Global ionosphere product based on new mapping function

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Introduction

The electron density field of the ionosphere (stretching from about 80 to 2000 km) is highly variable in space and time. Still, the so-called Single Layer Model (SLM) Mapping Function (MF), which is based on a thin shell approximation of the ionosphere, is applied to generate global ionospheric maps. At the GFZ we developed a MF which is based on a realistic electron density field, i.e., the International Reference Ionosphere (IRI). The station specific MF utilizes a look-up table which contains a set of ray-traced ionospheric delays. Hence, unlike the simple MFs that are currently in use, the developed MF depends on the time, location, elevation and azimuth angle. Ray-bending is taken into account, which implies that the MF depends on the carrier frequency as well.

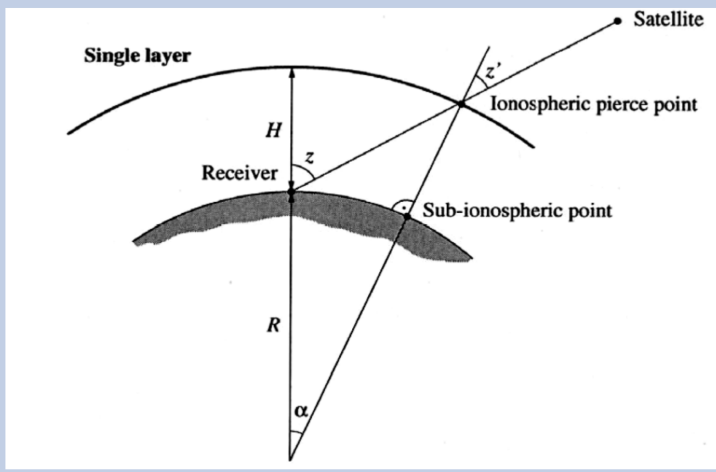
Since satellite- and station–specific Differential Code Biases (DCB) are estimated together with vertical total electron content (VTEC) maps, the proposed new MF can reduce the correlation between VTEC and DCBs. In order to verify the new MF concept we modified the Bernese software Version 5.2. The data from 264 stations on 15 March 2012 is used to estimate global VTEC maps and station DCBs. After comparing the results of the proposed MF to the SLM MF we find significant differences, in particular around the equatorial anomaly. The VTEC differences is up to 14 TECUs, while the station DCBs can have a difference of up to 4.6 ns. In mid-/high- latitudes the DCBs and VTEC differences are typically below 1 ns and 2 TECUs.

Ionospheric delay and mapping function

The ionosphere is a shell of free electrons and electrically charged atoms and molecules, which surrounds the Earth. The charged particles in the ionosphere have a frequency-dependent effect on GPS signal propagation. From dual-frequency observations the ionosphere combination can be formed as:

$$P_I = P_1 - P_2 \approx 40.28 \cdot STEC / f^2 - DCB_{rec.} - DCB_{sat.}$$

P_I is proportional to slant total electron content (STEC). The DCBs are satellite– and station–specific Differential Code Biases, which are assumed as constant during one day. In the single ionospheric layer model the STEC can be represented as VTEC with a Mapping Function. Under this assumption together with DCB parameters a global VTEC map can be estimated from data of global GNSS networks.



The most commonly used MF is the so-called Single-Layer Model (SLM) MF (Schaer, 1999), which assumes that the electron density field over one GNSS station is spherically symmetric.

$$M(z) = \frac{1}{\cos(z')}; \text{ where } \sin(z') = \frac{R}{R+H} \cdot \sin(z)$$

$$VTEC = STEC / M(z)$$

Ionospheric Mapping Function based on IRI

Ray-integral computation

In order to determine the ionospheric delay from a 3D electron density field the ray-integrals must be computed. Given the position of the satellite and the position of the station the ray-paths are calculated using Fermat's principle. Once the ray-paths are computed the ray-integrals are computed by numerical integration. The ionospheric delay can be computed with high speed and millimetre level precision for any elevation angle down to 3°.

The accuracy of the computed ionospheric delay depends mainly on the underlying electron density field. From International Reference Ionosphere (IRI) (Bilitza, 2001) we extract a grid every hour with a horizontal resolution of 2° by 2° on 97 equidistant altitude levels between 80 and 2000 km. Below (above) the IRI the electron density is obtained by log linear extrapolation.

For a given station and epoch 144 elevation- and azimuth- depended values of the ionospheric delay and VETC at sub-IPP are computed and stored in a look-up table; the elevation angles are 3°, 5°, 7°, 10°, 15°, 20°, 25°, 30°, 40°, 50°, 70°, 90° and the azimuth angles are 0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300°, 330°. The orbital altitude is chosen to be 20,200 km and the sub-IPP is chosen to be 450 km.

Simulation study

To analyse the effect of the new MF a simulation study is carried out (Zus, 2015). 783 stations with global coverage are used. For each station the 144 STEC are calculated from IRI (12 UTC 15 March 2012). Using SLM MF the VTECs at the sub-IPP are calculated from the STECs and compared with the VTECs at IPP from the look-up tables.

Fig.1 shows the VTEC error at the elevation angle 3° and the azimuth angle 180° for each station. In Fig.2 the statistic over all stations as a function of elevation is given. It can be seen, that the SLM MF causes an overall overestimation of VTEC in this case.

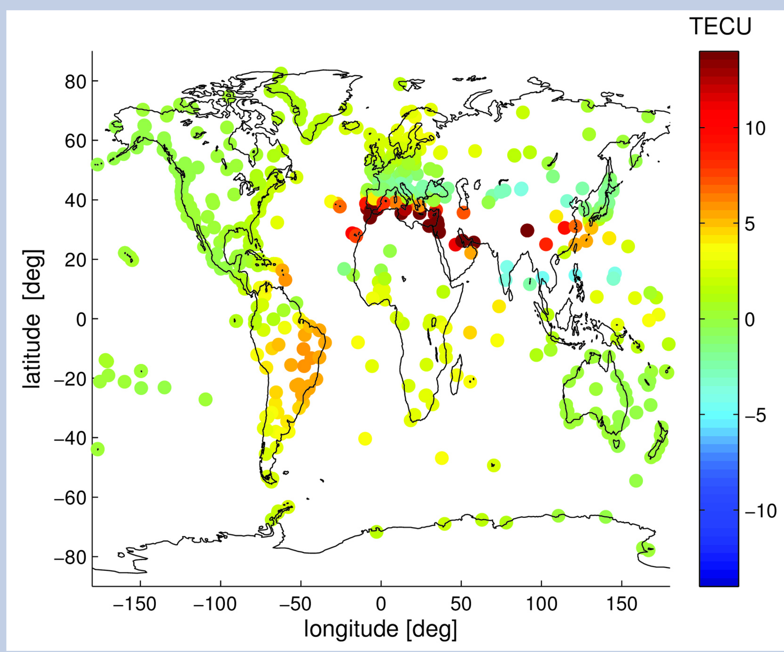


***Fig. 1:** Global map showing the error of the VTEC [TECU] at the sub-IPP 450 km due to the error of the SLM MF. The elevation angle is 3° and the azimuth angle is 180° (12 UTC on 15 March 2012). For this specific elevation and azimuth angle the global map shows the deviation between the SLM MF and the MF measured in terms of the VTEC at the sub-IPP.*

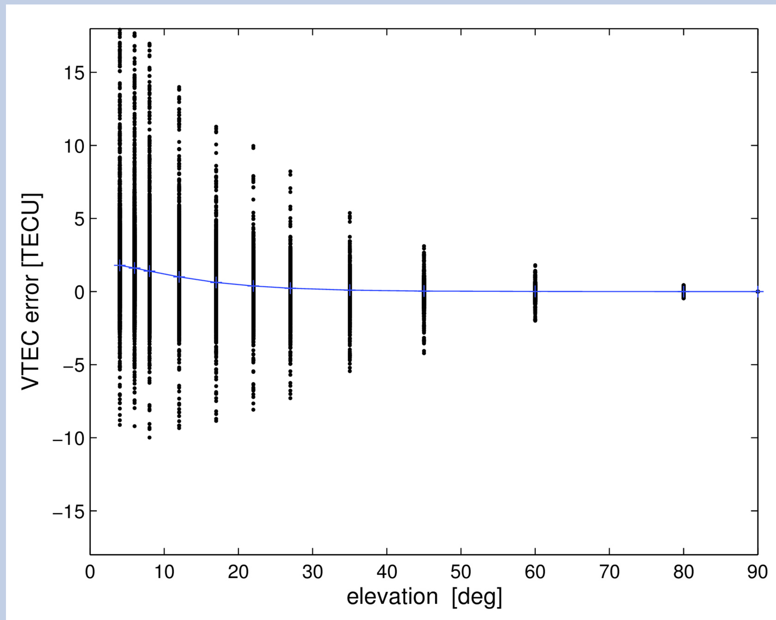


***Fig. 2:** The error of the VTEC [TECU] at the sub-IPP 450 km due to the error of the SLM MF as a function of the elevation angle (12 UTC on 15 March 2012). The blue line indicates the mean deviation as a function of the elevation angle.*

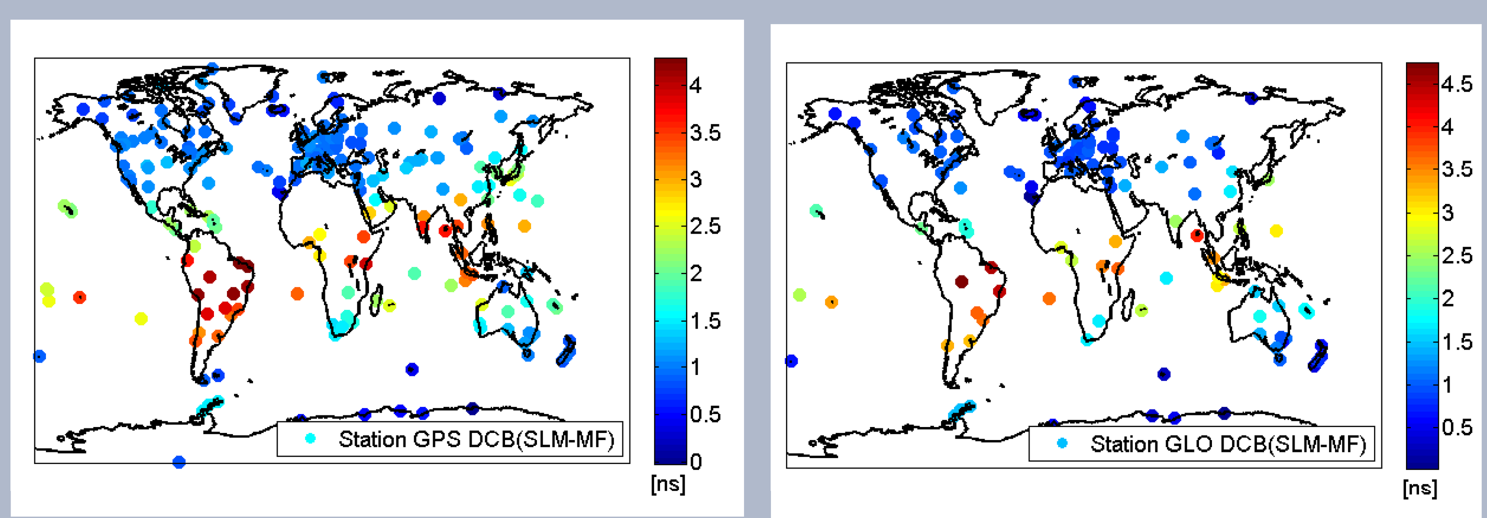
Ionospheric products comparison

To verify the new MF we estimated VTEC maps and DCB parameters with Bernese software Version 5.2. In order to use the new MF we modefied the Bernese software. For the analysis GPS and GLO data of 15th March 2012 of 264 global IGS stations is used. Two solutions are generated, 1) with the SLM-MF 2) with the new MF.

For the two solutions all the processing settings are the same except for the MFs:
24 hour session, 2 hour solution VTEC map, 24 hours satellite– and station–specific DCB, zero-mean condition for satellite DCBs, 10 degree elevation cut-off angle, 450 km single layer, maximum 15 Degree of Spherical Harmonics.

In the comparison the satellite DCBs of both solutions are identical. The station DCB differences are given in Fig.3 (left for GPS, right for GLO). To avoid comparing VTEC area without observations we only compute VTEC differences for areas with or close to stations (Fig.4 right). Significant differences are found around the equatorial anomaly. For mid-/high- latitude areas the differences are typically below 2 TECUs.

***Fig. 3:** DCB difference for each station in ns (left for GPS, right for GLO)*



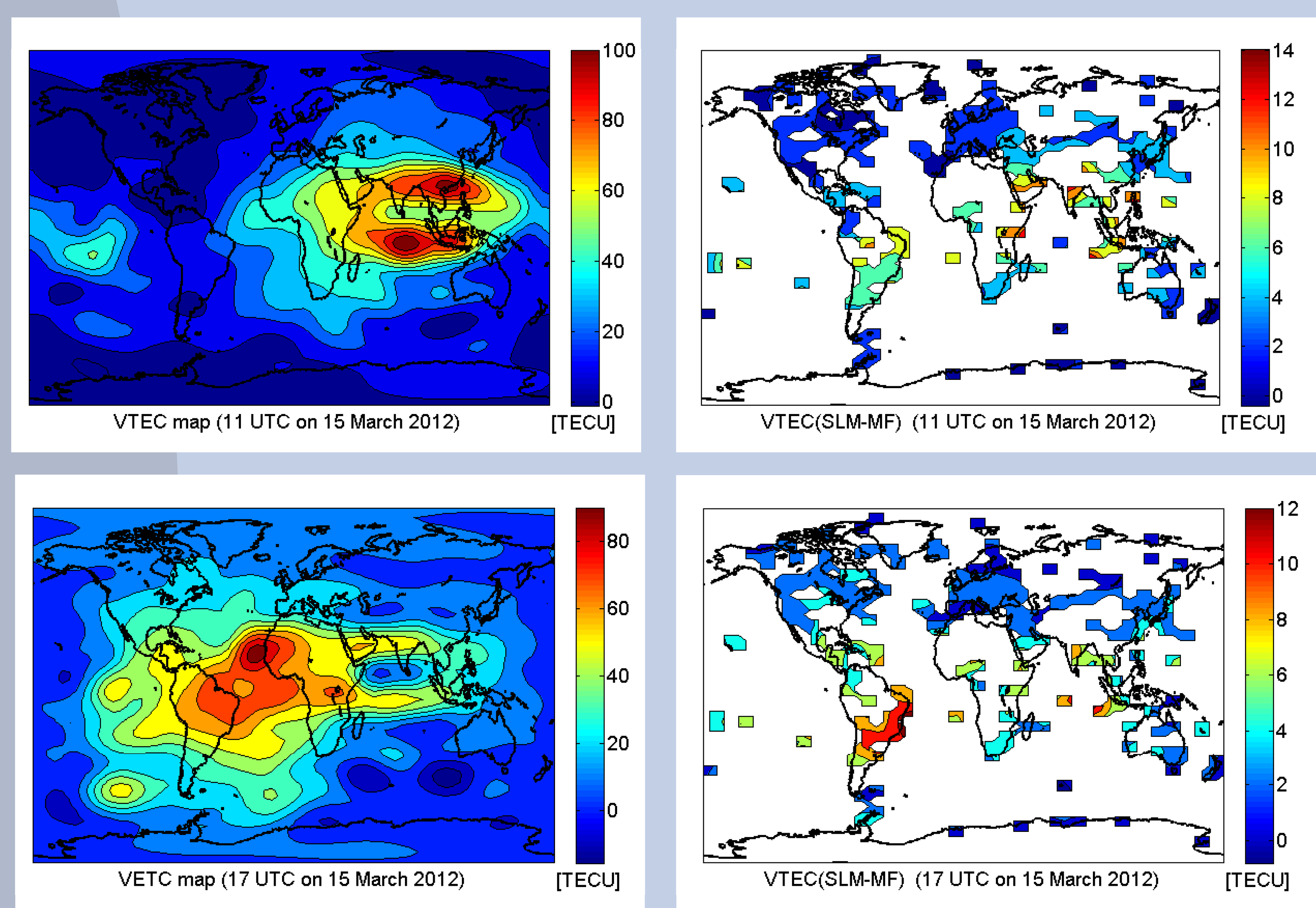


***Fig. 4:** Left panel: VTEC map [TECU] for two epochs (11 UTC and 17 UTC 15 March 2012). Right panel: VTEC difference [TECU].*

Summary/Outlook

More advanced ionospheric mapping functions can reduce the correlation between VTEC and station DCB parameters. In this work we present a new mapping function based on ray-traced ionospheric delays from the IRI model. We compare the new mapping function to the single layer model mapping function and obtain differences in station DCBs of up to 4.6 ns and VTEC differences of up to 14 TECUs around the equatorial anomaly. In the next step longer time series will be used to analyze the repeatability of DCBs; and we will experiment with lower elevation cut-off angles.

Ref: Schaer, S. (1999), Mapping and predicting the Earth's ionosphere using the Global Positioning System, Ph.D. thesis, Univ. Bern, Bern, Switzerland.
Bilitza, D. (2001), International Reference Ionosphere 2000, Radio Sci., 36(2), 261–275, doi:10.1029/2000RS002432.
Zus, F. (2015), Ionospheric mapping functions based on electron density fields, GPS-Solution, submitted.