MODULATION OF ELECTRON DENSITY MODELS TO TAKE INTO ACCOUNT SMALLER SCALE STRUCTURES

Reinhart Leitinger, Erika Feichter, Markus Rieger

Institut für Geophysik, Astrophysik und Meteorologie, Universitätsplatz 5, 8010 Graz, Austria; e-mail: reinhart.leitinger@uni-graz.at

ABSTRACT

Electron density models provide larger scale spatial structures only. Our modulation method adds smaller scale features like the main trough, ridges, TIDs etc. as three dimensional and time dependent models by multiplication. There are no restrictions to the nature of the large scale model provided it takes height and horizontal coordinates as input. Examples are "profiler" type models which use large scale "maps" for profile anchor points like the International Reference Ionosphere (IRI) or the "family" of models developed at Trieste and Graz, NeQuick, COSTprof and NeUoG–plas. We demonstrate the method with models for the main trough and for TIDs.

INTRODUCTION

Regional and global electron density models provide larger scale spatial structures and smooth out the smaller scale features of the electron density distribution in the ionosphere. The following "modulation" scheme can take into account smaller scale structures by multiplication:

$\mathcal{M}(h,\, \varphi,\, \lambda,\, t) = \mathcal{L}(h,\, \varphi,\, \lambda,\, t)\; \mathcal{S}_1(h,\, \varphi,\, \lambda,\, t)\; \mathcal{S}_2(h,\, \varphi,\, \lambda,\, t)\; \cdots\; \mathcal{S}_n(h,\, \varphi,\, \lambda,\, t)$

$\mathcal{M}$: resulting electron density distribution, $\mathcal{L}$: large scale model, $\mathcal{S}_1 \cdots \mathcal{M}_n$: modulating models for the smaller scale structures; h: height, φ, λ: geographic coordinates, t: Universal Time. There are no restrictions to the nature of the large scale model provided it takes height and horizontal coordinates as input. Examples are models of the "profiler" type which use large scale "maps" for profile anchor points (e.g., E, F1, F2 peak properties from ionosonde parameters) like the International Reference Ionosphere (IRI) or the "family" of models developed at Trieste and Graz, **NeQuick**, **COSTprof** and **NeUoG–plas**. Typical examples for smaller scale structures are ridges, troughs and wavelike disturbances. The advantage of modulation by multiplication is that there is no danger to get zero or negative values of electron density as long as the background and modulations everywhere are > 0. For each modulation model unity means "undisturbed". Of course it is necessary to use the modulation scheme with care and it is recommended to use one modulation for a given range of spatial scales, e.g., to superpose the main trough of the F region by means of modulation $\mathcal{S}_1$, large scale TIDs by means of $\mathcal{S}_2$, small scale TIDs by means of $\mathcal{S}_3$, etc.

We discuss examples for three types of modulations: (1) for the main trough of the F region a model based on Dynamics Explorer 2 (DE2) in–situ electron density; (2) 3 D and time dependent model for Large Scale TIDs with thermospheric sources (source points in the auroral zone) and for smaller scale TIDs with arbitrary apparent ionospheric source points; (3) 2 D and time dependent model for smaller scale wavelike disturbances with arbitrary source points.

MODEL FOR THE MAIN TROUGH

The model for the main trough of the F region consists of two parts: a model for the location of the minimum of the trough which depends on season, time and geomagnetic activity ([1]) and a model for depth and shape of the trough ([2]). For depth and shape the DE2 in–situ data were scaled to the F2 layer peak using the **COSTprof** model. This scaling was necessary to compensate the height change of the satellite due to the eccentricity of its orbit. An automatic trough scaling system was used to gain depth, equatorward and poleward width of the main trough and the steepnesses of the walls of the trough. The seasonal medians of these trough characteristics are used as trough model parameters. A formula is used for trough depth and shape which makes use of these parameters. The trough is shifted to the position defined by its minimum for which we use the model developed by Werner and Prölss out of DE2 data ([1]). Since the trough minimum position depends on invariant magnetic latitude our model troughs are automatically magnetic field aligned.

TID MODEL

The three dimensional and time dependent model is applicable for Large Scale TIDs with thermospheric sources (source points in the auroral zone) and for smaller scale TIDs with arbitrary apparent ionospheric source points. The tilt of the

wave fronts, a realistic height dependence of amplitude and phase, and a radiation pattern is included in the model. To ensure global usability the geometric dilution of TIDs has to be "flattened out" near their source points. The model is highly flexible and TID activity can be composed of several TID wave trains with very diverse properties.

The model is based on the assumption that TIDs are the plasma signatures of Atmospheric Gravity Waves (AGWs) with point sources in the thermosphere (see, e.g., [3]). For most of the Large Scale TIDs this assumption is justified with source points in the auroral zone. We have to assume that the primary AGWs behind a large part of Medium Scale TIDs originate in the troposphere or the stratosphere. In these cases our thermospheric "replacement" sources have no direct relation to the primary AGWs but allow us to model TIDs far enough from the source points in a not too unrealistic way.

For simplicity we have assumed
(1) constant neutral atmosphere (thermosphere) properties, pressure scale height $H = 50$ km, ratio of specific heats $\gamma = 1.6$, acceleration of gravity $g = 9$ m s^{-2}, no wind,
(2) a Chapman layer for the height variation of the relative TID amplitudes $Ch = \exp[1 - z - \exp(-z)]$ with $z = (h - h_o)/H_{Ch}$, $h_0 = 250$ km, $H_{Ch} = 100$ km. This vertical structure of TID amplitudes reflects more our lack of knowledge on amplitude details than physics but takes into account that a) we have reason to assume an amplitude maximum below the F2 maximum (see [4]), b) in the E region and the lower F region ion drag is not too effective and the amplitude of the AGWs should increase exponentially.
(3) a geometric dilution $d = 1 \,/\, \sqrt{1 + b}$ with $b = \sin(\Psi) \,/\, \sin(\Lambda_s)$, Ψ being the angular distance from the source point, Λ_s the angular horizontal wavelength of the TID. Distribution over a sphere would give a dilution like $1 \,/\, \sqrt{b}$. Our "modified" dilution ensures global continuity of the TID disturbance.
(4) an exponential attenuation $\exp(-\chi\,\Psi)$ which takes into account loss of wave energy through ion drag,
(5) radiation into a single "beam" of the form $\cos^{\kappa}[(\sigma - \sigma_o)/2]$, σ being the azimuth for the connection from source point to field point, σ_o the azimuth for the radiation maximum. κ regulates the beam width, a half width of δ degrees needing approximately $\kappa \doteq 18200 \,/\, \delta^2$ (valid if $\delta < 10$ degrees).

SMALLER SCALE WAVELIKE DISTURBANCES

In the case of model applications which involve slant or vertical electron content but no details of the electron density profile it is sufficient to modulate electron content with smaller scale wavelike disturbances. This corresponds to assuming that amplitudes and phases of the disturbances are independent of height.

EXAMPLES

We have applied the modulation method to the IRI and to the "family" of models developed at Trieste and Graz. The latter were used both in the "ITU–R map" and in the "data grid" mode for magnetic storm conditions. Data grid based models with modulations are especially suited for assessment studies in connection with user systems for satellite to ground or satellite to satellite propagation of radio waves ([5]). Electron density can be extracted along arbitrarily chosen ray paths which enables to calculate various propagation effects like total and partial electron contents, the Faraday effect, higher order propagation errors, etc. Examples for trough modulations are shown in Fig. 1 and Fig. 2, the effect of Large Scale TIDs is demonstrated with Fig. 3, that of smaller scale wave like disturbances with Fig. 4.

REFERENCES

[1] S. Werner, and G.W. Prölss, "The position of the ionospheric trough – an empirical model based on DE2 observations," Kleinheubacher Berichte vol. 38, pp 143–154, 1995

[2] E. Feichter, and R. Leitinger, "Properties of the main trough of the F region derived from dynamic explorer 2 data," in press, Ann. di Geofisica, 2001

[3] R. Leitinger, "Travelling Ionospheric Disturbances (TIDs) — Wissensstand und neuere Entwicklungen," Kleinheubacher Ber. vol. 35, pp 1–14, 1992

[4] M.G. Morgan, and K.A. Ballard, "The height dependence of wave–normal depression and disturbance amplitude in TIDs," J. Geophys. Res. vol. 83, pp 5741–5744, 1978

[5] R. Leitinger, S.M. Radicella, and B. Nava, "Electron density models for assessment studies – new developments," in press, Acta Geodet. Geophys, Hung., 2001

[6] R. Leitinger, S. Radicella, and E. Feichter, "The data grid method to actualize empirical electron density models," in press, Proceedings Ionospheric Effects Symposium 2002

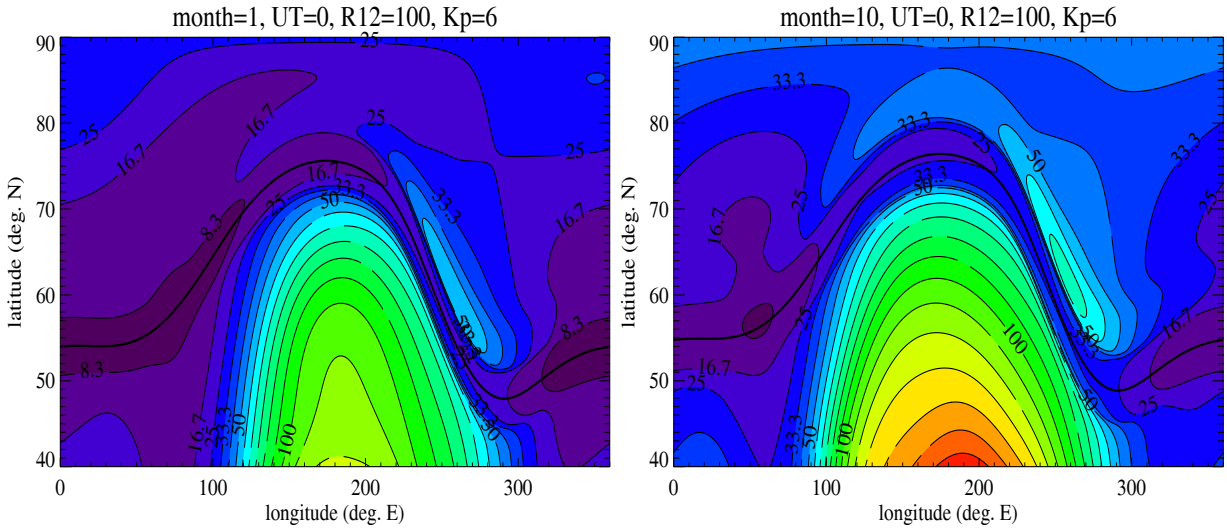

Fig. 1. Peak electron density from the ITU–R map modulated with the trough model for Kp=6. Isolines of electron density in units of 10^9 m^{-3} in a geographic coordinate system. The trough minimum is marked by a heavy line. Midnight UT, $R_{12} = 100$; left: January, right: October.

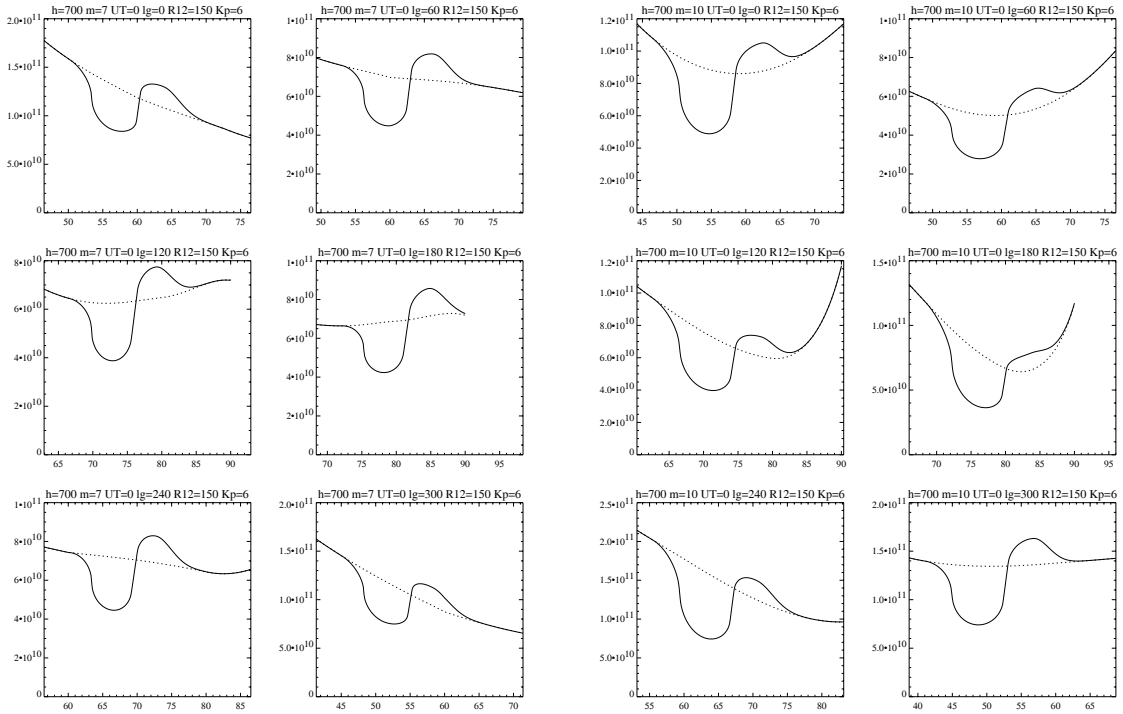

Fig. 2. **NeUoG–plas** modulated by the trough model. Electron density in a height of 700 km vs. geographic latitude. Dotted: unmodulated **NeUoG–plas** results. Fixed UT=0 hours, R12 = 150, Kp=6, geographic longitudes 0°E, 60°E, 120°E, 180°E, 240°E (corresponding LT: 0, 4, 8, 12, 16, 20 hours). Lefthand panel: July, righthand panel: October.

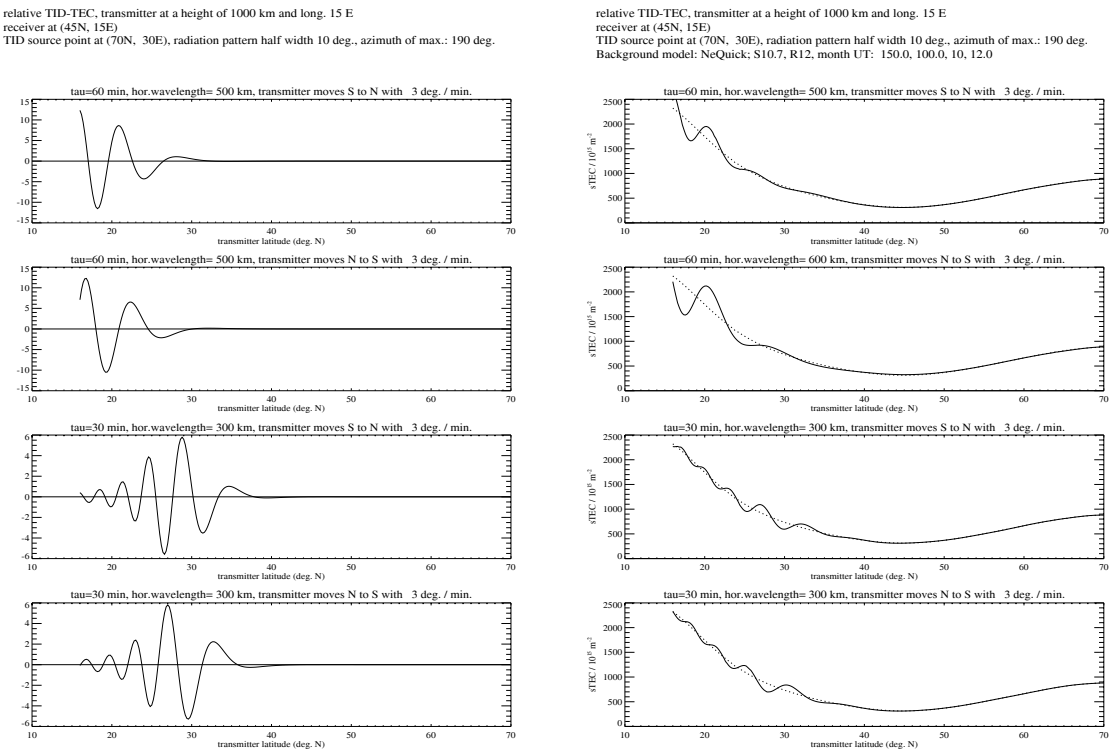

Fig. 3. Example for modulation by Large Scale TIDs. Left panel: Integrated TID model (arbitrary units), right panel: TID modulation on **NeQuick**. Imitation of slant electron content gained from observations of signals transmitted from a LEO satellite in a meridional orbit at a height of 1000 km, rotation of the Earth neglected. Receiving station at 45° N.

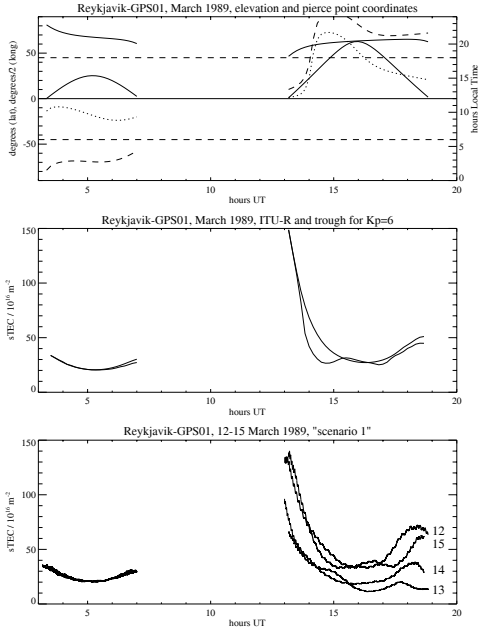

Fig. 4. Example for modulation by trough and small scale wavelike disturbances. Receiving station at (64.1° N, 21.6° W), GPS satellite, 4 consecutive days (12, 13, 14, 15; "storm" scenario for March). Top panel: Geometric situation (for first day). Satellite elevation (solid bold), ionospheric points at 400 km, latitude (solid), longitude (dotted) and local time (dashed). Middle panel: 10 minutes slant electron content calculated by **NeQuick** in ITU–R "map" mode and with trough modulation (bold). Bottom: slant electron content calculated by **NeQuick** in "data grid" mode (spline interpolation from 10 minutes to 1 seconds data, "Small Scale TID modulation" with two wave trains. See [6] for more explanation.