CAHPTER - 3

THERMOSPHERIC-IONOSPHERIC MODELLING

3.1 Introduction

The ionosphere is the region from about 60 km to 2000 km altitude. Where the solar radiance produces a partially ionized plasma of mostly H^+ and He^+ above 1000 km, O^+ from 300 to 500 km and molecular ion (NO^+, O^+, N_2^+) below 200 km. Total ion densities (=electron density) range from 10^8 to 10^13 m^{-3}. Driven by neutral winds and electric fields the ionospheric electrons and ions move along geomagnetic field lines.

Knowledge of the ionospheric electron density is essential for a wide range of applications, e.g., radio and telecommunications, satellite tracing, and earth observation from space. Considerable efforts have, therefore, been concentrated on modeling these ionospheric parameters.

In the late 1940's and 1950's, the location of peak electron density well above the peak of ion production was an enigma to the ionospheric physicists. Whereas the lower layers (E and F_1) confirm closely to the Chapman's theory of layer formation, the ionization distribution in the F_2 region differs considerably from the expected morphology. So, it was recognized that the behavior of the F_2 layer is complex and inexplicable in terms of solar ionizing radiation and chemical recombination alone. *Mitra* **[1]**, first realized the importance of motion of plasma along the magnetic field lines at heights where the plasma-neutral collision frequencies are small, and hence the geomagnetic control of ions and electrons in the F_2–region of ionosphere. Under the forces of gravity and of its own partial pressure gradient, diffusion of ionization along the magnetic field lines in the vertical direction affect the shape and height of F_2–layer considerably **[2]**. It was *Martyn*, who first realized that the morphology of the F_2– layer might be explained with inclusion of electrodynamic drifts of the ionospheric plasma. *Duncan* **[3]** showed that a uniform vertical drift would alter the equilibrium height of F_2–layer.

The diffusion of plasma in the upper atmosphere is important .The expression of the diffusion contribution to overall motion of F_2–layer plasma was derived by *Shimazaki* **[4]**. It was *Yonezawa* **[5]** who solved the equations for a particular atmospheric model to arrive at appropriate analytic function which revealed the formation of the F_2 peak by action of diffusion. *Rishbeth and Barron* **[6]** showed relationship between the diffusion and recombination rates, that determines the position and magnitude of the F_2 peak for equilibrium conditions.

Briggs and Rishbeth **[7]**, considered an equivalent electrical network with series of condensers and resistors and obtained a solution to the continuity equation for F-region electron density. The charge on the condenser represented the electron density at a certain height, and the resistor provides a path for the leakage of this charge, represented the loss and diffusion coefficients.

Fewer mostly mission-specific models have been developed for the electron temperature, ion composition (relative ion densities in percent) and the ion drift, the later being closely related to the forcing electric field. The International Reference Ionosphere, the most complete representation of the ionosphere, includes models of the ion temperature, ion composition, and ion drift. At present, almost all empirical models of ionospheric parameters are limited to non-auroral, magnetically quiet conditions. Major efforts are underway to extend ionospheric predictability beyond these limitations.

3.2 Thermospheric Modeling

Several models have been developed in recent times to predict the upper atmosphere. The range is from simple empirical specifications of a few selected parameters to highly complex three dimensional numerical methods.

3.2.1 – Empirical Methods:

The empirical methods give the average behaviour of the atmosphere under specified conditions. These models are based on the data sets collected over a long period by means of remote and in-situ techniques .The data sets are synthesized, binned with proper indices and then fitted with simple analytic expressions .The first model is *Jacchia – 1965* **[8]** and was based on total densities of the atmosphere. From *Jacchia-1965* **[8]**, the era of empirical and semi-empirical models began. *Hedin* **[9]** has been developed *OGO-6* model after realization that the mass spectrometer measurements of densities of individual species were different from those expected from the *Jacchia-1965* and *1971* models [8,10]. Later on the OGO –6 model has been modified to the MSIS – 77 model.

3.2.2 MSIS –77 Model

In this model temperature data from three incoherent scatter radars have been incorporated making use of a wider data base. This model has been modified twice to represent the seasonal differences in composition and temperature and variations in magnetic storms. The *MSIS–86* model has been adopted as the new *COSPAR* international atmosphere (*CIRA*) empirical model which is now available in computer compatible from.

3.2.3 The Global Empirical and Semi-Empirical Models

These models represent the variations of a thermospheric parameter by an expansion in vector spherical harmonics with each expansion coefficient represented by a fourier series. The input parameter they need are the solar decimetric index, the geomagnetic activity index (A_p), the local time and geographic co-ordinates.

3.2.4- Empirical Global Model On The Thermospheric Winds

The *HWM-87* is an empirical global model on thermospheric winds and based on the wind data obtained from AE-E and DE-2 satellites. The limitations to this model are that it yields neither the altitude variations nor the solar cycle variations of horizontal winds, due to the data coverage. This model has been revised incorporating ground based data from several incoherent scatter radar, by Fabry-Perot interferometers extending the data coverage in both solar activity and altitudes.

3.2.5 The Other Currently Used Thermospheric Model

They include analytical and simple numerical models and thermospheric general calculation models. This MVH (Mary, Volland and Haris) model makes use of a semi-analytical approach in which physical parameters are described in an expansion of spherical and fourier harmonics by applying linear perturbation theory. The thermospheric general calculation (TGCM) model have been formulated primarily to study global circulation, temperature and compositional structure of the thermosphere.

3.3 – Ionospheric Modeling

The ionospheric models are:

(I) Empirical model based on extensive worldwide data sets.

(II) Simple analytic models for a restricted number of ionospheric parameters.

(III) Comprehensive three-dimensional time dependent models.

(IV) Spherical harmonic models.

(V) Model driven by real time magnetospheric inputs.

In the ionospheric modeling the most comprehensive empirical model is "International Reference Ionosphere" (IRI) that provides the information of electron density, ion composition and electron, ion temperature **[11].** Due to the adequate data coverage, the IRI is sited to mid-latitude F-region. The altitude variations of electron density, ion composition and electron, ion temperatures are distributed in terms of the mathematical functions, whereas variations with respect to latitude and longitude are described by orthogonal polynomials.

The physical models of the ionosphere solve the continuity, momentum and energy equations for the electrons and ions either as a function of altitude or long curved geomagnetic field lines.

The simulation of both thermospheric and ionospheric parameters, ion neutral coupling is important and fully coupled self consistent thermospheric general circulation models have been developed by *UCL* and *NCRA* group.

3.3.1 MSIS Model

For the MSIS-86 model the data source of temperature and density measurements is from several rockets, satellites (*OGO-6, SAN MACRO-3, AEROSA, AE-C, AE-D, AE-E, ESPO-4, DE-2),* and incoherent scatter radars (*Millstone Hill, St. Santin, Arecibo, Jicamarca* and *Malvern*).

The inputs to the model are year, day of year, universal time, altitude, geodetic latitude and longitude, local apparent solar time, solar $F_{10.7}$ flux (for previous day and three month average) and magnetic A_p

index (daily or A_p index history for last 59 hours). For this conditions the following outputs are calculated : number density of the O, N_2, O_2, Ar, H and N and total mass density, neutral temperature and exospheric temperature.

3.3.2 –Model Calculations

From the knowledge of atmospheric parameters the emission of OI 630.0 nm and 557.7 nm atomic oxygen lines can be estimated.

Hedin A. E. **[12],** developed MSIS-86 empirical model for the numerical computation of atmospheric parameters. The altitude profile of the main species (N_2, O_2 and O) of thermosphere vary with magnetic activity represented by Ap index.

The rate of optical emission and energy deposition produced by precipitating particles in the thermosphere are important for understanding the physical processes occurring in the thermosphere.

The first MSIS model was developed in 1977 and it was revised in 1983. The MSIS-86 model is its third version. The atmospheric model used in our studies is MSIS-86 model **[12]**. It is most up-to-date atmospheric model. This model is constructed using mass spectrometer data from seven satellites and numerous rocket measurements as well as data from five ground based incoherent scatter radar stations. The model calculations of the atmosphere above the Kolhapur station are made by selecting four parameters: geophysical location, 16.8° N, 74.2° E

(Kolhapur station), the day of the year, F-10.7 solar flux and time of day. The Ap index is chosen as 10, 50 and 100 to see the dependence of the thermosphere density variations on magnetic activity. The Ap index is the diurnal average of three-hour Ap indices, which are transformations of Kp to a linear scale. Generally, the densities of the neutral species (O, O_2, N_2) decreases with the increase in the altitude (about four to five order decrease from 100 km to 500 km altitude) at a given time. The number densities of neutral species specially 'O_2' molecules increases in equinoctial month (March) from their respective values in month of December at 300 km altitude due to increase in geomagnetic activity. This causes generally enhancement in integrated 630.0 nm intensity at the ground during geomagnetic storms.

3.4 Recent Results from Modeling

I) Though both the thermospheric and ionospheric model provides a reasonable behavior of respective regions, they do not represent the actual conditions that persist in the real neutral-plasma medium.

(II) We have a non-linear medium that is strongly distributed not only by changes in solar input and by a continuing, fluctuating, transfer of energy and momentum from the magnetosphere but also from lower and middle atmospheric inputs. The effect of the perturbation due to these external sources are understood only in a climatological sense.

(III) Apart from the disturbances of external origin many of the features of the thermosphere ionosphere system are not properly explained. The geomagnetic field configuration near the dip-equator makes it unique on the principles that are not applicable to mid-latitude may not be valid at all in this region.

(IV) The coupling process of thermosphere-ionosphere system plays a different role in the equatorial and latitude regions that had been not explored till recently.

(V) The limitations in our understanding of the many physical processes of the low-latitude thermosphere-ionosphere system have been due for various geophysical and geomagnetic conditions.

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