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Status of available *N*(*h*) model profiles

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Abstract
This paper attempts to highlight progress in the ionospheric electron-density height profile modelling made during the last few years. It consists of a brief review of some major aspects associated with available theoretical, parameterised and empirical *N*(*h*) models. Emphasis is placed on pointing out the key issues in the areas that are relevant for the COST 238 PRIME project.

Key words *ionosphere – electron-density models – height profiles*

1. Introduction

Modelling of the ionospheric electron-density height profile over the whole altitude range for all geographic positions, time spans, and geophysical conditions is an essential part of ionospheric physics and a critical element in the development of practical schemes for providing reliable HF radiopropagation prediction. The existing models are at best approximations of the final goal.

Theoretical modelling, trying to solve the Boltzmann equation for the ionospheric plasma, starts from the continuity, energy, and momentum equations for electrons and ions (Anderson, 1993). The most advanced models have been developed at Utah State University – Time Dependent Ionospheric Model (TDIM) by Schunk *et al.* (1986), at University College London and the University of Sheffield – SHEF/UCL Model by Fuller-Rowell *et al.* (1987) and at the National Center for Atmospheric Research – NCAR Thermospheric Global Circulation Model (TGCM) by Roble *et al.* (1988). Because of their complexity and despite the increasing availability of multiple processor PC's, these models are still essentially confined to modern day supercomputers. For example, several hours on a CRAY XMP computer are required to specify the electron density on a global scale. Therefore, the main disadvantage of using theoretical models for prediction and forecasting is the large amount of computer time needed. In addition, as Sojka (1989) in his review paper has pointed out, extensive preparation of inputs is needed to obtain meaningful results. For most PRIME applications these would be a fundamental limitation.

The parameterised model approach is a relatively new one where the theoretical model is parameterised in terms of solar-terrestrial parameters and geographical locations. At present, there are a few parameterised versions of theoretical models available for different ionospheric regions: the Semi-Empirical Low-Lati-

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tude Ionospheric Model (SLIM) by Anderson *et al.* (1987); the Fully Analytical Ionospheric Model (FAIM) by Anderson *et al.* (1989); the Parameterised Ionospheric Model (PIM) by Daniell *et al.* (1993a,b) and its version adjusted by real time inputs known as Parameterised Real-Time Ionospheric Specification Model (PRISM); the Ionospheric Conductivity and Electron Density (ICED) model by Tascione *et al.* (1988).

Empirical modelling tries to extract periodic behaviour from past data records. Thus, empirical models describe average conditions of the quiet ionosphere (*e.g.*, monthly or seasonal mean values) and they are, by their conception, unable to represent the range of ionospheric variability or storm dynamics. However, day-to-day deviations from these mean values can range from 10 to 30% for quiet magnetic conditions and even higher for magnetic storm conditions. In addition, empirical models being based on observations are not very realistic in providing electron density profiles in those areas where observations are sparse or lacking. Recently an excellent review of empirical models of electron density was presented by Bilitza (1992).

From the PRIME point of view only the electron-density height profile is relevant and we shall concentrate on modelling this ionospheric parameter in the parameterised and empirical models. The following models by no means represent a complete picture of this field of research. They are simply typical examples of models which are available in the form of computer programs, currently in use and/or the subject of the VIM (Validation of Ionospheric Models) study (Reinisch *et al.*, 1992).

Table I. Parameterised models of ionospheric electron density.

Model	Characteristics	Extent
SLIM (Anderson *et al.*, 1987)	Based on theoretically obtained grid values for electron density profiles normalized to the F_2-peak and then represented by modified Chapman function using six coefficients per individual profile	Low latitude
FAIM (Anderson *et al.*, 1989)	Uses the formalism of the Chiu model with coefficients fitted to the SLIM model profiles and requires a smoothed Zurich sunspot number	Low- and mid-latitude
ICED (Tascione *et al.*, 1988)	Controlled by the sunspot number (SSN) and geomagnetic Q index and conceived to allow for real-time updates of the input parameters from a number of sensors	Global, improved performance in the high latitude
PIM (Daniell *et al.*, 1993a,b)	Amalgam of a number of other models and uses either the f_0F_2 CCIR coefficients for normalisation of the electron density profiles or coefficients produced by the TDIM	Global

Table II. Empirical models of ionospheric electron density.

Model	Characteristics	Data source
	Models with CCIR peak	
Bottomside only		
Bradley and Dudeney (1973)	Parabolic and linear segments, no F_1, no valley, no D region	Ionosonde
Dudeney (1978)	Improved functional description, no valley, no D region	Ionosonde
IONCAP Model 1983 (Teters *et al.*, 1983)	Parabolic and linear segments, valley of constant density, exponential tail below E parabola	Ionosonde
RAL multi-quasiparabolic model (Dick and Bradley, 1992)	A seven segment quasiparabolic model, at each segment interface there is continuity of profile and gradient	Ionosonde
Top and bottomside		
Bent ionospheric model (Llewellyn and Bent, 1973; Bent *et al.*, 1976)	Three exponential topside segments, bottomside bi-parabola	Satellite, ionosonde
International Reference Ionosphere - IRI (Bilitza, 1990)	Analytical description of Bent's topside, E valley, D region	Ionosonde, incoherent scatter, rocket, satellite
	Models without CCIR peak	
Chiu ionospheric model (Ching and Chiu, 1973; Chiu, 1975)	Three superposed Elias-Chapman layers (E,F_1,F_2), phenomenological description of peak parameters	Ionosonde
Kohnlein (1978)	One Elias-Chapman layer with parameterised scale height, phenomenological description of peak parameters	Rocket, ionosonde, topside sounder, *in situ*
Di Giovanni and Radicella - DGR (Di Giovanni *et al.*, 1992)	Analytical model based on routine ionogram scaling	Ionosonde

2. Parameterised models

Parameterised models of the ionosphere give a more realistic representation of the ionospheric spatial structure using a limited number of numerical coefficients. The list and description of the parameterised models which are available for testing is given in table I.

3. Empirical models

Several empirical models of the ionospheric electron density profile have been developed, as listed in table II. They differ very much in the data base used for model generation, in the number of coefficients and in the epoch represented.

Introduction of real-time values at certain altitudes can improve the prediction accuracy of the empirical models at all altitudes. The IRI model, for example, has an option for using real-time F peak density and altitude instead of the CCIR mapped values. Phenomenological descriptions of the peak parameters, as used in the last two models in table II need fewer coefficients, but they cannot describe global variations in as much detail as the spherical harmonics development can. They have, however, the advantage of small computational effort and easy accessibility of global and temporal trends.

4. Discussion and conclusions

This review has focused on the development and role of parameterised and empirical models of the electron-density height profile. It is important to emphasize that modern development of parameterised models allows realistic ionospheric models to be adjusted in real-time and incorporated in the three-dimensional ray tracing programs for HF propagation purposes. It has been shown that one of these models, the ICED model, can be used with near-real-time data to provide an accurate specification of the instantaneous ionosphere (Reilly *et al.*, 1991). Although there is a limit to the accuracy with which any parameterised model may represent the instantaneous ionosphere, this approach has been found useful in many applications. However, when near-real-time data are not available, knowledge of the monthly median values of ionospheric characteristics and their natural variabilities can also be a useful tool.

Besides every evaluation on the different performances of the different models considered, it is important to point out their utilization whether for scientific purposes or for radiocommunication applications. It is clear that for geophysical and scientific purposes, both parameterised models and empirical models may be used to obtain the required results. Instead, for radiocommunication applications, considering that the practical and easy utilization of software is very important, the empirical models are more suitable to these needs.

Furthermore, empirical models are structured so that it is possible to improve separately a part of them. They are, in some cases, an improved version of the older models. On the other hand, parameterised models, based on theoretical considerations, are suitable only for specific geophysical problems.

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REFERENCES

ANDERSON, D.N. (1993): Global ionospheric modelling, in *Modern Radio Science*, edited by H. MATSUMOTO (Oxford University Press), pp. 159.

ANDERSON, D.N., M. MENDILLO and B. HERNITER (1987): A semi-empirical low latitude ionospheric model, *Radio Sci.*, **22**, 292-306.

ANDERSON, D.N., J.M. FORBES and M. CODRESCU (1989): A fully analytical, low- and middle-latitude ionospheric model, *J. Geophys. Res.*, **94**, 1520-1524.

BENT, R.B., S.K. LLEWELLYN, G. NESTERCZUK and P.E. SCHMID (1976): The development of a highly successful world-wide empirical ionospheric model and its use in certain aspects of space communications and world-wide total electron content investigations, in *Effects of the Ionosphere on Space Systems and Communications*, edited by J. GOODMAN, Springfield, Va. U.S.A., pp. 13.

BILITZA, D. (Editor) (1990): *International Reference Ionosphere 1990*, NSSDC 90-22, Greenbelt, Ma. U.S.A.

BILITZA, D. (1992): Solar-terrestrial models and application software, *Planet. Space Sci.*, **40**, 541-579.

BRADLEY, P.A. and J.R. DUDENEY (1973): A simple model of the vertical distribution of the electron concentration in the ionosphere, *J. Atmos. Terr. Phys.*, **35**, 2131-2146.

CHING, B.K. and Y.T. CHIU (1973): A phenomenological model of global ionospheric electron density in the E-, F_1-, and F_2-regions, *J. Atmos. Terr. Phys.*, **35**, 1615-1630.

CHIU, Y.T. (1975): An improved phenomenological model of ionospheric density, *J. Atmos. Terr. Phys.*, **37**, 1563-1570.

DANIELL, R.E., W.G. WHARTENBY and L.D. BROWN (1993a), *Parameterised Real Time Ionospheric Specification Model*, PRISM version 1.2, Algorithm description (Computational Physics, Inc., Newton, Ma. U.S.A.).

DANIELL, R.E., W.G. WHARTENBY and L.D. BROWN (1993b): *Parameterised Real Time Ionospheric Specifi-*

cation Model, PRISM version 1.2, Validation Report (Computational Physics, Inc., Newton, Ma., U.S.A.).

DICK, M.I. and P.A. BRADLEY (1992): The RAL multi-quasiparabolic model ionosphere, in *Proceedings of the PRIME/URSI Joint Workshop on «Data Validation of Ionospheric Models and Maps (VIM)»*, Roquetes, 4-8 May 1992, *Memoria*, **16**, COST238TD(93)001, pp. 67.

DI GIOVANNI, G., S.M. RADICELLA and M.-L. ZHANG (1992): Further development of the DGR ionospheric model and comparison with the IRI current model, COST238TD(92)021, May 1992.

DUDENEY, J.R. (1978): An improved model of the variation of electron concentration with height in the ionosphere, *J. Atmos. Terr. Phys.*, **40**, 195-203.

FULLER-ROWELL, T.J., D. REES, S. QUEGAN, R.J. MOFFETT and G.J. BAILEY (1987): Interaction between neutral thermosphere composition and the polar ionosphere using a coupled ionosphere-thermosphere model, *J. Geophys. Res.*, **92**, 7744-7748.

KOHNLEIN, W. (1978): Electron density models of the ionosphere, *Rev. Geophys. Space Phys.*, **16**, 341-354.

LLEWELLYN, S.K. and R.B. BENT (1973): Documentation and description of the Bent Ionospheric Model, Report AFCRL-TR-73-0657, Hanscom AFB, Ma. U.S.A.

REILLY, M.H., F.J. RHOADS and J.M. GOODMAN (1991): Updated climatological model predictions of ionospheric and HF propagation parameters, *Radio Sci.*, **26**, 1017-1024.

REINISCH, B.W., D. ANDERSON, R.R. GAMACHE, X. HUANG, C.F. CHEN and D.T. DECKER (1992): Validating ionospheric models with measured electron density profiles, in *Proceedings of the PRIME/URSI Joint Workshop on «Data Validation of Ionospheric Models and Maps (VIM)»*, Roquetes, 4-8 May 1992, *Memoria*, **16**, COST238TD(93)001, pp. 41.

ROBLE, R.G., E.C. RIDLEY, A.D. RICHMOND and R.E. DICKINSON (1988): A coupled thermosphere/ionosphere general circulation model, *Geophys. Res. Lett.*, **15**, 1325-1328.

SCHUNK, R.W., J.J. SOJKA and M.D. BOWLINE (1986): Theoretical study of the electron temperature in the high-latitude ionosphere for solar maximum and winter conditions, *J. Geophys. Res.*, **91**, 12041-12054.

SOJKA, J.J. (1989): Global scale, physical models of the *F* region ionosphere, *Rev. Geophys.*, **27**, 371-403.

TASCIONE, T.F., H.W. KROEHL, R. CREIGER, J.W. FREEMAN, R.A. WOLF, R.W. SPIRO, R.V. HILMER, J.W. SHADE and B.A. HAUSMAN (1988): New ionospheric and magnetospheric specification models, *Radio Sci.*, **23**, 211-222.

TETERS, L.R., J.L. LLOYD, G.W. HAYDON and D.L. LUCAS (1983): Estimating the performance of telecommunication systems using the ionospheric transmission channel – Ionospheric Communications Analysis and Prediction Program User's Manual, Report NTIA 83-127, Boulder, Colorado, U.S.A.