EGU2020-18785
https://doi.org/10.5194/egusphere-egu2020-18785
EGU General Assembly 2020

Global Multi-layer Electron Density Modeling Based on Constraint optimization

Ganesh Lalgudi Gopalakrishnan, **Michael Schmidt**, and Eren Erdogan
Technical University of Munich, DGFI-TUM, Munich, Germany (ganeshlg@gmail.com)

Electron density is the most important key parameter to describe the state of the ionospheric plasma varying with latitude, longitude, altitude and time. The upper atmosphere is decomposed into the four layers D, E, F1 and F2 of the ionosphere as well as the plasmasphere. Space weather events manifest themselves with specific "signatures" in distinct ionospheric layers. Therefore, the role of each layer in characterizing the ionosphere during nominal and extreme space weather events is highly important for scientific and operational purposes.

Accordingly, we model the total electron density as the sum of the electron densities of the individual layers. The key parameters of each layer, namely peak electron density, the corresponding peak height and scale height, are modeled by series expansions in terms of polynomial B-splines for latitude and trigonometric B-splines for longitude. The Chapman profile function is chosen to define the electron density along the altitude. This way, the electron density modeling is setup as a parameter estimation problem. In the case of modelling multiple layers simultaneously, the estimation of coefficients of the key parameters becomes challenging due to the correlations between the different key parameters.

One possibility to address the above issue is by imposing constraints on the ionospheric key parameters (and by extension on the B-spline coefficients). As an example, we constrain the F2 layer peak height to be always above the F1 layer peak height. We also constrain the key parameters to be non-negative and possibly to to certain well defined bounds. This way the physical properties of the ionosphere layers are included in the modelling. We estimate the coefficients with regard to the imposition of the bounds in form of inequality constraints using a convex optimization approach. We describe the underlying mathematical procedure and validate it using the IRI model as well as GNSS observations and electron density measurements from occultation missions. For the specific case of using IRI model data as the reference “truth”, we show the performance of the optimization algorithm using a “closed loop” validation. Such a validation allows an in-depth analysis of the impact of choosing a desired number of unknown coefficients to be estimated and the total number of constraints applied. We describe the parameterization of the different ionosphere key parameters considering the specific requirements from operational aspects (such as the need for modelling F2 layer), scientific aspects with regard to ionosphere-thermosphere studies (need for modelling the D, E or F1 layers) and also considering the aspects related to computation load.

We describe the advantages of using the optimization approach compared to the unconstrained least squares solution. While such constraints on key parameters can be fixed under nominal ionospheric conditions, but under adverse space weather effects these constraints need to be modified (constraints become stricter or more relaxed). For this purpose, we show the dynamic effect of modifying the constraints on global modelling performance and accuracy. We also provide the uncertainty of the estimated coefficients using a Monte-Carlo approach.