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The New Technique for Calculating the Ionospheric Phase Advance and the Mapping Function for TEC Built on the Basis of NeQuick Model of the Ionosphere

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ABSTRACT

Recently the new technique for calculating the full phase advance (or the ionospheric contribution into the full phase) of the monochromatic signal on a transionospheric path of propagation was introduced [1]. Unlike in the traditional approach, where the perturbation theory for the ray paths and phase advance utilizes the integration along the straight lines in vacuum as the main term, the alternative technique is constructed in the style, where the zero-order approximation is based on the rigorous solution for the spherically layered ionosphere. This means that the vertical gradients of the electron density of the ionosphere are always explicitly and rigorously taken into account. The horizontal gradients of the ionospheric electron density are much smaller, than the vertical gradients (even in the equatorial anomalies), and then they may well be accounted for in terms of the perturbation theory for the ray paths and phase calculations constructed in the spherical co-ordinates. In addition, this means that the series in the inverse powers of the working frequency, constructed in the traditional treatment, are explicitly summed up already in the zero-order approximation. In turn, this means that the new technique is particularly useful when the working frequency reduces. It also appears that in the alternative technique the second order corrections to the phase advance is negligibly small for all practically possible values of the parameters of propagation. This means that the solution with properly chosen zero-order spherically symmetric ionosphere and the linear (first order) correction, taking account of the horizontal gradient of the electron density of the ionosphere, provides practically rigorous solution to the propagation problem.

As mentioned above, the core point of this scheme is to properly choose the zero-order approximation, i.e. at what point along the path of propagation the zero-order vertical profile is to be chosen, and what type of the profile it is. If this was correctly done, then even the first order correction due to the horizontal gradients of the electron density in the spherical co-ordinate system are fairly small. As is showed here, in most cases, except of the

equatorial anomaly, it was quite appropriate to use in calculations the ionospheric vertical profile at the pierce point. However, for the extreme case, when the ray paths of propagation traverse the equatorial anomaly (where the greatest values of the horizontal gradients of the electron density of the ionosphere are observed), it was found that the best procedure to perform calculations according to the new technique is to utilize a specially constructed for the pierce point artificial spherically-symmetric electron density profile corresponding to the electron density distribution along a straight line of an oblique path of propagation. With this kind of the profile utilized, even the first-order correction to the phase in terms of the appropriately introduced horizontal gradients appears to be very small. The slant profiles may be taken from any available ionospheric model. In this investigation the NeQuick generated ionospheric electron density vertical and slant profiles were utilized.

Here the NeQuick model was utilized to, on the one hand, investigate how the zero-order vertical profile of the electron density should be properly introduced and independently validate the new technique, and on the other hand, to employ this new technique with properly specified vertical profile in order to assess the mapping function of the realistic 3D ionosphere, which is capable of properly transforming the vertical TEC into the slant TEC and vice versa.

In the following consideration the paths in the meridian plane (40° E) are considered from a satellite in the northern hemisphere in the direction south to the point of observation on the Earth's surface at (0^o, 40° E) as shown in Fig. 1.

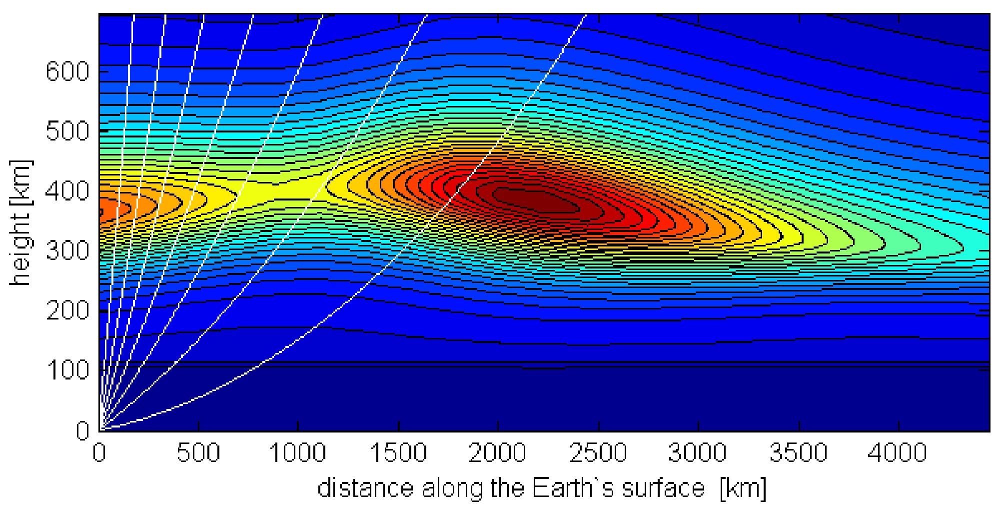

Figure 1. The NeQuick model generated distribution of the electron density in the meridian plain of propagation to the south from a satellite for July, UT=12, R_{12}=100. The ray paths of propagation correspond to the different latitudes of the satellite with 10^0 steps starting from 12^0 to 72^0

The performance and possibilities of the new technique for the phase advance calculations being discussed here is demonstrated by the comparison of the TEC values along the paths of propagation shown in Fig. 1, directly provided by the NeQuick model, and those calculated in the numerical experiment according to the new technique, which reproduces the dual-frequency mode of operation of the GPS. In the next Fig. 2, the left panel shows the difference between the

NeQuick directly generated TEC and those obtained utilizing the appropriate NeQuick slant profiles to reproduce the dual-frequency propagation experiment for different angle distances between the transmitter and receiver.

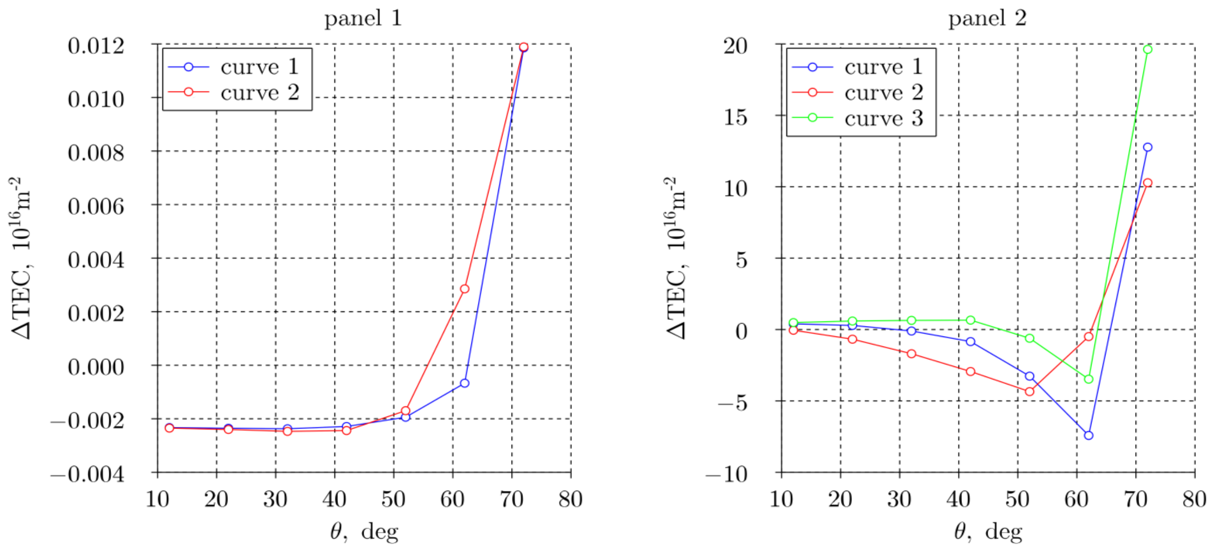

Figure 2. Results of calculation of TEC utilizing the new technique, and their comparison the TECs directly generated by NeQuick model.

It is seen on the left hand panel, where the blue curve 1 corresponds to the artificial spherically-layered ionosphere and the red one also takes account of the horizontal gradients to the artificial spherically –layered profile, that both demonstrate negligibly small difference to the true TEC, directly generated by NeQuick model. The error is only of the order of 10^{-3} – 10^{-2} TEC units. This well validates the presented here propagation technique.

Finally, on the right hand panel of Fig. 2 the results of the mapping function assessment are presented in the form of the difference between the true values of the slant TEC (from NeQuick) and those calculated employing the version of the propagation model with the vertical electron density profile of the spherically-layered ionosphere at pierce point (blue curve 1), and also taking account of the vertical profile of the horizontal gradients at pierce point (red curve 2). The green curve 3 shows the error due to the standard cosine mapping function.

Key words: Phase advance, Ionosphere, TEC, Mapping function

References:

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