Evaluation of NTCM-G ionospheric delay correction model for single-frequency SPP users

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Motivation

- The adverse effects of ionospheric delays limit the positioning accuracy of single-frequency GNSS users.
- To mitigate these effects, GNSS system providers make several ionospheric delay models available for the users (Klobuchar, NeQuick G, BDGIM).
- In the meantime, several independent models available for **real-time navigation** have emerged: NTCM-G (alternate for NeQuick G, from DLR), RT-GIMS (based on GNSS data streams, from CNES), etc.
- Due to the increasing availability of correction models, there is a need to evaluate their performance in positioning.
- Hence, in this contribution, we evaluate the performance of several global ionospheric delay correction models in 'precise' SPP mode (using precise orbit and clock corrections to reduce the impact of other error sources).

Evaluated ionospheric delay correction methods

1. No ionospheric correction

   Neglecting ionospheric delay.

2. CODG GIM

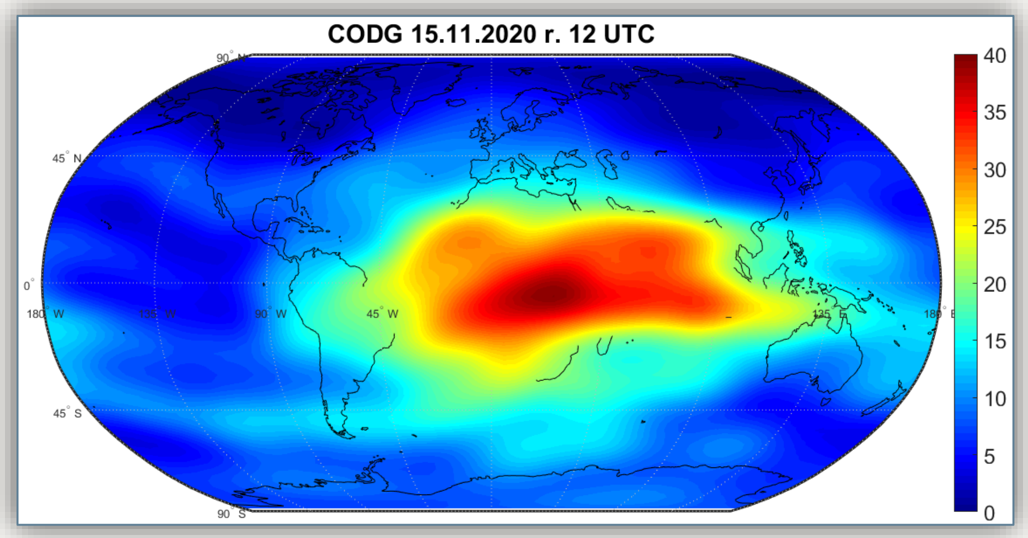
   Global ionosphere map (GIM) – reference #1.

3. Iono-free combination

   Requires dual-frequency obs. – reference #2.

4. Klobuchar model

   Broadcast parameters by the GPS satellites.



CODG GIM

```
     3.02           N: GNSS NAV DATA    G: GPS              RINEX VERSION / TYPE
GR50 V4.31          IGG of WUELS        20210109 235952 UTC PGM / RUN BY / DATE
GPSA   7.4506D-09 -1.4901D-08 -5.9605D-08  1.1921D-07       IONOSPHERIC CORR
GPSB   9.0112D+04 -6.5536D+04 -1.3107D+05  4.5875D+05       IONOSPHERIC CORR
GPUT  1.8626451492D-09 3.552713679D-15 233472 2140          TIME SYSTEM CORR
    18    18  1929     7                                    LEAP SECONDS
                                                            END OF HEADER
```

Klobuchar parameters from GPS navigation message.

Evaluated ionospheric delay correction methods

5. NeQuick 2

Empirical electron density model from ICTP.

Nava, B., Radicella, S. M., & Azpilicueta, F. *Data ingestion into NeQuick 2.* Radio Science, 46(06), 1-8 (2011). https://doi.org/10.1029/2010RS004635

6. NeQuick G

The new version developed for Galileo.

```
     3.02           N: GNSS NAV DATA    E: GALILEO          RINEX VERSION / TYPE
GR50 V4.31          IGG of WUELS        20210109 235952 UTC PGM / RUN BY / DATE
GAL      5.0500D+01  1.4453D-01 -2.8687D-03  0.0000D+00     IONOSPHERIC CORR
GAUT  9.3132257462D-10-8.881784197D-16 518400 2139          TIME SYSTEM CORR
GPGA  1.1932570487D-09-3.552713679D-15      0 2140          TIME SYSTEM CORR
    18     18  1929      7                                  LEAP SECONDS
                                                            END OF HEADER
```

NeQuick G Az parameters from Galileo navigation message.

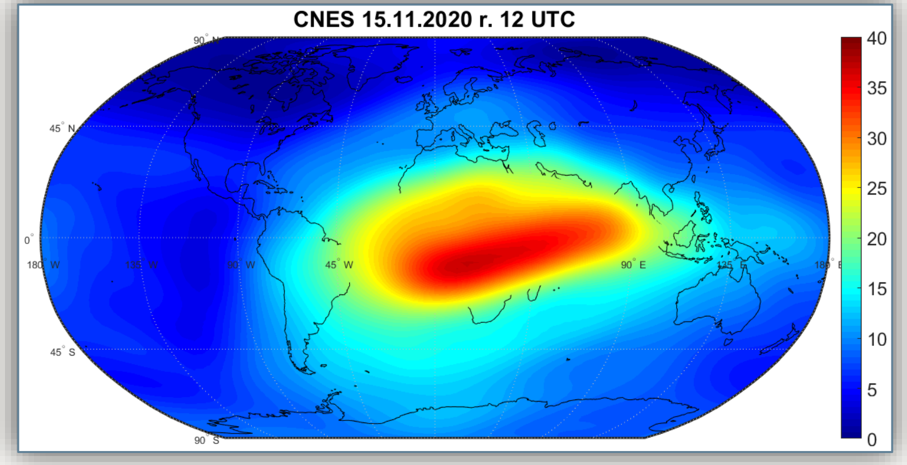
7. NTCM-G

Alternate for NeQuick G driven by Galileo Az parameters, developed by DLR.

Hoque, M.M., Jakowski, N. & Orús-Pérez, R. *Fast ionospheric correction using Galileo Az coefficients and the NTCM model.* GPS Solut 23, 41 (2019). https://doi.org/10.1007/s10291-019-0833-3

8. CNES RT GIM

Real-time GIMs transmitted as SSR corrections developed by CNES.



CNES RT GIM

Processing parameters

Positioning model

SPP (single-epoch)

Estimated parameters

Geocentric XYZ coordinates,
1 receiver clock correction /GNSS system

Troposheric delay

Modified Hopfield

Code observations

GPS (C1C), GLONASS (C1P)

Galileo (C1C), BDS-3 (C2I)

Weighting scheme

1/cosZ

Ionospheric delay

CODE, IF, Klobuchar, NeQuick 2, NeQuick G, NTCM, CNES RT GIM

Interval

180 seconds

Orbit and clock corr.

Precise GREC products from GFZ

Software

Own Matlab code

Elevation cut-off

15 degree

Hardware delays

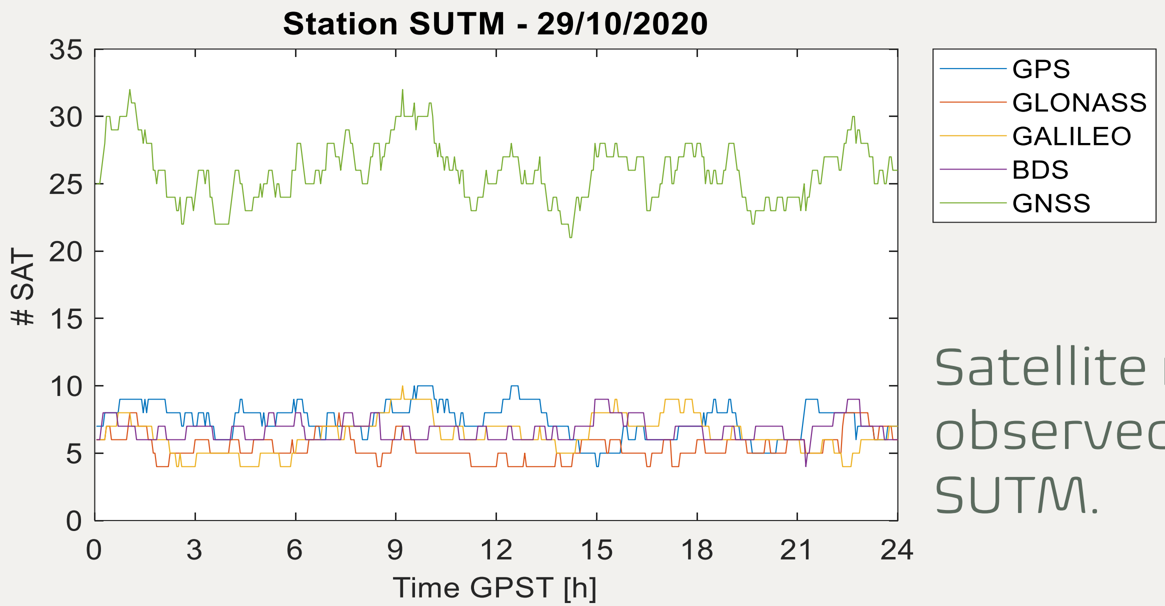
Absolute daily OSB from CAS

Reference coordinates

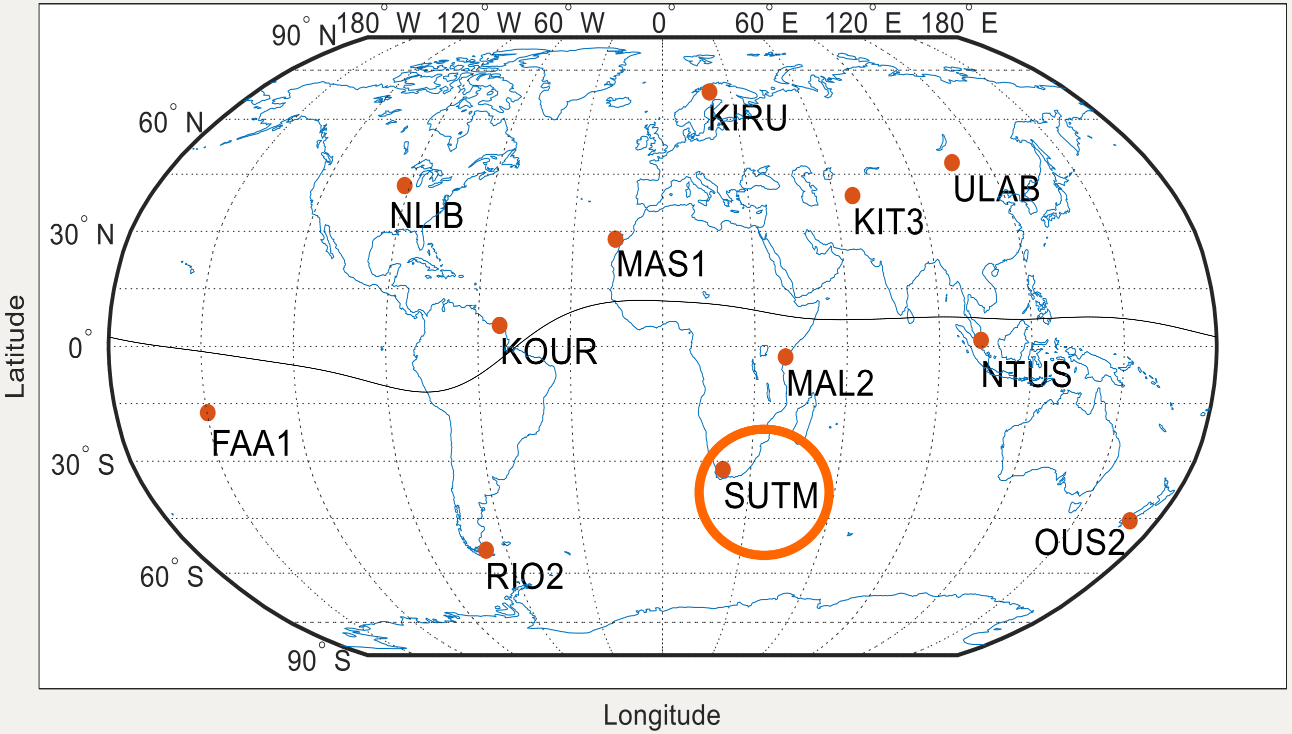
IGS14 frame

Test data

- The test data includes GNSS observations (GREC) **from DOY 166/2020 to DOY 80/2021**, covering a period of increasing solar activity.
- For the evaluation, we used single-frequency pseudorange data from 12 GNSS stations distributed globally, covering different latitudes.

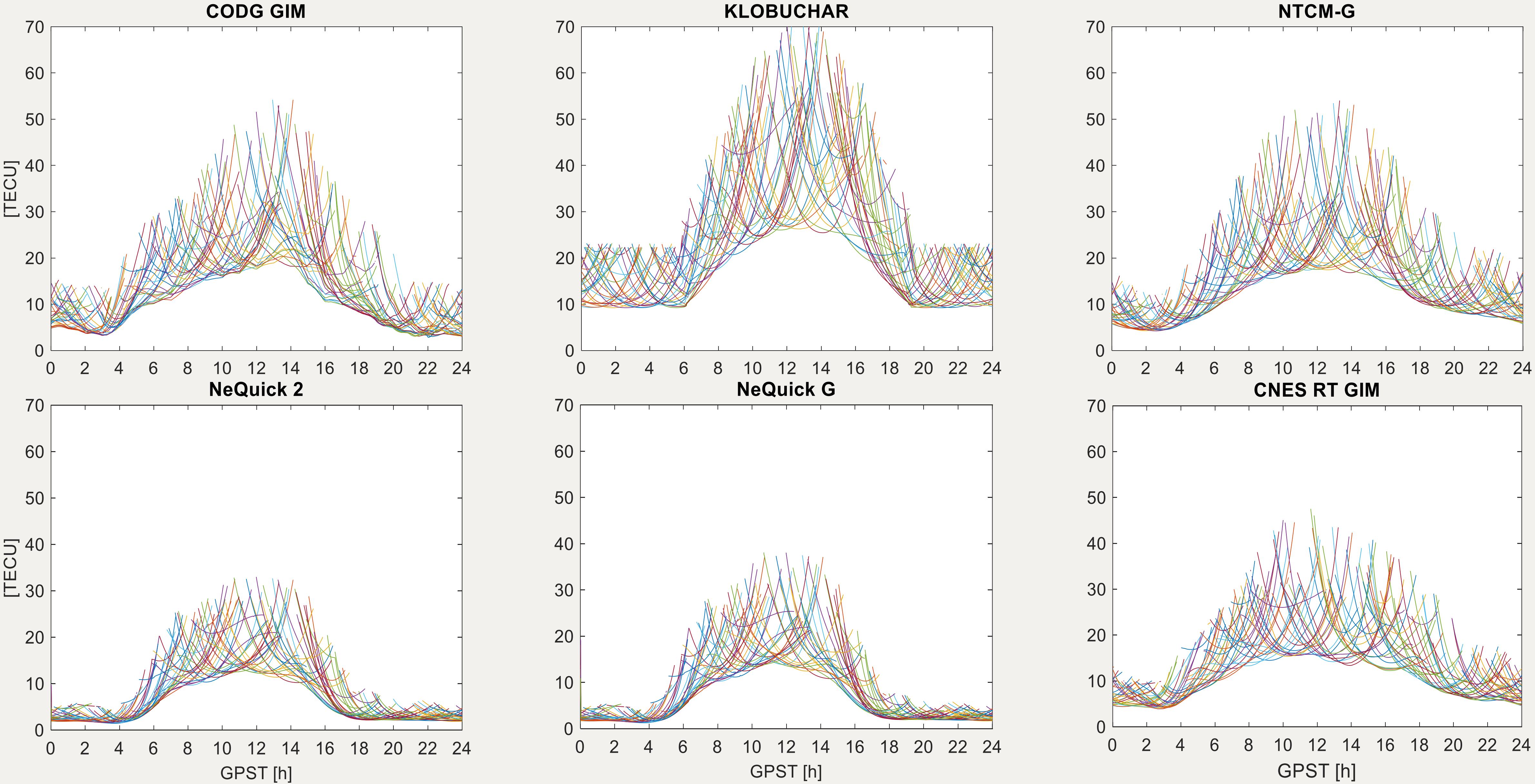


Satellite no. observed at SUTM.

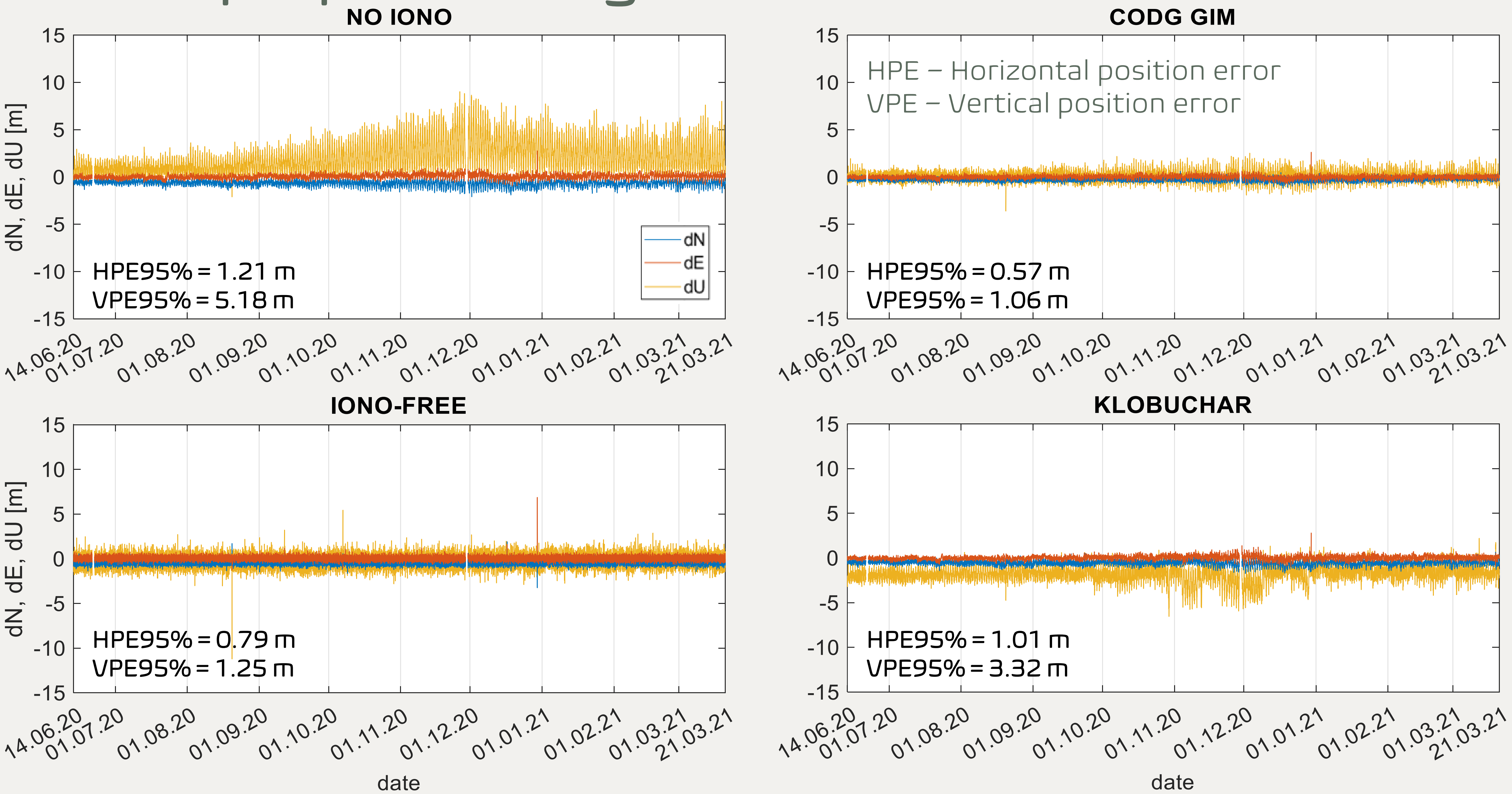


GNSS-tracking stations used for evaluation.

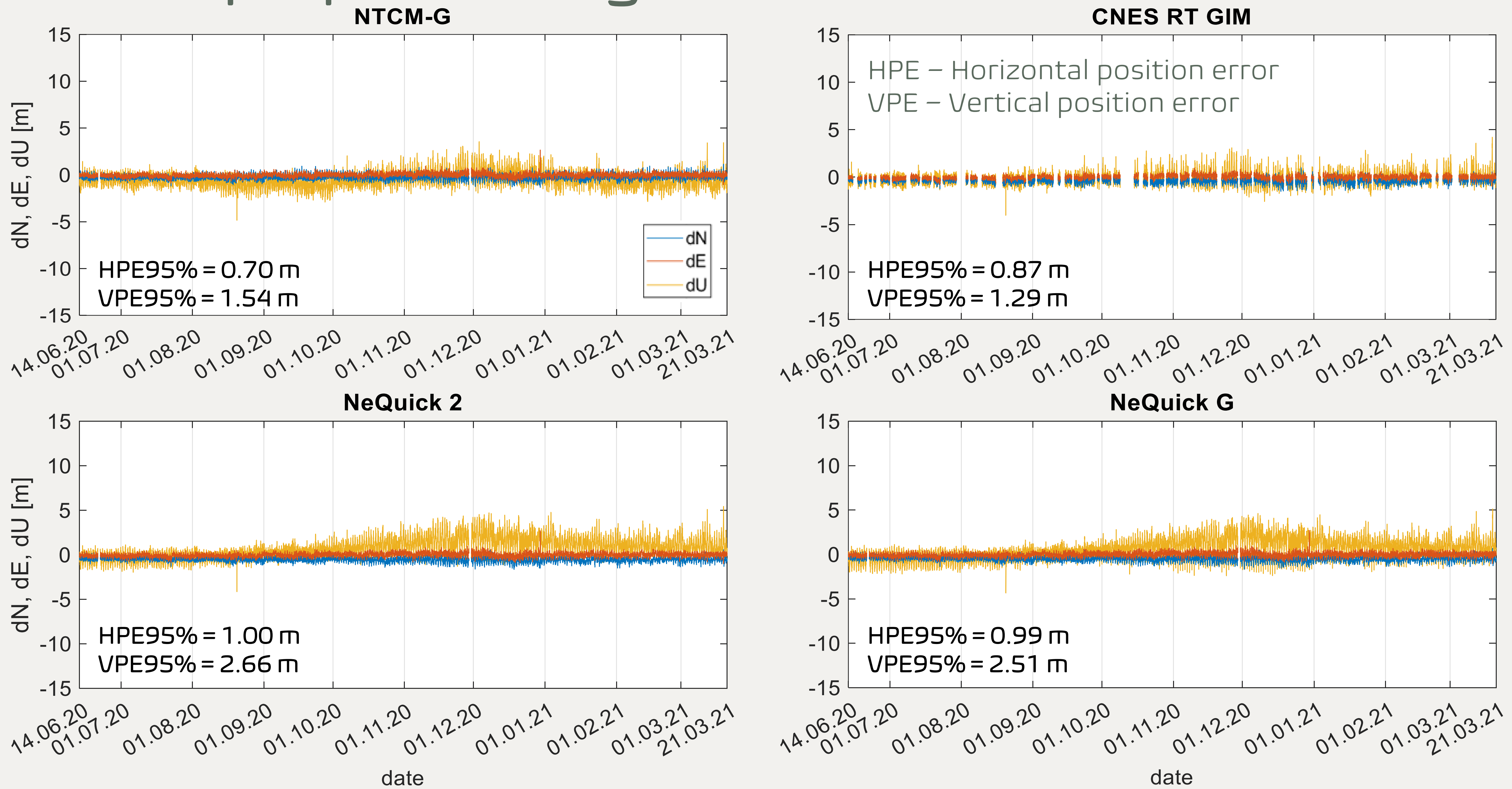
Example STEC – station SUTM, 29/10/2020



Example positioning results for station SUTM



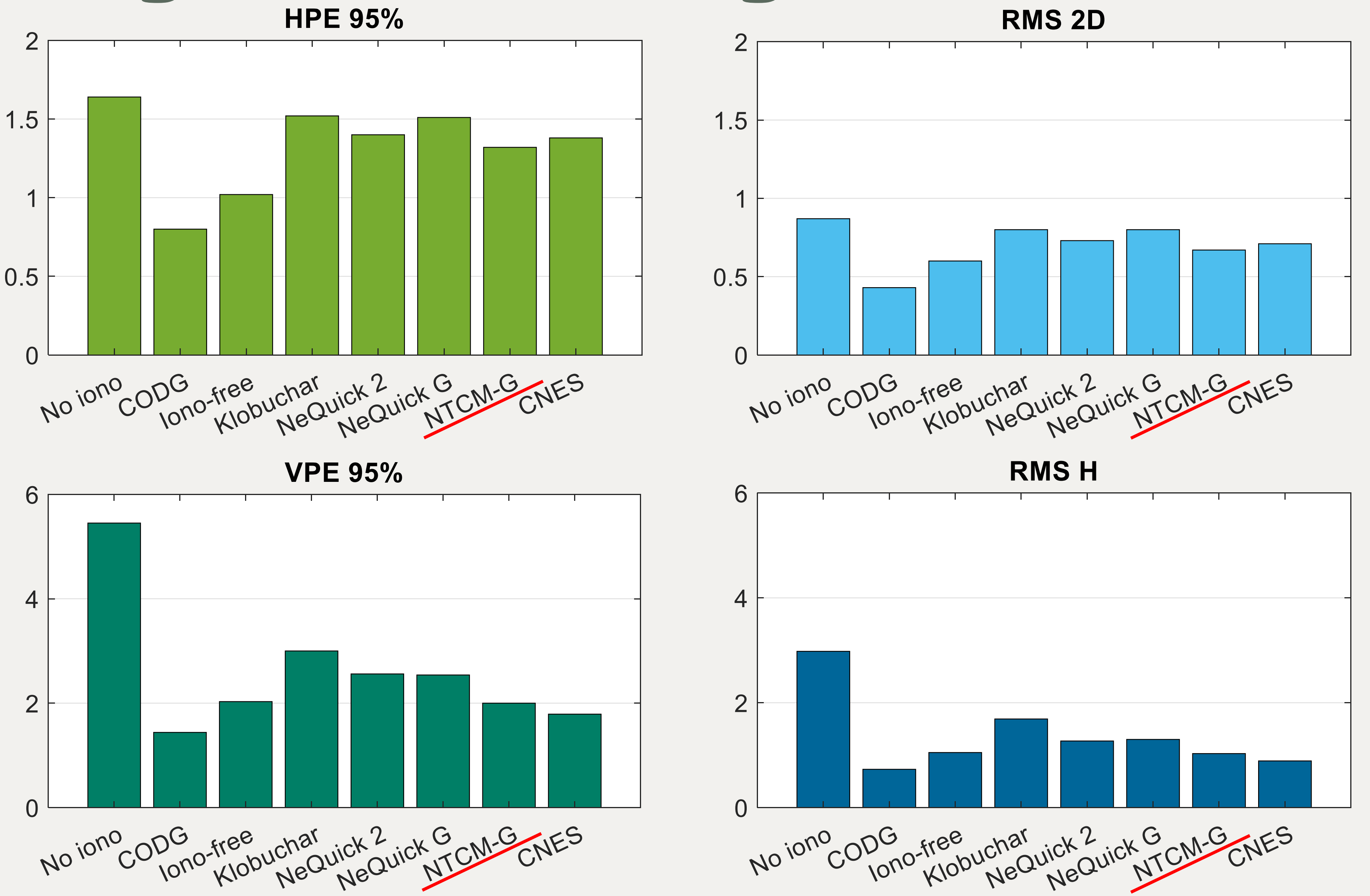
Example positioning results for station SUTM



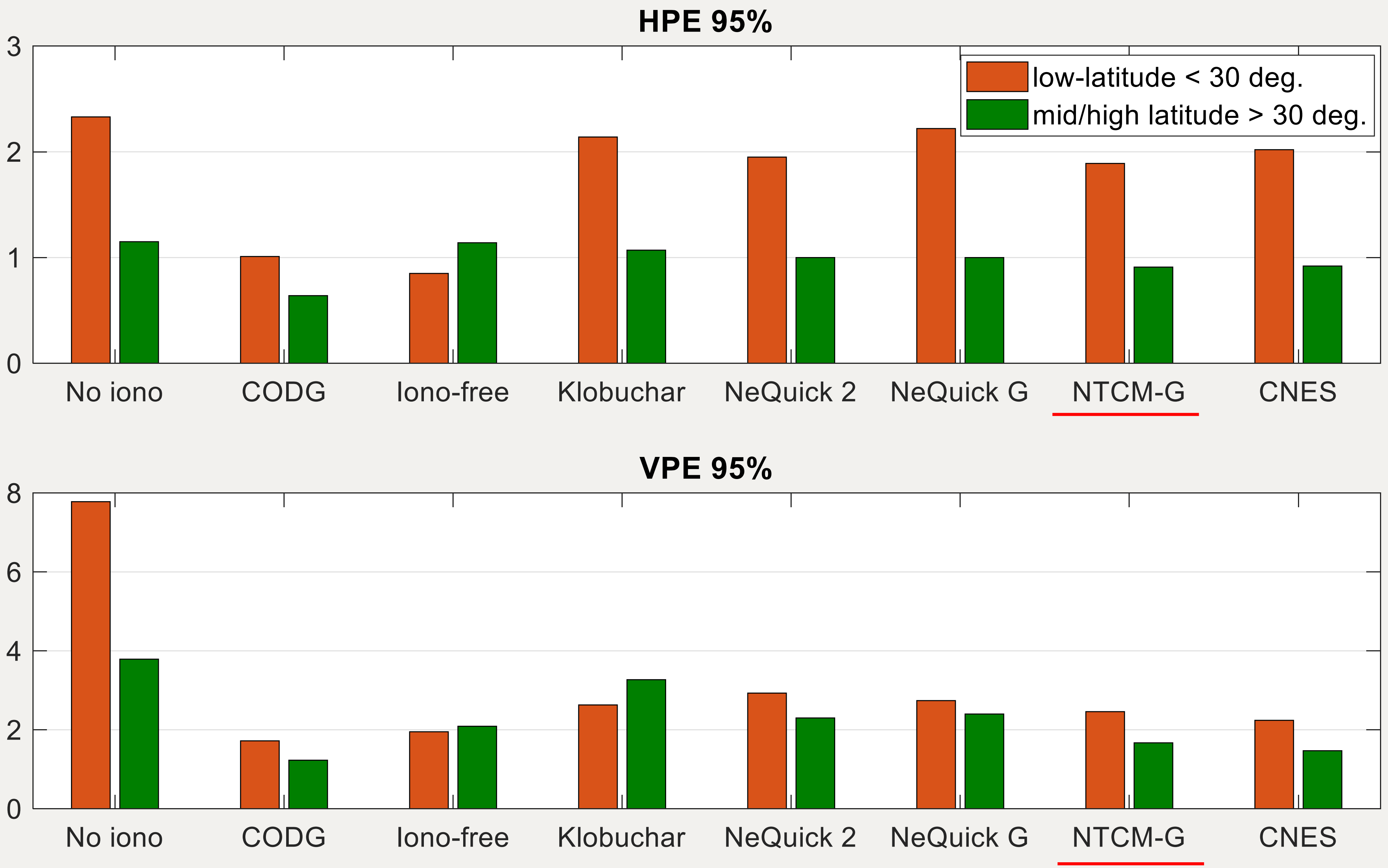
Positioning results – average from all stations

HPE –
Horizontal
position error

VPE –
Vertical
position error



Positioning results wrt station latitude



Conclusions

- Aplication of the Klobuchar model results in the highest coordinate errors.
- Both CNES and NTCM-G performs the best among tested methods.
- NTCM-G is a very good alternative for NeQuick G due to its performance and simplicity.
- Single-frequency solution supported with accurate ionospheric corrections often gives better results than iono-free combination based on dual-frequency signals.

Future studies: evaluation of BDGIM and EGNOS corrections.