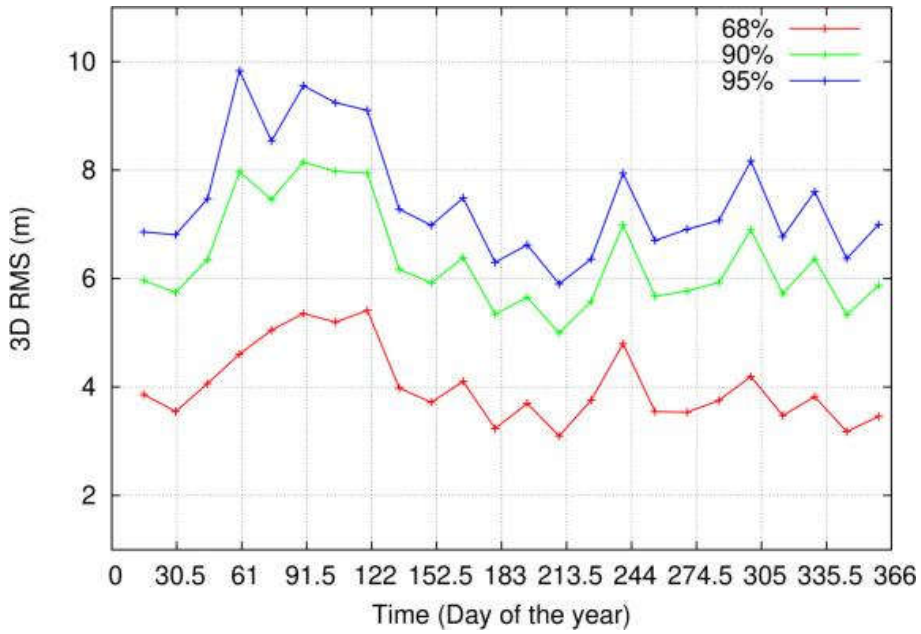
- An implementation of the precise point position (PPP) technique, following Sanz Subirana et al. (2013), is used to obtain the daily reference position for the receivers that are going to be used for the test.



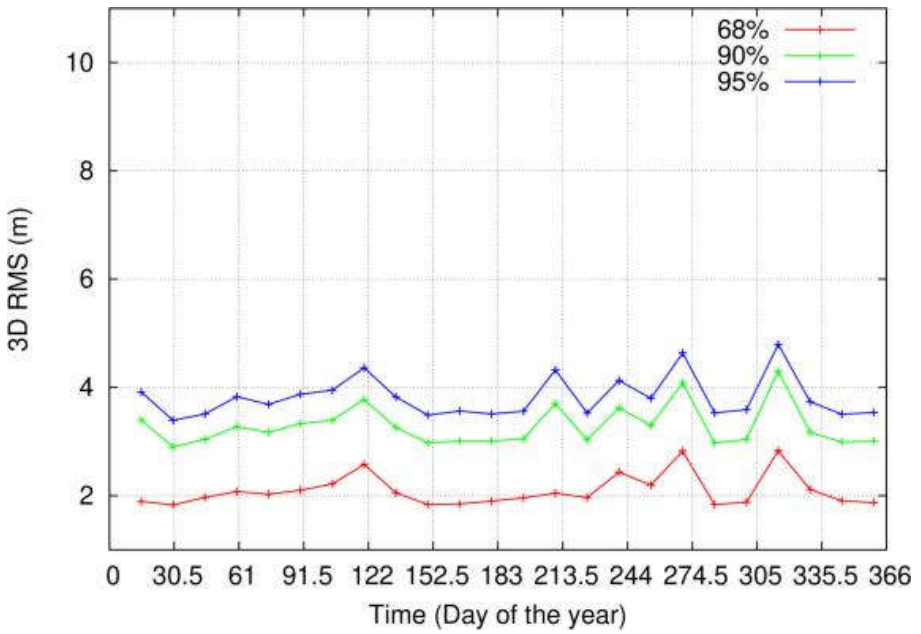
- Global set of IGS receivers (about 47) used for the position domain performance for 2014 and 2019.

Global mean of 3D Position error- 2

2014



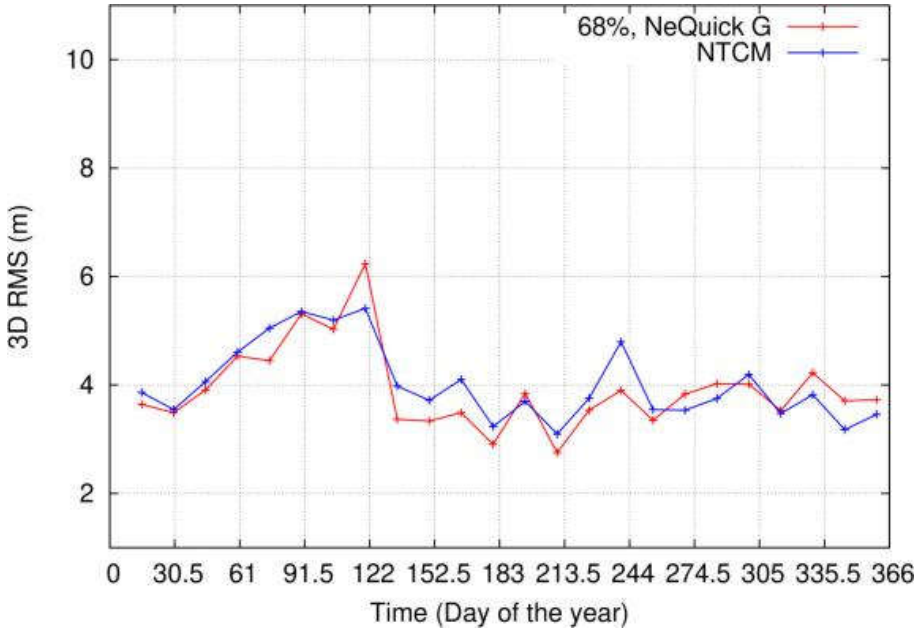
2019



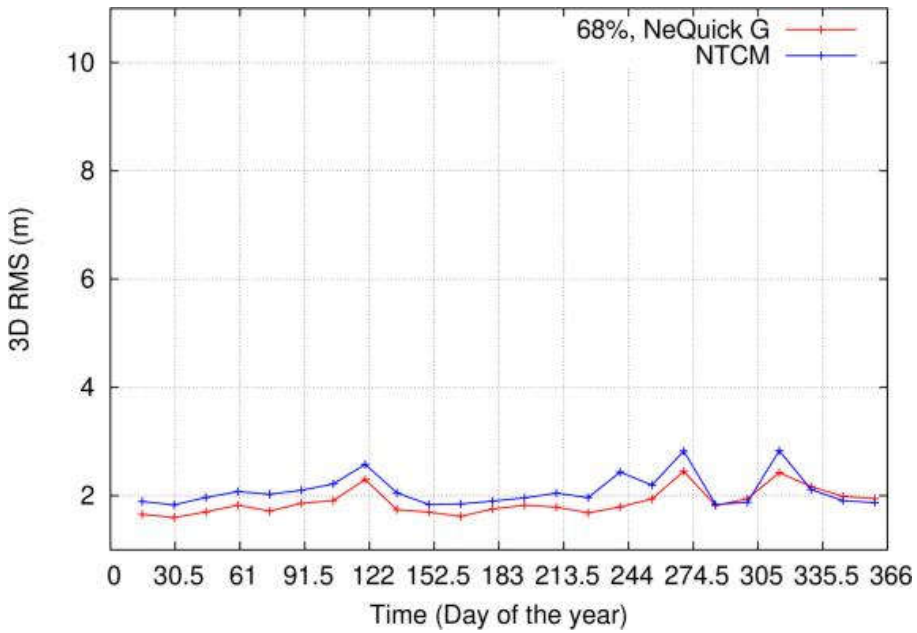
- 3D error as a function of the day for different percentiles and years. Left is 2014 and Right is 2019. Notice that the error is the 15-day weighted average

Global mean of 3D Position error- 3

2014



2019

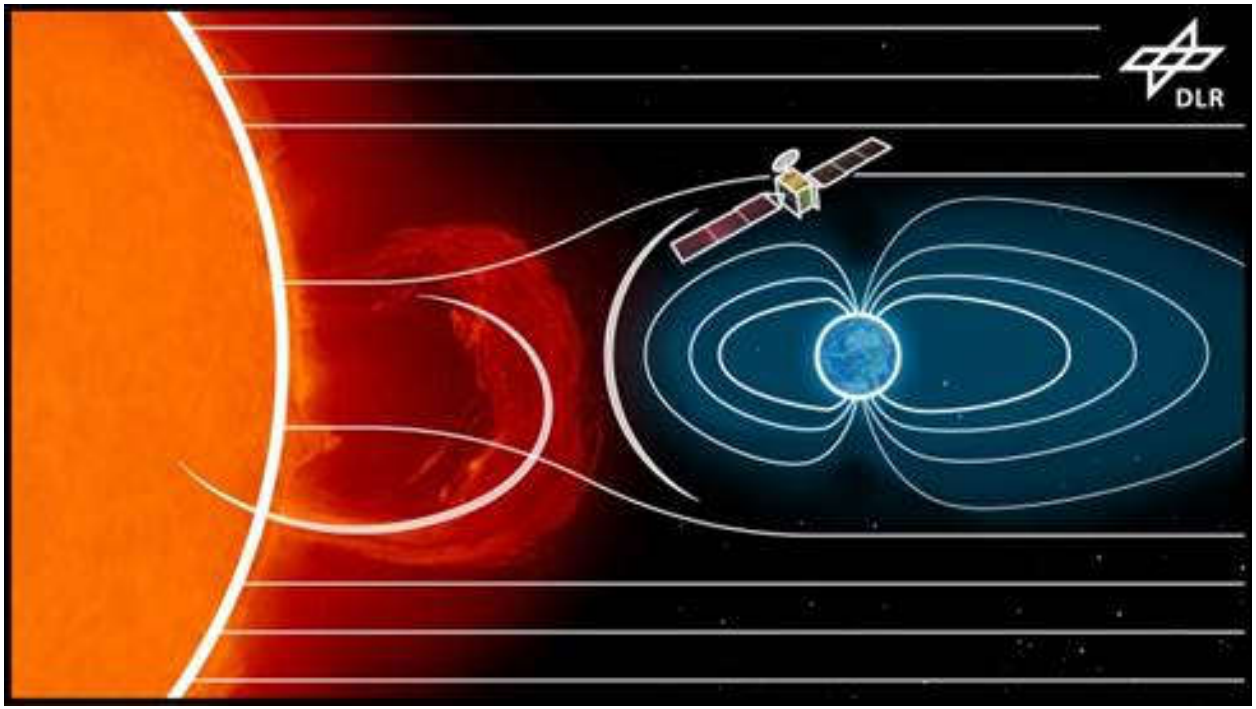


- 3D error as a function of the day for 68% percentile and years. Left is 2014 and Right is 2019. Notice that the error is the 15-day weighted average

Summary

- The investigation shows that the NTCM can be successfully driven by Galileo broadcast ionization coefficients.
- The global and regional performance analysis with reference VTEC data from IGS shows that the performance of the NTCM was at least equal to, or better than, the NeQuickG model in the global average.
- A comparison with reference STEC data shows that there is no significant difference between both models performance in terms of RMS residual statistics.
- A comparison with reference 3D position data shows that there is no significant difference between both models performance in terms of RMS residual statistics.
- NTCM-G runtimes (in C under VS) more than x1000 faster than NeQuick-G (from F. Menzione, M. Sgammini, „NTCM G Software Package," May 2022)
- Due to its low computational load, NTCM-G can be exploited for particular user communities, in particular Aviation
- It is assumed that most mass market and geodetic receiver manufacturers would favor a compact algorithm.

Thank you!



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