ADAPTING EMPIRICAL ELECTRON DENSITY MODELS TO DISTURBED CONDITIONS

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Abstract

Three dimensional and time dependent electron density models are used for various tasks in connection with the transionospheric propagation of radio waves. If not "updated" the usual empirical electron density models provide monthly median conditions. In general "updating" means replacing map values for the F2 peak density (and peak height) by actual values. If this is done for isolated height profiles of electron density we need no further modification. However, realistic updating for propagation parameters calculated along a slant ray path (e.g., from a satellite transmitter or from an extraterrestrial source to a ground receiver) needs updating along the entire ray path. Assessment studies need slant electron content calculation for many rays. Therefore we replace the monthly median "maps" by "data grids". Presently, the data grids are based on hourly data and have a grid spacing of 2.5 deg. in latitude and 5 deg. in longitude. This grid resolution is not sufficient to resolve smaller scale structures like the main trough of the F layer and the time intervals of one hour are not well suited to deal with dynamic disturbances, e.g., with the wavelike Traveling Ionospheric Disturbances (TIDs) or with magnetic storm related disturbances. Therefore we have developed a "modulation method" which adds smaller scale and dynamic structures by multiplying the background (= data grid driven) model with sub-models for these structures.

1 Introduction

Three dimensional and time dependent electron density models are used for various tasks in connection with the transionospheric propagation of radio waves. If not "updated" the usual empirical electron density models provide monthly median conditions. In general "updating" means replacing map values for the F2 peak density (and peak height) by actual values. If this is done for isolated height profiles of electron density we need no further modification. However, realistic updating for propagation parameters calculated

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along a slant ray path (e.g., from a satellite transmitter or from an extraterrestrial source to a ground receiver) needs updating along the entire ray path. Therefore we have developed "data grids" which replace the monthly median "maps". Furthermore, smaller scale and dynamic structures like Traveling Ionospheric Disturbances (TIDs) and geomagnetic storm disturbances are taken into account by means of "modulations" which are three dimensional and time dependent sub–models. For use with the "model family" developed at Graz and at Trieste we have now "simplified monthly median maps" which improve considerably the computation performance of the models.

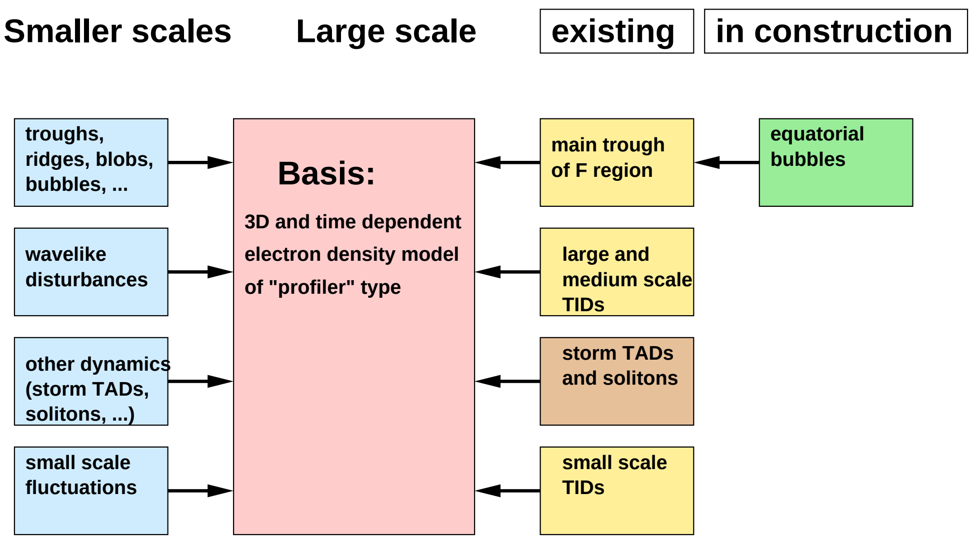

Figure 1: Modulation scheme: The basic large scale model (middle box) is "modulated" with sub–models. The left hand boxes give the (geo)physical structures to be taken into account, the right hand boxes list the sub–models which currently are available or in construction.

2 Model adaptation

Starting with a suitable monthly median model we have adopted the following adaptation scheme.

1. (Monthly median model)
2. Large scale adaptation by means of data grids, especially
   - Storm grids: add regional effects to global grids
     depressions (negative storm effect)
     enhancements (positive storm effect)
3. Model modulation (add smaller scale dynamic structures like troughs, ridges, TIDs).

2.1 Basis: Monthly Median model

Any monthly median model of the "profiler" type which has the peak of the F2 layer as the main anchor point can be used, e.g., the International Reference Ionosphere (IRI) [Bilitza, 2001] or the "family" of models developed at Trieste and Graz [Hochegger et al.,

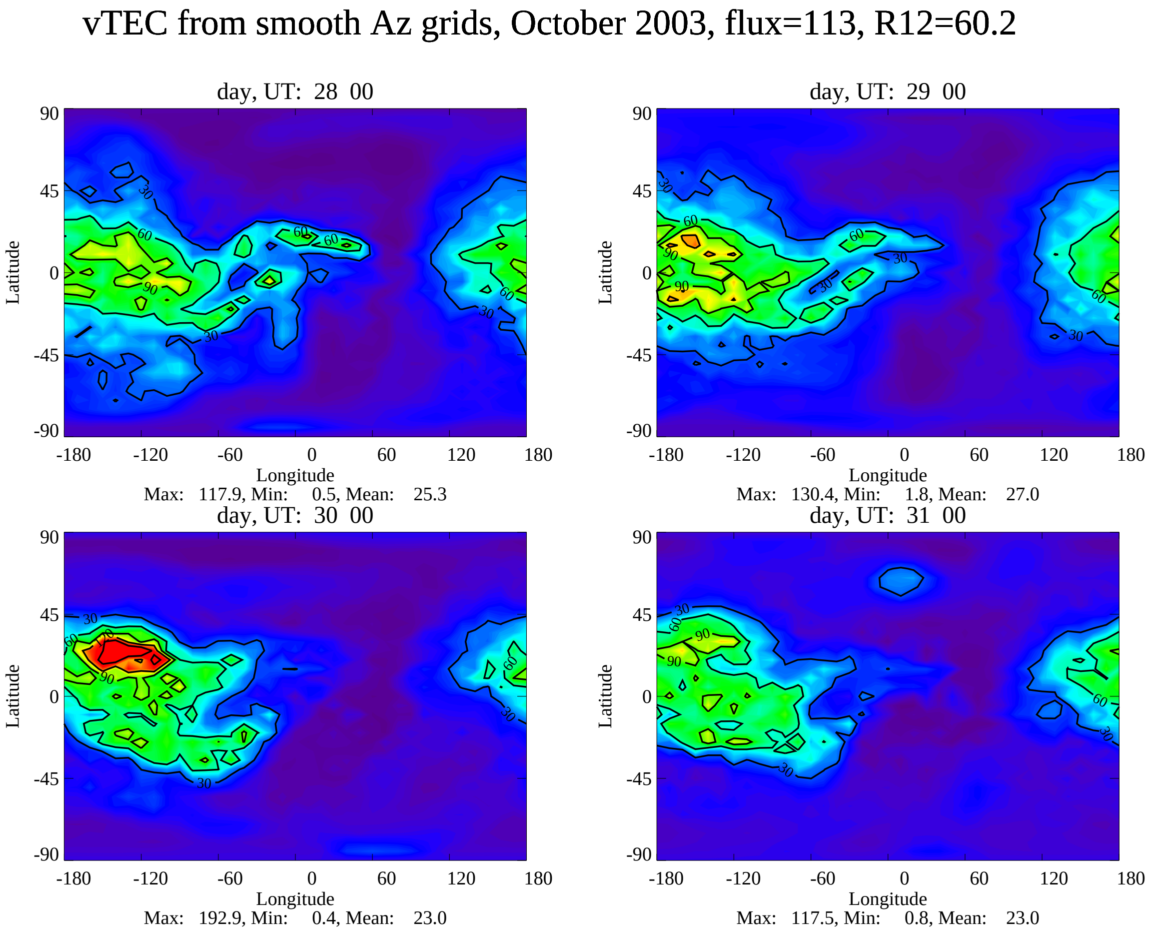

Figure 2: Global distribution of vertical ionospheric electron content in units of 10^{15} m^{-2}*. The Az grids were based on global GPS observations in October, 2003 (major geomagnetic storms with sudden commencements on October 29 and 30). Days 28, 29, 30 and 31, "snapshots" for 0 UT.*

2000] *NeQuick*, *COSTprof* and *NeUoG–plas* that are profilers using the peaks of the E layer, of the F1 layer and of the F2 layer as anchor points. Like the IRI the model family uses so–called "maps" for some of the anchor point Maps are algorithms, which give monthly median values as functions of geographic coordinates, diurnal and annual time and solar activity. The most widely used maps are those which have been produced by the Comité Consultatif International des Radiocommunications (CCIR) of the International Telecommunication Union – ITU. In case of the F2 peak they provide the critical frequency foF2 and the propagation parameter M(3000)F2.

The models allow

- to be updated with actual data from various sources
- to be adjusted to disturbed conditions
- to be combined with smaller scale models
- to calculate a variety of propagation effects along arbitrarily chosen raypaths.

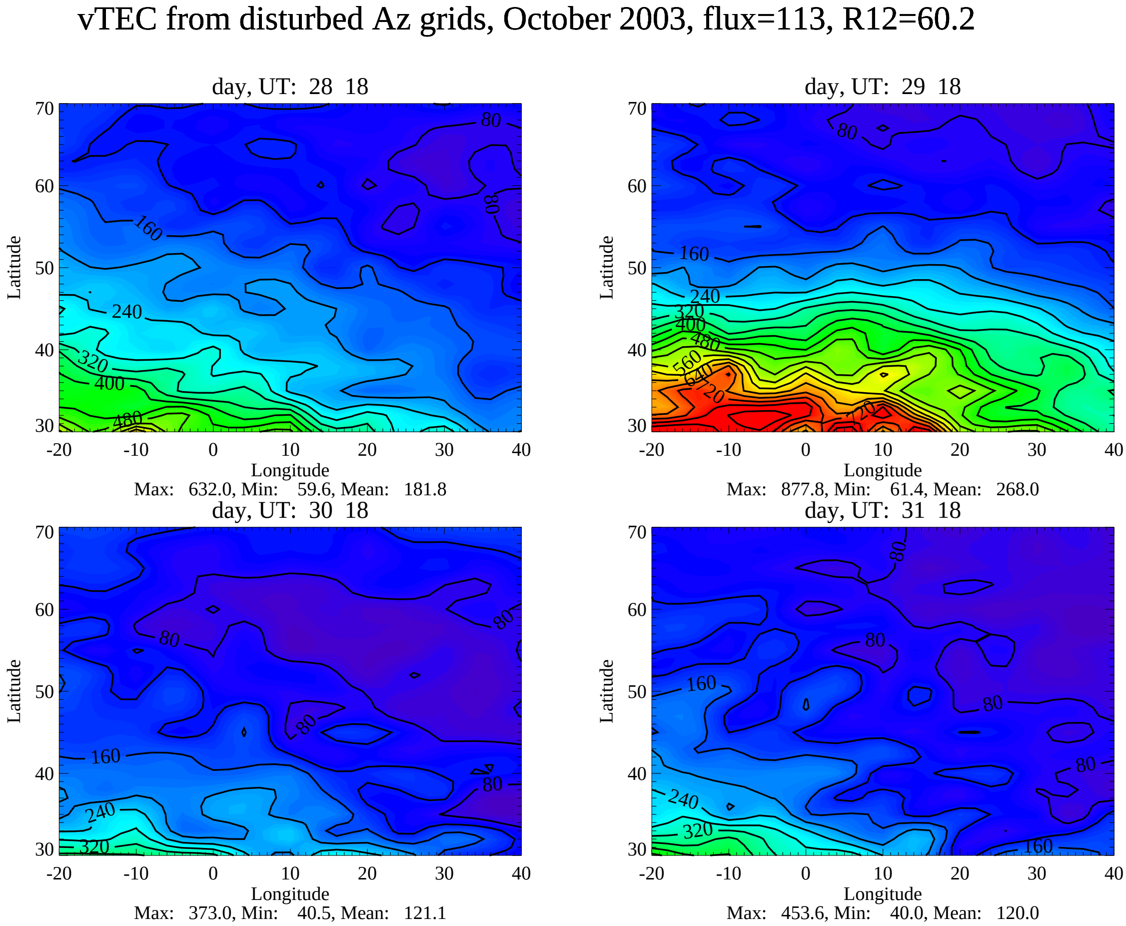

Figure 3: Regional distribution of vertical electron content for 18 hours UT from disturbed Az grids (see text). Otherwise like Fig. 2.

2.2 Data grids

There are several different ways to adapt "profiler" models to actual ionospheric conditions. One possibility is to use observed F2 peak values to replace those provided by the CCIR maps. For calculations along arbitrarily chosen ray paths this is not practicable because one would need the actual peak conditions under the entire ray path. Therefore we have developed a "data grid" method. In this case the CCIR maps for foF2 and M(3000)F2 are replaced by data over global equidistant grids in geographic coordinates. For locations between the grid points third order interpolation is used both for latitude and for longitude [Leitinger et al., 2001].

We distinguish between *global* and *regional* grids. For global grids spacing is 2.5° in latitude, 5.0° in longitude. This corresponds approximately to the resolution of the CCIR maps. Basic spacing in time is 1 hour, denser global grids are produced by means of spline or Fourier interpolation. For the F2 peak properties we have now three options:

(1) grids for foF2 and M(3000)F2

(2) grids for peak electron density NmF2 and peak height hmF2 (physical peak conditions)

(3) Effective Ionization level grids (Az–grids).

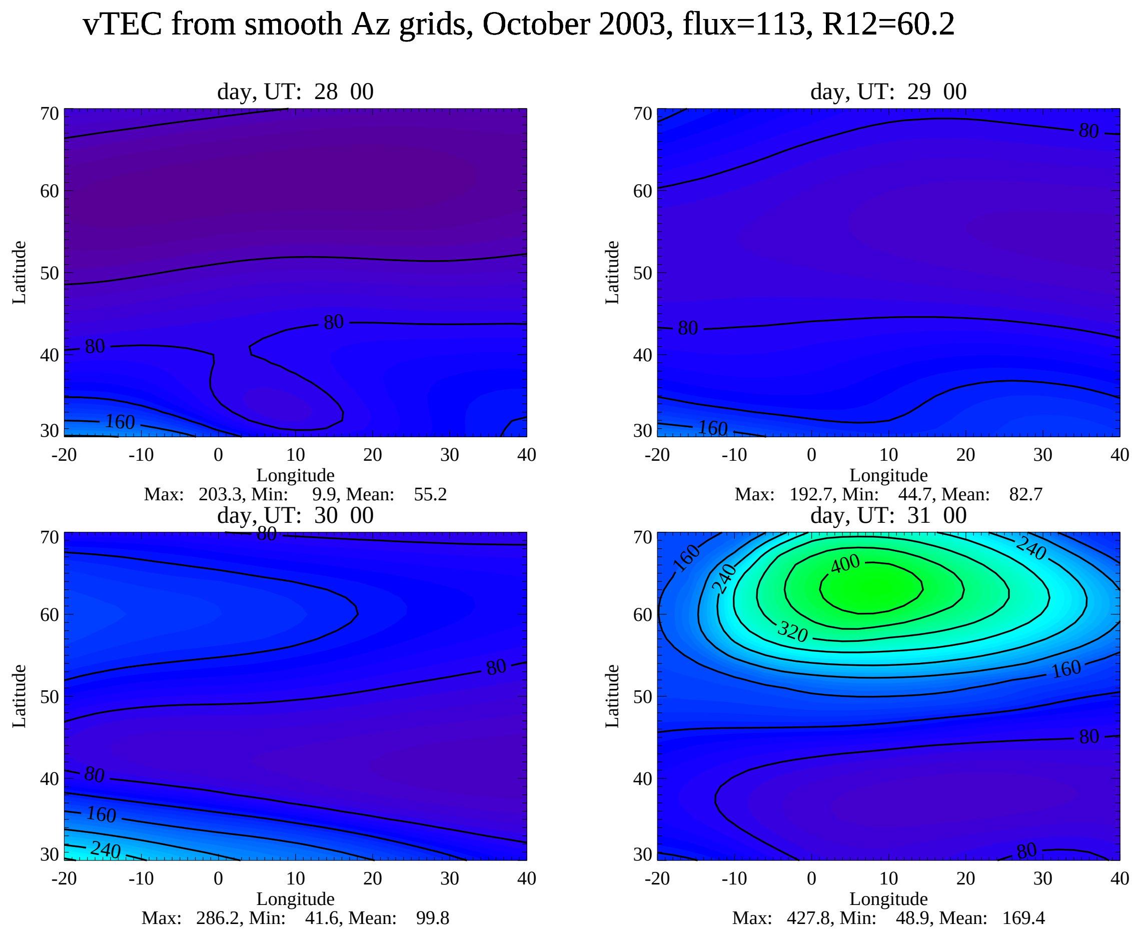

Figure 4: Regional distribution of vertical electron content for 0 hours UT from smooth Az grids (see text). Otherwise like Fig. 2.

In case (1) peak density (symbol N_m) is derived from foF2 (symbol f_{F2}) by means of $N_m = f_{F2}^2/80.6$ (foF2 in MHz, peak density in 10^{12} m^{-3}) and peak height is calculated from M(3000)F2 and the ratio of (foE) / (foF2) using Dudeney's form of the Bradley and Dudeney [1973] formula [Dudeney, 1983].

The Effective Ionization level is that solar activity value which is needed by the electron density model chosen to produce an observed vertical electron content. By means of the appropriate Az–grid the model would reproduce a given grid of vertical electron content. As in cases (1) and (2) the main application of Az–grids is the adaptation of models to actual conditions for the calculation of electron density (or propagation parameters like slant electron content) along arbitrarily chosen rays.

One application for *regional* grids is to provide more accurate or more actual information than can be provided by global grids.

2.3 Model modulation

The resolution of our global grids is restricted to large scale structures. When finer scales are needed the models have to be "modulated" by means of multiplication with

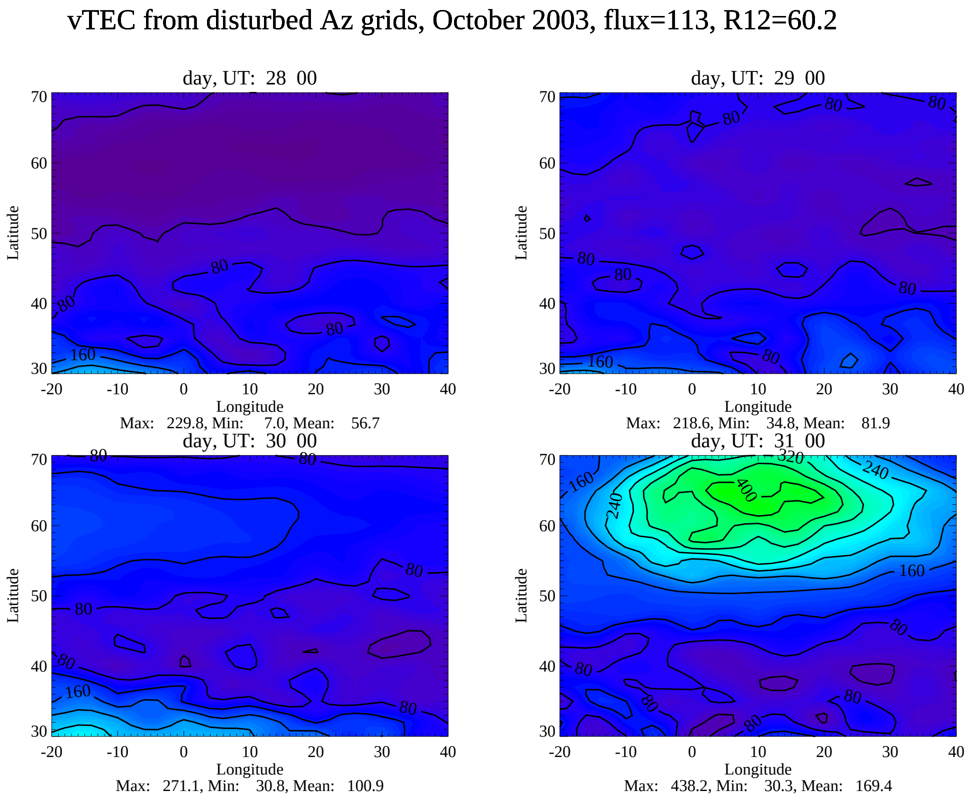

Figure 5: Regional distribution of vertical electron content for 0 hours UT from disturbed Az grids (see text). Otherwise like Fig. 2.

sub–models.

$$M(h,\,\varphi,\,\lambda,\,t) \;=\; L(h,\,\varphi,\,\lambda,\,t)\;\;T(h,\,\varphi,\,\lambda,\,t)\;\;S_1(h,\,\varphi,\,\lambda,\,t)\;\;\cdots\;\;S_n(h,\,\varphi,\,\lambda,\,t) \qquad \text{or}$$
$$M(h,\,\varphi,\,\lambda,\,t) \;=\; L(h,\,\varphi,\,\lambda,\,t)\;\;T(h,\,\varphi,\,\lambda,\,t)\;\;[S_1(h,\,\varphi,\,\lambda,\,t)\;+\;\cdots\;+\;S_n(h,\,\varphi,\,\lambda,\,t)]$$

M: resulting electron density model,
L: large scale model (IRI, member of Graz–Trieste “model family”, etc.)
T, S: modulations, e.g., for the main trough and for TIDs,
h: height,
φ: geographic latitude,
λ: geographic longitude,
t: Universal Time.

All models are three dimensional and time dependent. The second form of the modulation scheme indicates that smaller scale structures which affect one and the same region have to be added together before being used as a modulation. Otherwise one produces “harmonics”.

Figure 1 illustrates the modulation scheme and gives a list of the sub–models which are currently available.

In detail the sub–models are described elsewere. See, e.g., [Feichter and Leitinger, 2002a and 2002b] for the main trough of the F region, [Rieger and Leitinger, 2002; Leitinger and Rieger, 2005]) for large and medium scale Traveling Ionospheric Disturbances (TIDs). For the two modulations which are important in the context of geomagnetic storm effects, Soliton Like Disturbances (SLDs) and Traveling Atmospheric Disturbances (TADs) see [Feichter and Leitinger, 2005].

2.4 Simplified maps

The "CCIR" maps [Jones and Gallet, 1962, 1965] consist of monthly sets of coefficients for a Fourier expansion in Universal Time (UT) and a spherical harmonics expansion in a strange mixture of a magnetic coordinate ("modfied dip latitude", [Rawer, 1963]) with geograpic latitude and geographic longitude (for constant UT). Coefficients exist for two levels of solar activity ($R_{12} = 0$ and $R_{12} = 150$); linear interpolation / extrapolation is used to derive map values for other levels of solar activity. The "simplified maps" use different coordinates: Fourier expansion in constant Local Time (LT) and spherical harmonics expansion in modified dip latitude and geographic longitude (for constant LT).

Re–mapping brought not only a simplification for the user algorithm but also removed strange and unrealistic smaller scale structures [Martinecz and Leitinger, 2005].

The simplified maps have been constructed for the properties of the peak of the F2 layer, peak height (hmF2) and peak electron density (NmF2). In the latter case the maps are formulated for the critical frequency foF2 but NmF2 is simply the square of foF2 divided by 80.6 (foF2 in MHz, NmF2 in 10^{12} electrons per cubic meter).

For "profiler" type electron density models the simplifide maps have two important advantages:

1. Simpler reconstruction algorithm and shorter computation time
2. removal of unrealistic smaller scale structures which are amplified when mapped upwards from the peak of the F2 layer into the upper ionosphere.

3 Examples

Here we show only a few examples for model adaptation by means of "effective solar activity" (Az–)grids (Figures 2 through 5). Displayed are global or regional distributions of vertical ionospheric electron content calculated by means of *NeQuick*. The Az–grids used have been constructed on the basis of global GPS calculations with a time resolution of 2 hours. The "smooth" grids were obtained by means of spherical harmonics expansions, for the "disturbed" grids independent random numbers were added to each grid point. It is clearly seen that the "disturbed" grids provide more realistic storm scenarios for assessment studies.

For examples of more complex propagation effects see [Leitinger, 2005].

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