Comparison of NeQuick G and Klobuchar model performances at single-frequency user level

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I. Introduction

The accuracy of global navigation satellite systems (GNSS) is significantly impacted by the ionosphere, which is one of the main error sources in GNSS positioning. Due to its dispersive nature, the ionosphere alters the propagation of radio signals, leading to measurement errors. This effect can be successfully mitigated by utilizing multi-frequency receivers, while single-frequency receivers must rely on a correction model. In this poster, we present the results of a collaborative study between the Vienna University of Technology (TUW) and the Norwegian Mapping Authority (NMA). The performance of the NeQuick G and Klobuchar models was evaluated in relation to ionosphere activity affecting single-frequency users.

The ***Klobuchar model*** is an empirical model, developed for single-frequency users. Approximately 50% of the range error caused by ionospheric refraction can be corrected by applying the Klobuchar model. Its algorithm uses eight ionospheric coefficients, which can be found within the GPS navigation message [1]. The ***NeQuick G model*** is a three-dimensional and time-dependent ionospheric electron density model, adapted to provide real-time Galileo single-frequency ionospheric corrections. These real-time predictions are based on the Effective Ionization Level, *Az*. Three coefficients, broadcast within the navigation message are used to determine the parameter *Az.* NeQuick G is designed to achieve a correction capacity of at least 70% of the ionospheric code delay across all locations, times of day, seasons, and levels of solar activity. However, it may not be as effective during periods of significant ionospheric disruption (eg. geomagnetic storms) [2].

II. Methodology

The NeQuick G and Klobuchar models' evaluation was performed in post-processing mode, based on 30s data RINEX observation files. The validation station networks were located in three geomagnetic-latitude regions (Fig. 1).

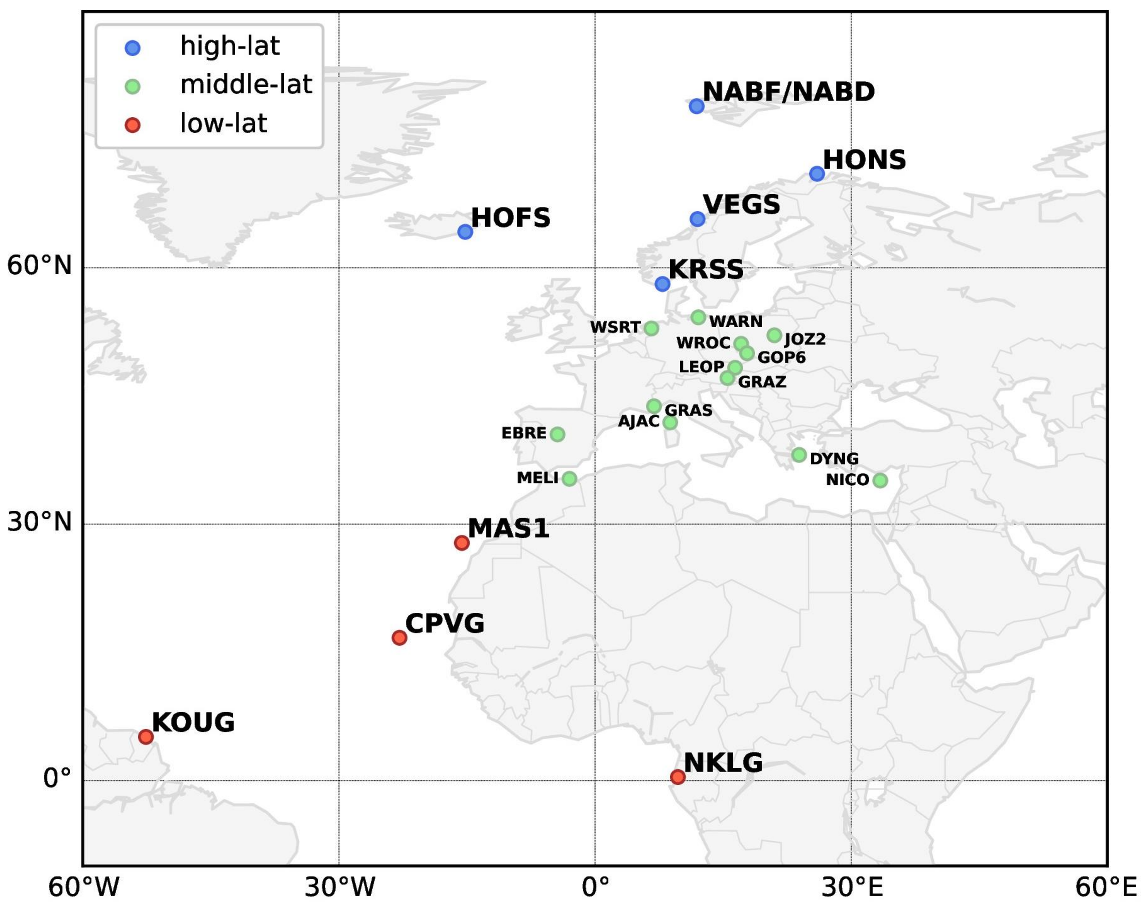

Fig. 1: Station validation map

VTEC accuracy (Section IV)

- **Vertical Total Electron Content (VTEC) values obtained from the tested models** at validation site locations are compared to **reference VTEC values** derived from respective dual-frequency observations via the geometry-free linear combination (L4).

Single-frequency (SF) position accuracy (Section V)

- The position accuracy is expressed by the 95th percentile **horizontal and vertical position errors** (HPE95, VPE95). Epoch-wise horizontal and vertical coordinate solutions of stations in Fig. 1 are calculated by applying the NeQuick G or Klobuchar model for ionospheric corrections and compared to the official station positions in ITRF2014.

Acknowledgements

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References

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4. Schaer, S., Beutler, G., Mervart, L., Rothacher, M., & Wild, U. (1996). Global and regional ionosphere models using the GPS double difference phase observable. In Proceedings of the IGS Workshop.
5. Buist, P., Mozo, A., & Tork, H. (2017, September). Overview of the Galileo Reference Centre: Mission, Architecture and Operational Concept. In Proceedings of the 30th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GNSS+ 2017) (pp. 1485-1495).

III. VTEC maps of the mid-latitude region (Europe)

The VTEC maps are based on a comparison of the NeQuick G and Klobuchar model (Fig. 2) w.r.t. the reference model CODG (global VTEC model provided by CODE [4]). The plots display the 95th percentile of the absolute VTEC difference (mean value of all days in June 2022), distributed over 12 2-hourly subplots.

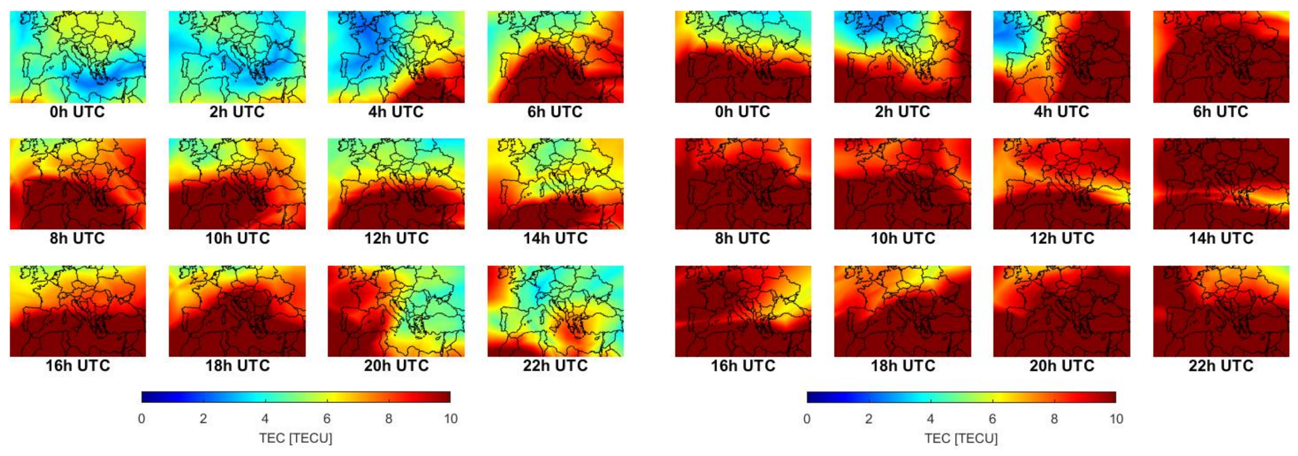

Fig. 2: NeQuickG VS Code (left), Klobuchar VS Code (right): Absolute VTEC difference 95th percentile (June 2022)

NeQuick G

- **04-20 UTC**: > 10 TECU* (southern part , below 45° latitude → entire region after **18 UTC**)

Klobuchar

- **06-22 UTC**: > 10 TECU (whole mid-latitude region)

* Total Electron Content Unit

IV. VTEC time series

The monthly mean VTEC error for the high/middle/low latitudes and for the NeQuick G and Klobuchar model are presented in Fig. 3. The average VTEC error values together with the standard deviations over the period 2019/01 - 2022/06 for both tested models are shown below.

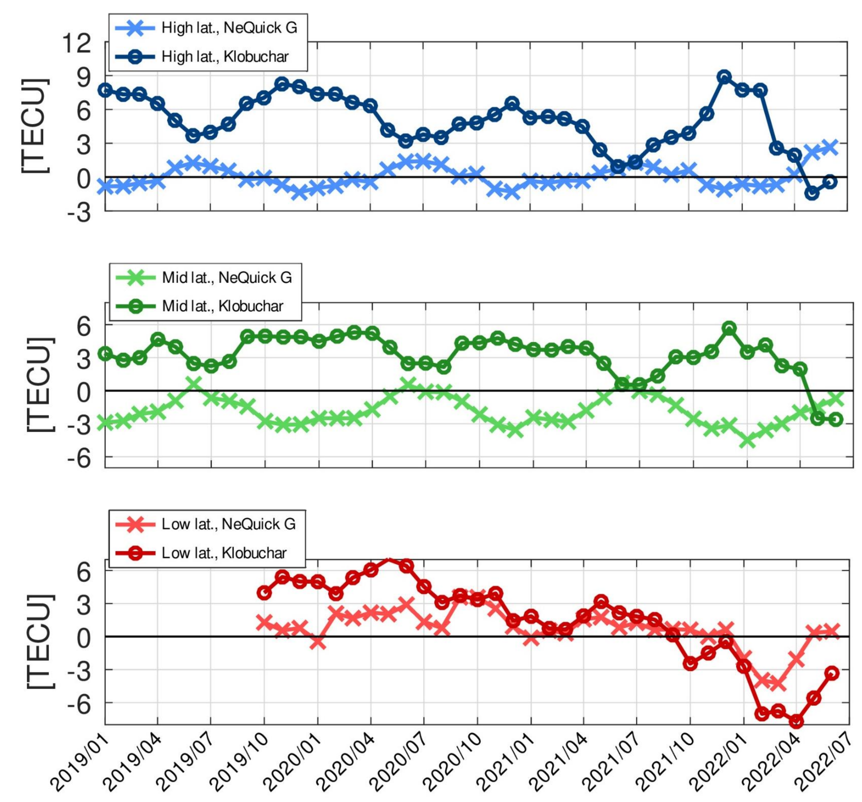

Fig. 3: Monthly mean VTEC error

High latitudes - ϕ [55°, 90°]

- NeQuick G: 0.1 $\pm$ 0.9 TECU
- Klobuchar: 4.9 $\pm$ 2.4 TECU

Mid latitudes - ϕ [30°, 55°]

- NeQuick G: -1.8 $\pm$ 1.3 TECU
- Klobuchar: 3.2 $\pm$ 1.8 TECU

Low latitudes - ϕ [-30°, 30°]

- NeQuick G: 0.7 $\pm$ 1.7 TECU
- Klobuchar: 1.4 $\pm$ 4.0 TECU

Starting from 2022/04 (high/mid lat) and 2022/01 (low lat) larger VTEC discrepancies → due to increasing ionization level and space weather activity as the Solar Cycle 25 (SC 25) approaches its maximum

V. Position errors

Monthly mean HPE95 and VPE95 values for the high/middle/low latitudes and for the NeQuick G and Klobuchar model are displayed in Fig. 4 and Fig. 5. The average position error values together with the standard deviations over the period 2019/01 - 2022/06 for both tested models are shown in corresponding subplots.

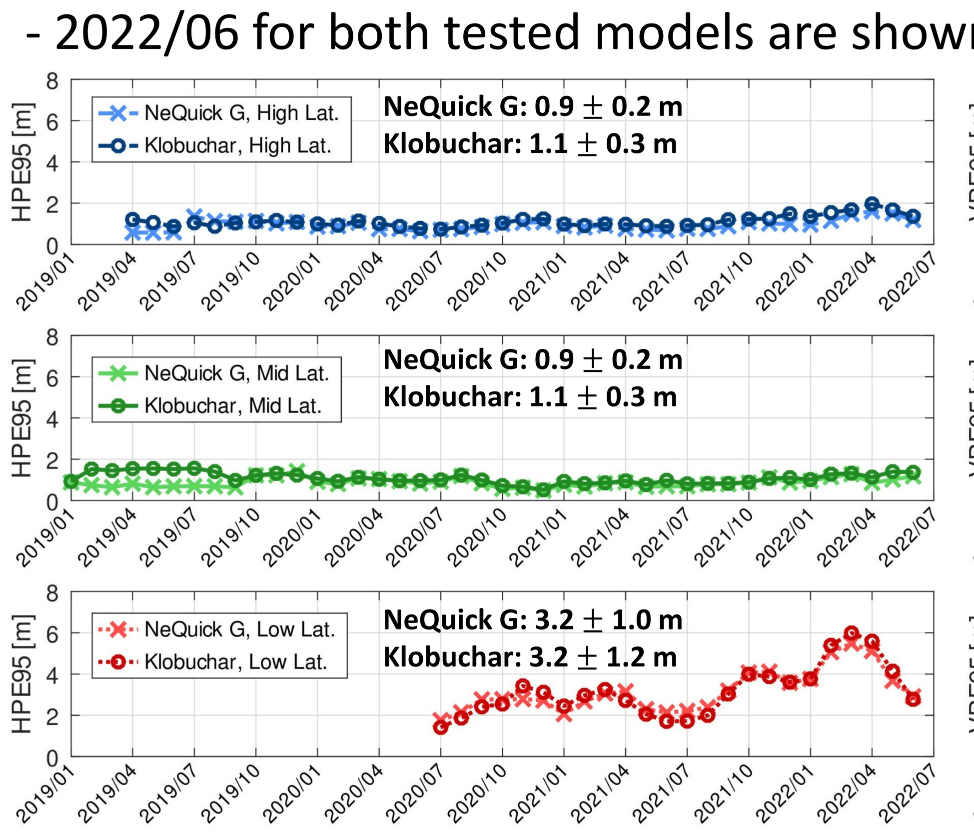

Fig. 4: Monthly mean horizontal position error (HPE 95%)

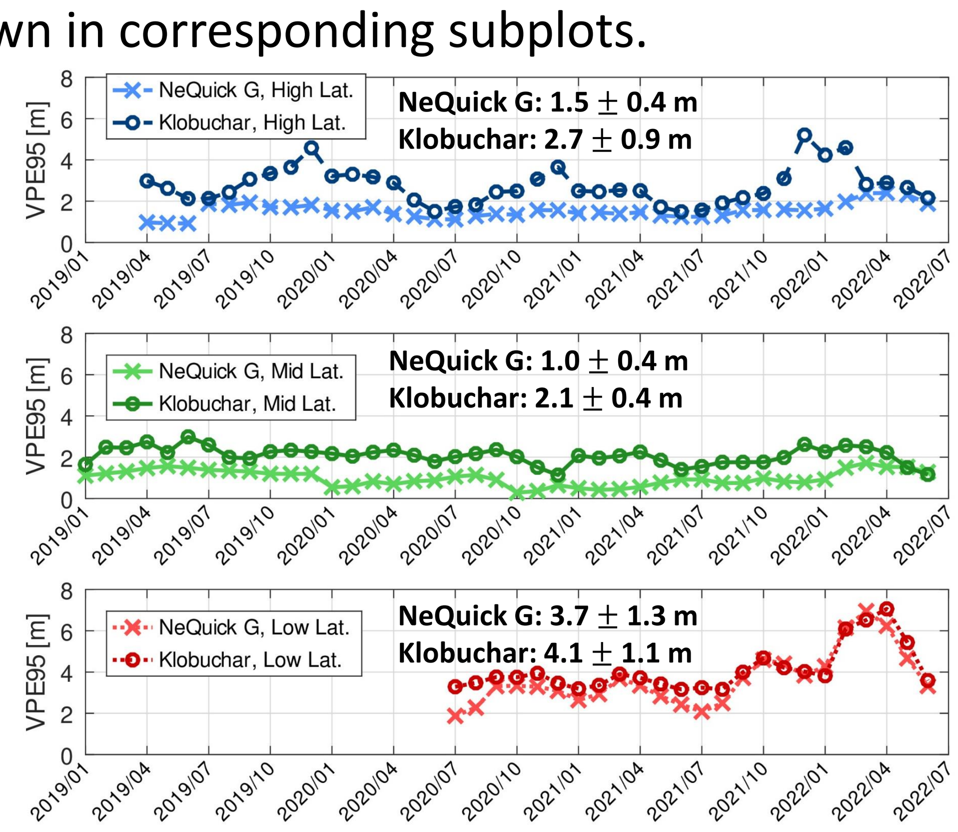

Fig. 5: Monthly mean vertical position error (VPE 95%)

Conclusions

- An annual and sub-annual VTEC trend is observed.
- NeQuick G provides better performance in terms of VTEC representation (smaller average mean VTEC errors) as well as ionospheric correction of station observations in GNSS positioning for single-frequency users (smaller average mean HPE95/VPE95 errors) compared to Klobuchar.
- The lower latitudes are under the highest influence of ionospheric activity, which is reflected in both VTEC and position error results.