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Ionospheric Modelling

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IONOSPHERIC MODELING

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Premise

- The understanding of the behaviour of the ionosphere and its effects GNSS operations is determined by the ability to model at least the height, geographical and time distributions of the electron density.
- There is no numerical code or model openly available that is able, at present time, to describe accurately both the three-dimensional and time-dependent distribution of the ionospheric plasma.
- In other words, no model is able to reproduce in a satisfactory way both the “climate” and the “weather” of the Earth ionosphere.
- In addition, it is mandatory to have well established experimental databases that can be used to verify and test the existing models in order to generate the improvements needed.
- At present most models are able to reproduce consistently the climate of the ionosphere over a given location or region, as defined mostly by diurnal, seasonal and solar cycle variations.

TYPES OF MODELS

- Theoretical or first-principle models
- Empirical or semi-empirical models
- Analytical “profilers”

THEORETICAL OR FIRST-PRINCIPLE MODELS

In these models conservation (continuity, momentum, energy, etc.) equations are solved numerically as a function of spatial and time coordinates to calculate plasma densities, temperatures and flow velocities.These models require magnetospheric and atmospheric input parameters and their accuracy depend on the quality of the input data. They can be powerful tools to understand the physical and chemical processes of the upper atmosphere. Examples of models:

- The Sheffield Coupled Thermosphere Ionosphere Plasmasphere Model (CTIP)
- Time dependent middle-latitudes model

SHEFFIELD CTIP MODEL

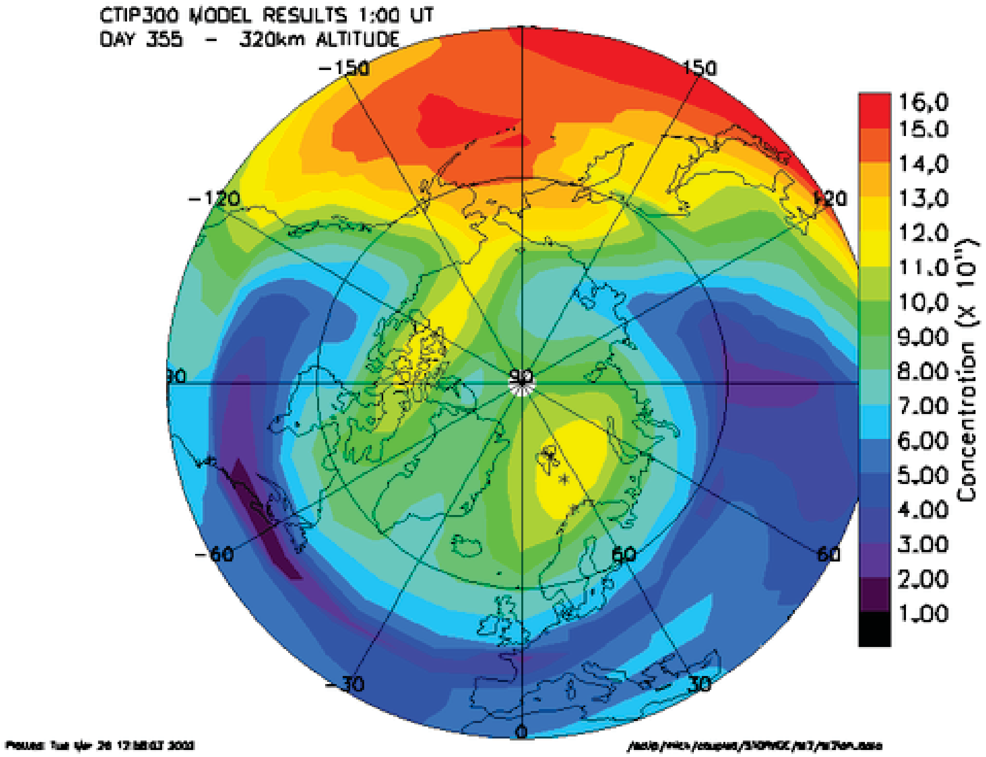
A three-dimensional, fully coupled, numerical model of the thermosphere, low-latitude plasmasphere and high-latitude ionosphere system based on solving the equations of continuity, momentum and energy balance (Fuller-Rowell et al., J. Geophys. Phys., 92, 7744, 1987).

- The current versions of CTIP have resulted from over twenty years of development. The model was enhanced at Sheffield to account for the mid and low-latitude ionosphere and to include a self-consistent plasmasphere.

- Species concentration solved include the atomic species O, H and N; the atomic ions O+, H+, N+ and He+; the molecular species O2 and N2, and the molecular ions NO+, O2+ and N2+.

- Calculated and derived quantities include also three-dimensional ion and neutral winds, ion, neutral and electron temperature,Joule Heating, Lorentz Forcing, and Hall and Pedersen conductivity.

CTIP Model results of electron density for Day 355 during a geomagnetic disturbance.



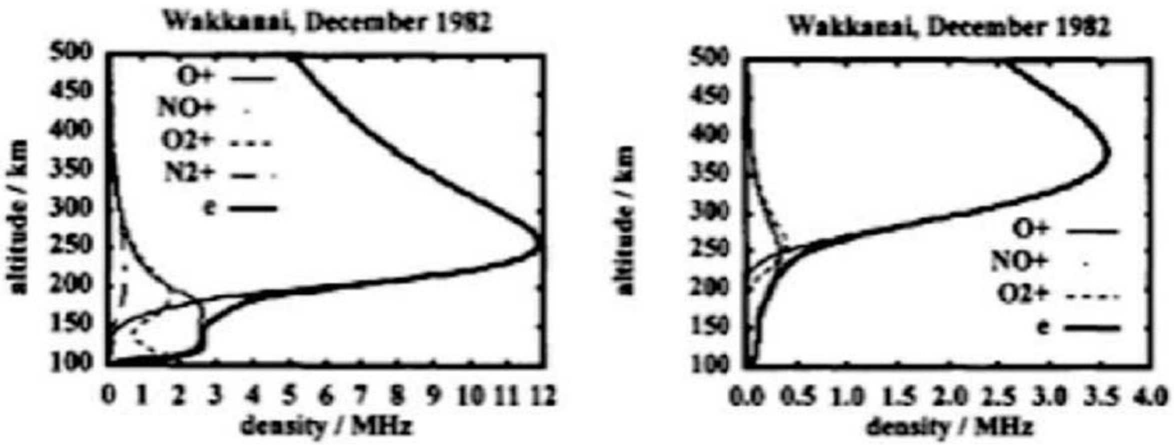
•http://www

TIME DEPENDENT MIDDLE-LATITUDES MODEL:

It solves a set of equations involving different ions and electrons. Both dynamic and photo-chemical processes are considered and stable and meta-stable species are taken into account (Zhang S. R., et al., Annali di Geofisica, 36, 5-6, 105, 1993. and Zhang S. R. and S. M. Radicella, Annali di Geofisica, 36, 5-6, 111, 1993). The model depends on EUV91 model data for solar radiation flux, MSIS 86 for neutral concentration and temperature and HWM 90 for neutral horizontal winds.

- Inputs are geographical latitude and longitude, day number, Ap index and daily and 81-day mean of F10.7.
- Output are electron and ion concentrations at a function of time and altitude.

EXAMPLE OF MODEL OUTPUT: NOON AND MID-NIGHT CONCENTRATIONS



S.-R. Zhang et al.; Adv. Space Res. Vol 18, n° 6, pp. 165-173,1996

EMPIRICAL AND SEMI-EMPIRICAL MODELS

Based on a analytical description of the ionosphere with functions derived from experimental data or adapted from physical models. Two global scale models:

- IRI: International Reference Ionosphere
- PIM: Parameterized Ionospheric Model

IRI

An international project sponsored by the Committee on Space Research (COSPAR) and the International Union of Radio Science (URSI), which aimed at producing a reference model of the ionosphere based on available experimental data sources. IRI is updated periodically and has evolved over a number of years. (D. Bilitza, Radio Science 36, #2, 261-275, 2001)

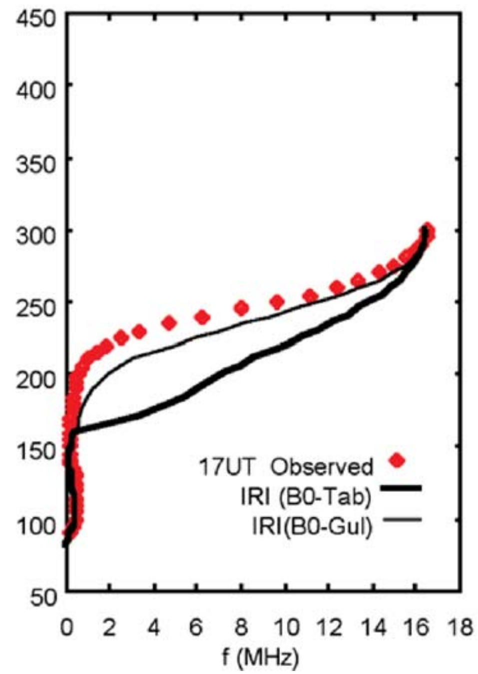
IRI data sources are :

- coefficients (foF2 and M(3000)) produced by ITU-R (former CCIR) from a large number of ground based sounders,
- incoherent scatter radars (Jicamarca, Arecibo, Millstone Hill, Malvern, St. Santin) measurements,
- ISIS and Alouette topside sounders ionograms,
- in situ measurements by several satellites and rockets.
- It can also use as input experimental values of F2 peak electron density (or foF2) and height .

IRI OUTPUT:

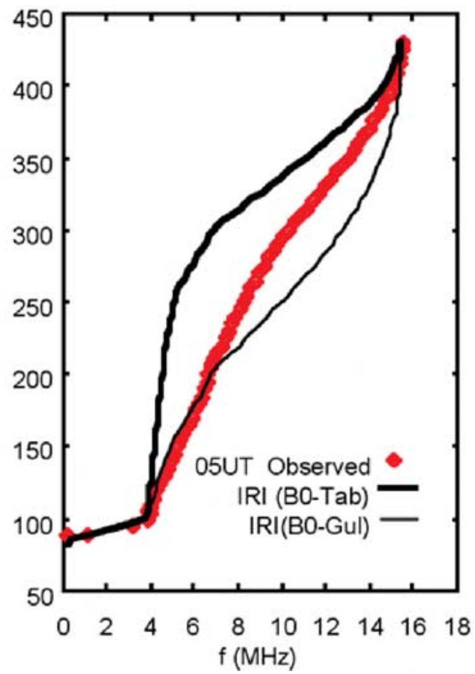
- For given location, time and date, IRI gives in the altitude range from about 50 km to about 2000 km:
  - electron concentration,
  - electron temperature,
  - ion temperature,
  - ion composition
  - total electron content (TEC).
- It provides monthly averages in the non-auroral ionosphere for magnetically quiet conditions.

IRI Profiles (bottomside)

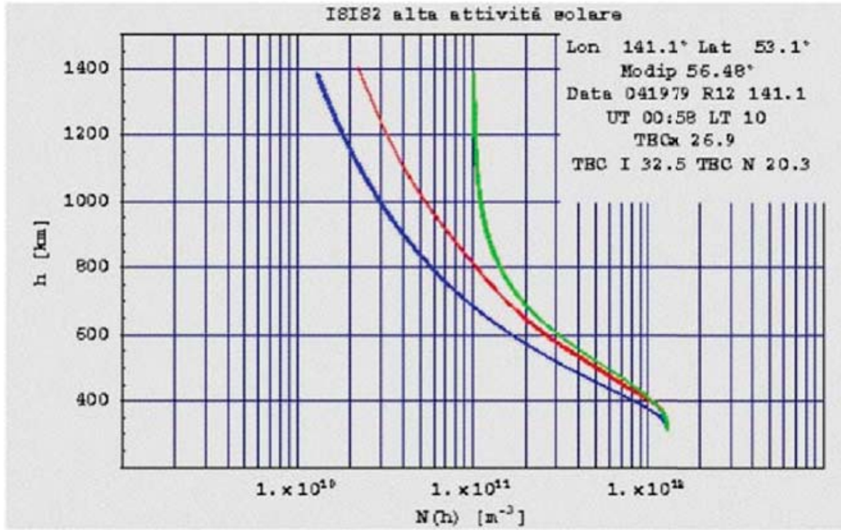


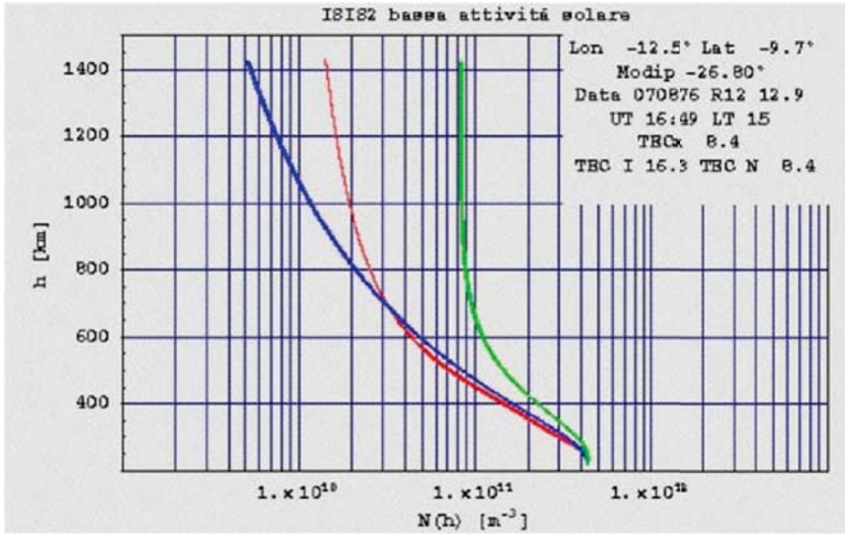
Hainan (19.4°N/109.0°E)
April 2002

Monthly average representative profiles (ARP)



IRI Profiles (topside)





(red)Experimental ISIS2

(blue)NeQuick

(green)IRI

New IRI topside

IRI model has adopted as default option for its topside
The NeQuick 2 model topside

PIM

- is a fast global ionospheric and plasmaspheric model based on a combination of the parameterized output of several regional theoretical ionosphere models and an empirical plasmaspheric model (Daniell et al., Radio Sci., 30, 1499-1510, 1995).
- In 1997 the Gallagher plasmaspheric model (Gallagher et al., Adv. Space Res., 8, 15-24, 1988.), a fast empirical model of plasmaspheric H+, was incorporated into PIM.
- From a given set of geophysical conditions (day of the year, solar activity index $f_{10.7}$, geomagnetic activity index Kp) and positions (latitude, longitude, and altitude), PIM produces electron density profiles between 90 and 25000 km altitude, corresponding critical frequencies and heights for the ionospheric E and F2 regions, and Total Electron Content (TEC).
- It represents the climatological portion of the Parameterized Real-time Ionospheric Specification Model (PRISM).

DIFFERENCES BETWEEN EMPIRICAL AND PARAMETERIZED THEORETICAL MODELS:

- Both type of models give the climatology of the ionosphere
- Empirical climatology gives an “average” ionosphere over potentially different ionospheric conditions that could be smeared by the averaging process
- Empirical climatology is limited by the amount of data and their spatial and temporal distribution
- Parameterized theoretical climatology yields a “representative” ionosphere with features similar to those that might be observed on any given day under specific geophysical conditions.
- Theoretically derived climatology is limited by the accuracy and completeness of the physics and chemistry included in the models.

“PROFILERS”

Another way to estimate the electron concentration distribution with altitude is to express an altitude profile in terms of simple mathematical functions, adjusted to ionospheric characteristics routinely scaled from the ionograms. The advantage of this type of "profile modelling" is that it can in principle use as inputs simply experimental values of basic ionospheric characteristics for both quiet and disturbed conditions. Examples of profilers:

- Bradley and Dudeney 1973
- Dudeney 1978
- Di Giovanni and Radicella 1990
- Family of Trieste-Graz profilers

BRADLEY AND DUDENEY 1973

Describes the electron concentration profile up to the peak of the F2 region with two parabolic layers for the E and F2 layer and a linear segment in between. This profile generation is still used by the ITU-R HF propagation prediction method (Bradley, P.A. and J. R. Dudeney, J. Atmos. Terr. Phys., 35, 2131, 1973).

DUDENEY 1978

A more refined profiler that uses routinely scaled characteristics, incorporates combinations of trigonometric functions segments, and provides optionally valley and F1 description. Electron concentration gradient with altitude is continuous (Dudeney, J. R., J. Atmos. Terr. Phys., 40, 195, 1978)

DI GIOVANNI AND RADICELLA (DGR) 1990

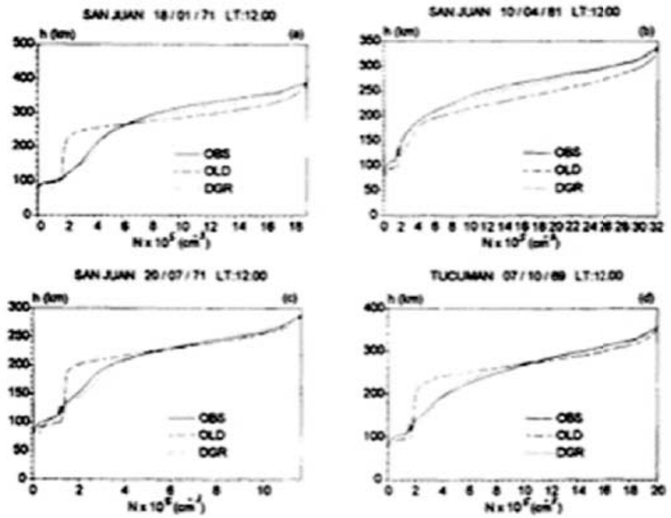
•Describes the electron concentration profile in the E-F1-F2 regions of the ionosphere by using simple analytical expressions.

•It is constructed as the sum of three Epstein layers that are formally identical considering the existence of characteristic points in the profile with co-ordinates (values of electron concentrations and its height) calculated by means of empirical expressions.

• It gives the electron concentration profile above the F2 peak making use of an effective shape parameter empirically derived for the topside ionosphere. Total electron content is computed with an analytical expression.

•This model has been adopted by the European Commission COST 238 (PRIME) action (Di Giovanni, G. and S. R. Radicella, Adv. Space Res., 10, No. 11, 27-30, 1990, and Radicella, S. M. and M. L. Zhang, Annali di Geofisica, 38, 1, 35-41, 1995).

- DGR PROFILES



- M.M. de Gonzalez, Adv. Space Res. vol 18, n° 6, pp. 53-56, 1996

TRIESTE-GRAZ FAMILY OF MODELS

- NeQuick, a quick-run model particularly tailored for transionospheric propagation applications;

- COSTprof, a more complex model for ionospheric and plasmaspheric satellite to ground applications;

- NeUoG-plas, a model to be used particularly in assessment studies involving satellite to satellite propagation of radio waves.

•COSTprof model was adopted by the European COST 251 action. NeQuick model has been used by the ESA EGNOS program and adopted by Recommendation P.531-6 of the International Telecommunication Union-Radiocommunication sector (ITU-R) as a suitable method for TEC modelling.

•Are particularly suitable for assessment studies in connection with advanced satellite navigation and positioning systems. They can be used to assess various radiopropagation effects observed in received satellite signals.

•They can simulate space and time regional ionospheric variations produced by geomagnetic storms, TIDs or trough, and their effects on transionospheric propagation (S. M. Radicella, and R. Leitinger, , Adv. Space Res., Vol. 27, n° 1, Pages 35-40 (2001)).

CHARACTERISTICS OF THE MODELS

They consist in two height regimes:

- The bottomside model for the height region below the peak of the F2-layer use a modified DGR profile formulation which includes 5 semi-Epstein layers with modelled thickness parameters and is based on foE, foF1, foF2 and M(3000)F2 values. Different sources for these ionosonde parameters can be considered depending on the purpose.
- The topside model for the height region above the F2-layer peak uses different approaches: Nequick: a semi-Epstein layer with a height dependent thickness parameter. COSTprof: three physical parameters: oxygen scale height at the F2 peak, its height gradient, O^+–H^+ transition height, modelled according to solar activity, season, local time and "modified dip latitude". NeUoG-plas: uses a magnetic field aligned formulation for an H^+ diffusive equilibrium for plasmaspheric heights above 2000 km.It takes over the (hydrogen) scale height found at the field line foot point at 2000 km.
- NeUoG-plas has an additional geomagnetic field aligned third part for the "plasmasphere".

INPUT PARAMETERS:

- ITU-R (former CCIR) coefficients for foF2 and M(3000)F2 and R12 and/or monthly mean F 10.7,
- Measured values of foE, foF1, foF2 and M(3000)F2 or F2 peak concentration and peak height,
- Regional maps of foF2 and M(3000)F2 based on grid values constructed from data obtained at given locations.

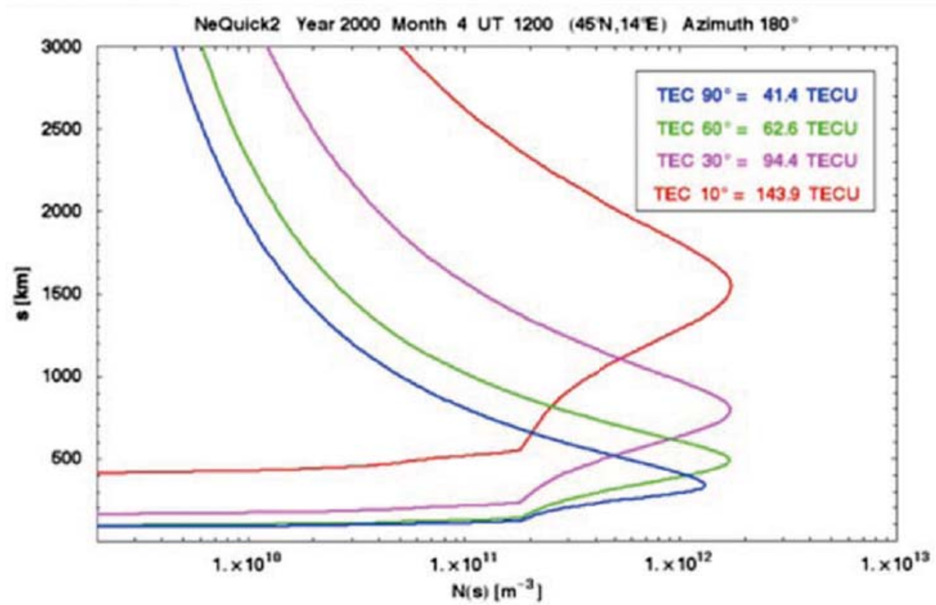
OUTPUT PARAMETERS

- Electron concentration vertical profile to a given height (including the GPS satellite altitude).
- Electron concentration along arbitrary ground to satellite or satellite to satellite ray paths.
- Vertical Total Electron Content (vTEC) up to any given height.
- Slant Total Electron Content between a location on earth and any location in space.

A NEW VERSION OF NeQuick

An improved version of NeQuick has been generated recently and will be outlined in the next lecture

SLANT PROFILES OBTAINED WITH NeQuick MODEL



Example of NeQuick 2 profiles and TEC along ray-paths. Different colors correspond to different path elevation angles. 90º means vertical profile and TEC.

FINAL REMARKS

- Theoretical, empirical or semi-empirical and "profilers" in their present state are not able to describe the variability of the ionosphere that define the "ionospheric weather".
- The way to follows is to assimilate or ingest data in the models to specify the ionospheric conditions globally or regionally at a given time.