A method to test HF ray tracing algorithm in the ionosphere by means of the virtual time delay

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Abstract

As well known a 3D ray tracing algorithm furnishes the ray's coordinates, the three components of the wave vector and the group time delay of the wave along the path. This last quantity can be compared with the measured group delay to check the performance of the algorithm. Simulating a perfect reflector at an altitude equal to the virtual height of reflection the virtual delay is assumed as a real group delay. For a monotonic electronic density profile we find a very small relative difference between the calculated and the simulated delay both for analytic and discrete 3D electronic density models.

Reflector simulation

According to the ray theory, the Three-Dimensional (3D) ray tracing algorithms calculate the coordinates reached by the wave vector and its three components. Another important quantity calculated is the group time delay t_g of the wave along the path. The group delay is a useful quantity that allows to check the performance of a ray tracing algorithm when a 3D ionospheric model is assumed correct. In case of a real measurement, as in OTH radar applications or in backscattering ionospheric soundings (or perfectly synchronized oblique sounding experiment), it is possible to compare the calculated time delay t_g with the measured group delay t_{real}. When the differences between the calculated group delay and the measured group delay are within an acceptable error due to discrete step of the mathematical process and the discrete 3D ionospheric model, we assume that both 3D ray tracing algorithm and 3D ionospheric model work properly. Nevertheless, the measured group time delay is usually not available for ionospheric 3D ray tracing users since real measurements of this quantity are quite uncommon. In order to test the algorithm performance, an alternative method to obtain something similar to the term t_{real} is thus required. Propagation theorems and refraction laws, widely used in ionospheric physics applications, have been exploited at this aim. Under the assumption of a flat layered ionosphere we image to put a perfect reflector at an altitude equal to the vertical virtual height of reflection (i.e. compatible with a path in which the wave velocity of the light is c). For a given frequency this quantity can be simply calculated analytically or directly from the ionogram (Davies 1990). The Breit and Tuve theorem assures that the time delay of the wave propagating in the effective path at group velocity compatible with the group refractive index is equal to the time of the wave propagating along the oblique virtual path at the velocity c. Another useful concept derived from the Martyn's theorem relates the oblique virtual reflection height at a frequency compatible with the oblique propagation f_{ob} with the vertical virtual reflection height at a vertical frequency f_v, according to the secant law. In order to test the ray tracing algorithm the two above mentioned propagating time must be considered. In this paper we deal about a ray tracing algorithm derived from 6 differential equations with Hamiltonian formalism in geocentric spherical coordinates. The ray tracing program is written in Matlab language for what concern input and output routine, while the executive computation nucleus derives from the Jones and Stephenson program (Jones and Stephenson 1974). The 3D ionospheric model used employs both the analytic and the discrete 3D electron density model elaborated at the INGV.

Conclusions

We employed a simple method to test a ray tracing algorithm. So we exploited the relation above described to obtain a quantity replacing the group time delay t_g that is a value obtainable from a real measurement. The last quantity can be compared with the virtual group delay t_v to check the performance of the algorithm. A perfect reflector placed at an altitude equal to the virtual height of reflection was simulated to calculate the virtual delay that is assumed as a real group delay. For monotonic electronic density profile we found a very small relative error between the calculated and the simulated delays both for analytic and discrete 3D electronic density models. Such errors are mainly due to the discrete step of the numerical integration of the differential equations of the ray tracing algorithm and to discrete electronic density profile.

References

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