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Comparing the different operational ionosphere models through total electron content and positioning errors

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Abstract

We used global ionosphere maps and single-frequency positioning error to compare different operational models: GPS (Klobuchar), Galileo (NeQuick-G), BeiDou (BDGIM), GLONASS. 11 GNSS stations and the 20-year data set was used. Preliminary, BDGIM and NeQuick-G overperform Klobuchar and GLONASS models in both domains.

1. Introduction

Ionosphere modelling is essential for different applications. There are physical models (including first-principle ones) and empirical models. Empirical models usually require fewer computational resources, hence they are used more often.

There are so-called operational models – they are empirical or numerical models with updating and broadcasting coefficients to increase their quality. Four operational models were created for single-frequency users of global navigation satellite systems (GNSS).

The current paper considers GNSS operational models and compares their quality from two points of view:

1) how they improve positioning (positioning domain);
2) how they forecast ionospheric total electron content (TEC domain).

To catch the peculiarities of a model (rather than an occasional feature), we need long-term investigations. Thus, we analyzed 20 years of data. The paper is our first step on multiple comparisons of different models.

2. Models and data

The models analyzed are:
- GPS (Klobuchar) model [1],
- BeiDou (BDGIM) model* [2],
- GLONASS model** [3]
- Galileo (NeQuick-G) model* [4].

We should note that:

* We have different statistics for models: BeiDou from 2010, NeQuick-G – from 2014.
** GLONASS model was not calculated based on the broadcasted parameters but instead on the F10.7 and Ap data.

Global ionospheric maps (GIM) of total electron content compose an excellent data source for model testing. As a reference, we use experimental total electron content data from UQRG global ionosphere maps produced by UPC [5].

We involved a 2000-2020 data set for 11 IGS stations. Fig. 1 shows the stations' location. The stations are located in different regions, including high-, low- and mid-latitudes.

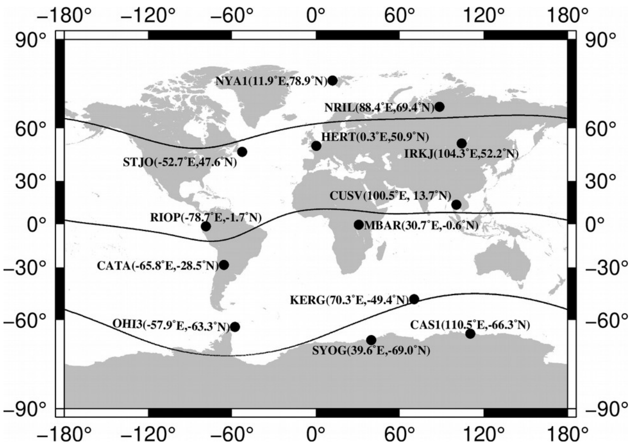

Figure 1. Location of GNSS stations.

3. Experimental results

3.1. Precision in the TEC domain

Fig. 2 shows TEC distribution from different models for 12:00 UT; January 1, 2020. The distribution differs a lot, especially in the equatorial anomaly crests. Klobuchar model does not reflect a two-crest structure, while

NeQuick-G does it. Maximal TEC values also vary significantly.

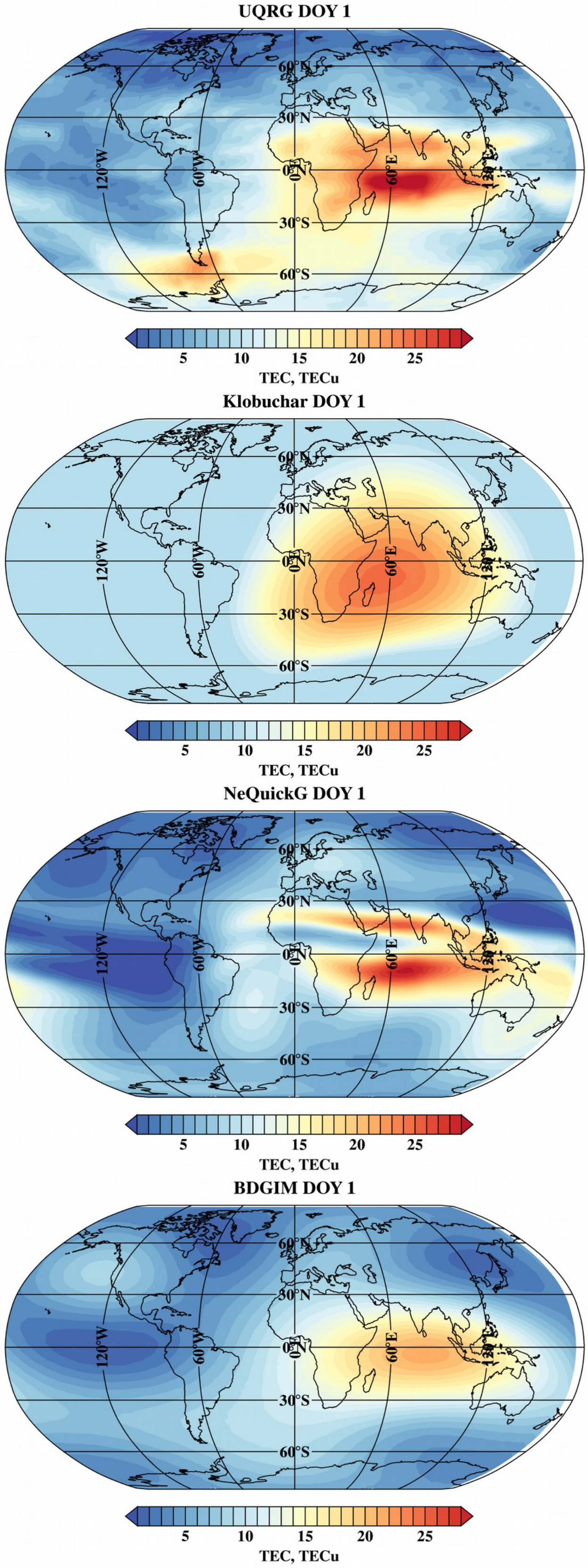

Figure 2. Global TEC distribution from global ionosphere maps and Klobuchar, NeQuickG and BDGIM models (top to bottom). 12:00 UT, January 1, 2020.

We calculated TEC distribution worldwide with resolutions of 1 hour in time, 2.5° in latitude, and 5° in longitude. Fig. 3 shows distributions of differences between model TEC and those from UQRG GIM for IRKJ region (52.5N, 105E – GIM cell) (the top panel) and worldwide (the bottom panel).

Data shows that BDGIM and NeQucik-G models are better in the TEC domain than GLONASS and Klobuchar models. It could be connected with different data sets. However, considering yearly data, the situation is similar: BGDIM and NeQuick-G overperform GLONASS and Klobuchar models.

The distributions show that the Klobuchar model overestimates ionospheric TEC, while other models provide almost non-biased estimates worldwide. For the Asian region (where IRKJ is located), BDGIM overperforms NeQuick-G. When we consider data year-by-years, we obtain the same results for BDGIM.

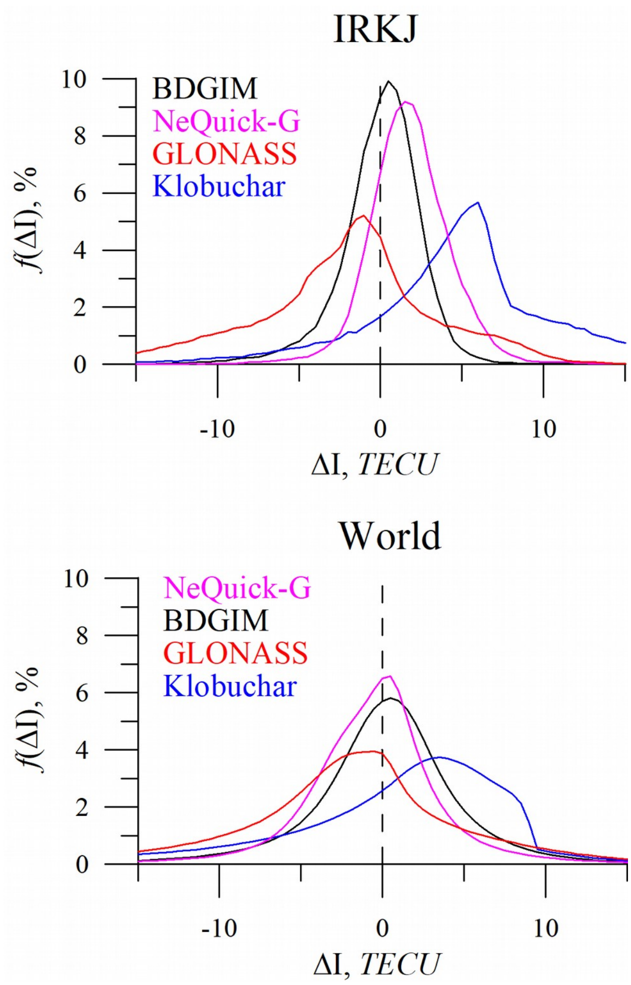

Figure 3. Distributions of differences between model TEC and those from UQRG GIM for IRKJ region (52.5N, 105E – GIM cell) (the top panel) and worldwide (the bottom panel).

3.2. Precision in the positioning domain

To calculate coordinates, we used a typical iterative single-frequency solution based on non-smoothed C/A pseudo ranges [6]. For each epoch, we have a coordinate estimation. The positioning error (for each coordinate) is calculated by calculating the difference between the median and estimated values for an epoch.

Fig. 4 compares different models in the positioning domain – it shows cumulative distribution functions. The distribution is based on data from all stations. Each of the models improves navigation solutions statistically. The best results are for the NeQuick-G model. But if we compare the same periods, BDGIM provides better results.

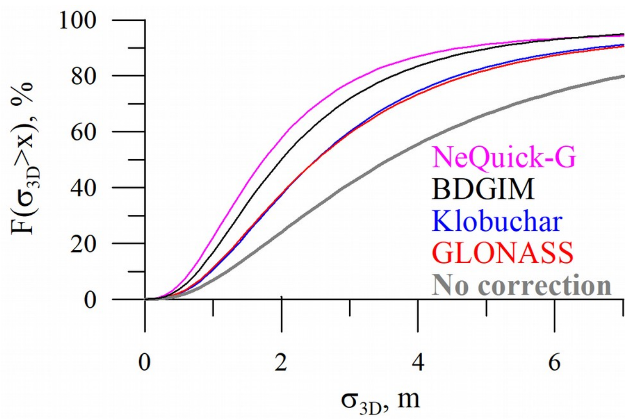

Figure 4. Cumulative distribution functions of 3D positioning errors for NeQuick-G (pink), BDGIM (black), Klobuchar (blue), GLONASS (red) models and no-corrected those (grey).

We should note a problem when we use the positioning domain. Fig. 5 shows 3D positioning errors for five stations and reveals sharp outliers for several periods observed by different stations. The outliers are caused by ephemeris problems (as preliminary results shown), so one should solve this problem before. Another problem could be with receiver problems.

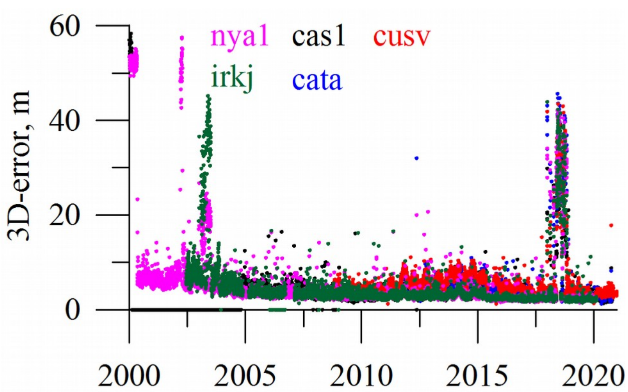

Figure 5. 3D-error dynamics at different stations

4. Conclusions

Preliminary results show that BDGIM and NeQuick-G provide better results in both positioning and TEC domains than Klobuchar and GLONASS model (while we should note that we used not specified indexes to drive the latter). The models feature different TEC root-mean-square and systematic errors. For the positioning domain, we should also note many events when a model deteriorates precision.

5. Acknowledgements

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