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Investigating the Fluctuating Dynamics of Refractive Index of Ionospheric Layer at Pakistan Region

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ABSTRACT

The ionosphere is the part of atmosphere, ionized by solar radiation. The ionosphere affects our modern society in many ways due to variability in ionosphere composition under the influence of solar radiations. This paper attempts to describe ionosphere communication and to compute & evaluate fluctuating dynamics of refractive index as a result of change in critical frequency, electron concentration of layers during daytime and night hours for the year 2000 at Pakistan region. The recorded ionosphere data (at SUPARCO Ionosphere Station in Karachi) has been used to calculate refractive index in relation with critical frequency, maximum useful frequency and propagation frequency at mid values of latitude. To investigate relationship between ionospheric parameters, descriptive statistical methods such as histogram, regression analysis and normal probability plot have been implemented. The results and conclusion obtained are useful for planning and successful uninterrupted radio wave propagation through ionosphere.

INSPEC Classification : A9420B, A9420D , A9420J

Keywords : Ionosphere, Critical Frequency, Refractive Index and Electron Concentration.

1. INTRODUCTION

The ionosphere contains charged particles due to intense UV radiations from the sun. It was discovered by Marconi in 1901 and Lodge in 1902 described composition of ionosphere these particles exhibit plasma behavior. It has been known that reflection of radio waves provided the first clue to the existence of an ionized layer at higher altitudes. To explore potential interaction of radio ways with the ionosphere we still need to learn about its

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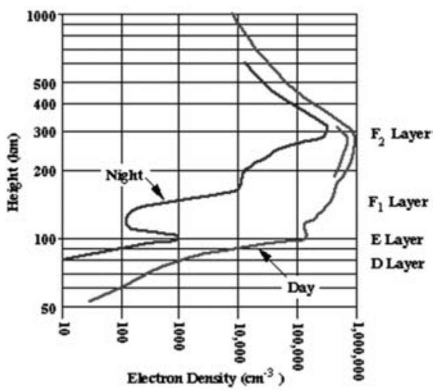
dynamic behavior. The varying solar radiation causes variability in electron concentration and thickness/disappearance of ionosphere layers. The most important ionospheric region: the *D*, *E*, F_1 and F_2 layers. The Fig-1 presents the level of ionization during the daytime and night hours. The ionization level and ionosphere heights vary majorly depends on (a) over 11 year solar cycle (b) difference in geographic location (c) different seasons of the year and (d) time of the day. The ionosphere undergoes a large variation in ionization from day to night. During no sun condition the no more new ions and recombination process depletes but the density of neutral particles does not vary from day to night (Davies, Kenneth, 1990), (Kelley, M.C.,1989). Furthermore; The D-layer, disappears completely with the Sun set. In the E-layer the electron (and ion) density decreases by a factor of 200:1. In the F_1 layer electron (and ion) density decrease is 1000:1, that is why F_1 and F_2 layers are merged and form single F layer. The most suitable layer for radio wave propagation for shorter and long distance communication.

2. Radio Wave Propagation Via Ionosphere

The ionosphere extends in the height from 80 to 1000 *Km* above the sea level. The ionosphere affects the propagation of all waves, up to 50MHz. Frequencies lower than approximately 30 MHz are propagated by reflection, while frequencies between 30 and 50 MHz are propagated by scattering. The *F* layer extends at altitude 160 to 450 Km (Armel Picquenard,1974). Thickness of this region in the daytime is divided into F_1(200 Km) and F_2(300 Km) layer as shown in Fig-1.

Fig-1
Ionization level Vs Ionization Height



During the night the distinction of layers does not hold. The F_2 layer is the highest and most ionized reflecting layer. The electron concentration of this layer varies between 5*$\mathbf{10^{11}}$ during the night and 20*$\mathbf{10^{11}}$ electron/m^3 (H. Sizun, 2005). The profile of electron density in the ionosphere acts as a reflecting medium capable of reflecting radio waves at high frequency (3-30 MHz) and below frequency return to earth. The electron density is stronger at day time and during periods of great solar activity having refractive index less than unity. The critical frequency varies in the same way as the solar activity. The critical frequency is higher in winter than in the summer. Ionospheric refraction is dominant at lower frequencies in the range of 3-30 MHz. In this paper the investigation and evaluation of ionospheric refraction is presented using numerical approach making use of electron density distribution in the ionosphere. According to Jordan and Balmain, 1968 and Griffiths, 1987 have suggested the relationship of refractive index n(h) of ionosphere varies as a function of height of layer depending upon the electron density N(h) for propagation frequency (f) (Georg Kennedy, Bernard Davis, 1993).

3. Methodology

To investigate the ionosphere parameters, standard numerical known techniques have been used. The ionospheric parameters such as electron density, refractive index from hourly recorded critical frequency at different altitude for the year 2005 at latitude 24.95 ° N and longitude 67.14° *E* have been calculated with the help of known mathematical. To compute the ionosphere parameters establish relationship between parameters descriptive statistical methods have been implemented.

3.1. Electron Density

The useful real time data has been monitored and recorded by ionosphere equipment DGS-256 located at Karachi Ionospheric Station (KIS) in SUPARCO. The geographic positioning of station is indicated on Pakistan map as shown in Fig-2. For F_2 layer the ordinary critical frequency ($f_\circ$) is related to peak value of electron density (N) *is* given by Equation-(1).

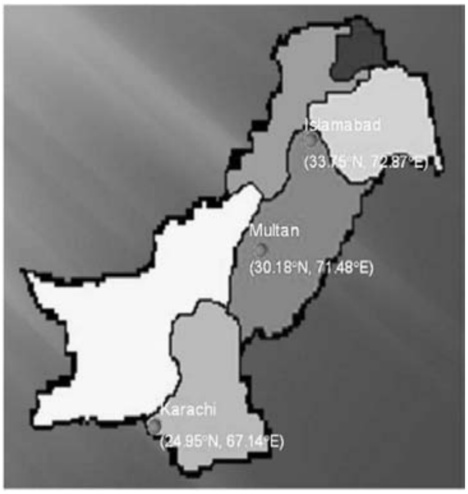
$$f_o = \sqrt{80.8}N(max) \cong 9\sqrt{N(max)} \quad (1)$$

The peak value of electron density of F_2 layer is computed in respect of measured ordinary critical frequency, the expression in Equation-(2) postulated by Anderson and Matsushita (Les Barclay, 2002), (Robert W. Schunk, Andrew F. Nagy, 2004), in 1974.

$$N(max) = 1.24 * 10^4 f_o^{\,2}(MHz) \quad e/cm^3 \quad (2)$$

The computed values of electron density with minimum $4.667*10^{10}$ and maximum of $3.427*10^{12}$ electrons/ under the influence daily hourly variations for the year 2005 in solar radiation allowing change in value of critical frequency. The magnetic field effects have not been considered in the computation.

Fig-2
Location of Ionosonde Stations in Pakistan (taken from SUPARCO Web Site)



3.2. Refractive Index

The travelling of radio waves in ionosphere will follow the Snell's Law i.e. the refraction n(h) occurs and bent of wave will be observed. This relationship between refractive index and electron density with propagation frequency is expressed in Equation-(3).

$$n(h) = \sqrt{[1 - 81\, N(h)/f^2]} \qquad (3)$$

It is known that n(h) equals to unity only if ionosphere is free from ionization otherwise it is less than unity and its variation is dependent upon electron density and propagation frequency. The travelling of radio waves in ionosphere will follow the Snell's Law i.e. the refraction occurs and bent of wave will be observed. The computed value of refractive index in this paper for the year 2000 at Pakistan-Karachi region has been witnessed. The refractive index of the ionized medium is given by Appleton-Hartee postulated in simplified form i.e. neglecting collision of ion-electron and magnetic field effect the relation of n(h) (Les Barclay, 2002) as in Equation-(4). The computed values are minimum of 0.9473 and maximum of 0.9555. The values show presence ionization in the ionization layers under consideration and reported in this paper.

$$n(h) = \sqrt{1 - (\omega_o/\omega)^2} \qquad (4)$$

where,
ω: Critical frequency in rad/sec
ωPropagation frequency in rad/sec

3.3. Radio Wave Propagation

The propagation of an electromagnetic wave is described through electric and magnetic fields. The refractive index is characterized from medium permittivity (e) and magnetic permeability (m) The propagation velocity of electromagnetic waves is described in Equation-(5).

$$v = \frac{1}{\sqrt{\varepsilon\mu}} \qquad (5)$$

The equation-(4) suggests that the wave propagation in ionosphere will take place only when $\omega < \omega_c$, refractive index is real and it is imaginary if $\omega > \omega_c$ and wave are vanished and no wave propagation takes place (Armel Picquenard,1974). The computed values of refractive index provide evidence ionization thereafter provision of radio wave propagation through ionosphere. To increase the skip distance as the frequency of radio wave increased, the critical angle must be reduced. In our case optimized value of critical angle q = 74° for computed propagation frequency range of 5.98 to 51.27 MHz and maximum useful frequency is calculated using Equation-(6).

$$f_{muf} = f_o\, Sec\, \theta \qquad (6)$$

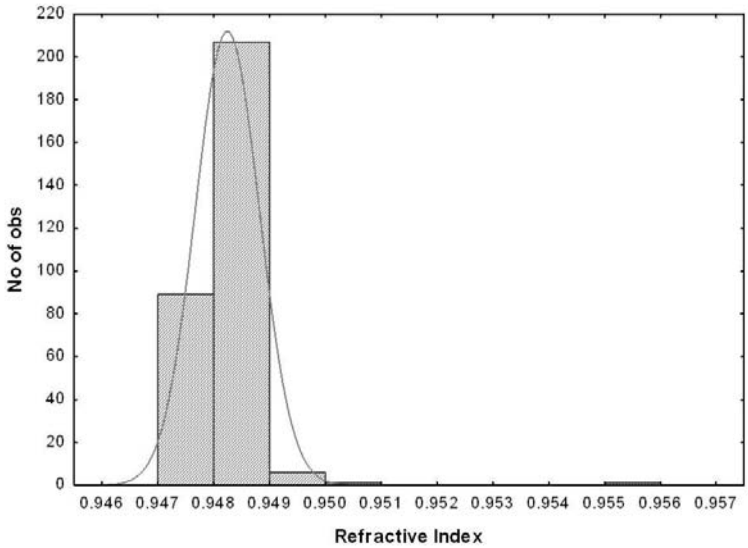
4. Statistical Analysis

The descriptive statistical analysis is an attempt to understand the process and establish knowledge about the relationship between the parameters. The exploratory data analysis (EDA) is focused to gain insight knowledge behind the data. Insight implies detecting and uncovering underlying structure in the data. In this paper the EDA have been implemented using interpretation of histogram, scatter and normal probability plot have been presented. The variability in parameters has been processed using statistical software tool. The graphical representations with trends presented relationships between parameters.

4.1. Univariate Data Analysis

A histogram, first time introduced by Karl Pearson, is a graphical representation showing a visual impression of the distribution of data (P.N. Arora, Sumeet Arora, S. Arora, 2007). The histogram of computed values of refractive index with normal curve fitting is shown in Fig-3. For year 2005, 304 sample data point the distribution suggests symmetrical and tend to show Gaussian normal distribution with the exception of outlying data between 0.955 and 0.956. The distribution show mean = 0.9482, standard deviation = 0.0006.

Fig-3
Histogram of Computed Refractive Index with Normal Curve

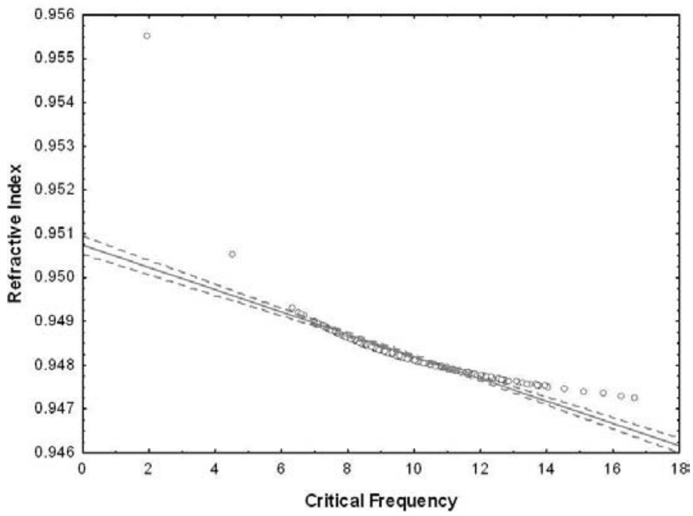


4.2. Regression Analysis

A scatter plot suggests relationship between two variables. Such relationships manifest themselves by any non-random structure in the plot. In this paper, the regression models for the computed parameters for layer have been shown in Fig-4 and 5. The regression line equation for refractive index and critical frequency is;

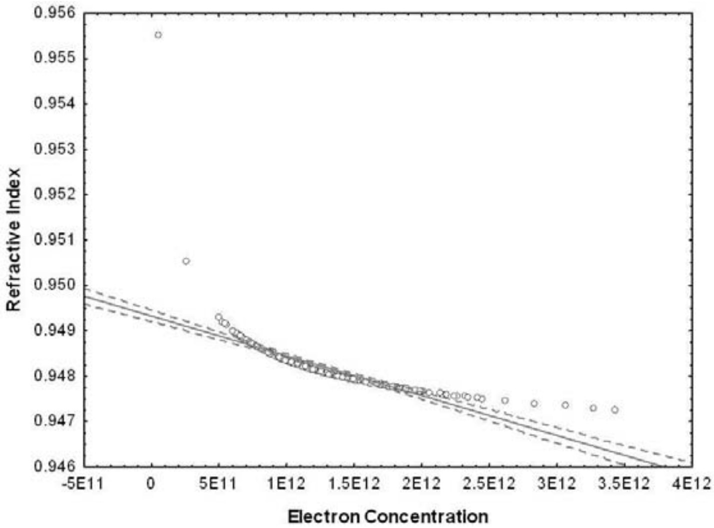
$$n = 0.9507 - 0.0003 * f_o \qquad (7)$$

Fig-4
Scatter Plot of Refractive Index and Critical Frequency



The association between refractive index and critical frequency show a negative correlation with few outliers. The Pearson's, coefficient of correlation, r = 0.8142 and coefficient of determinant, r^2 = 0.6629 with intercept 0.9507 and slop equals to - 0.0003. The coefficient of correlation is considered as measure of closeness to fit in the relative sense is away from unity show negative correlation.

Fig-5
Scatter Plot of Refractive Index and Electron Concentration



To show relationship between the computed values of refractive index and electron density of F_2 layer hourly recorded data, the scatter plot shown in Fig-5 has been presented. The regression line equation is;

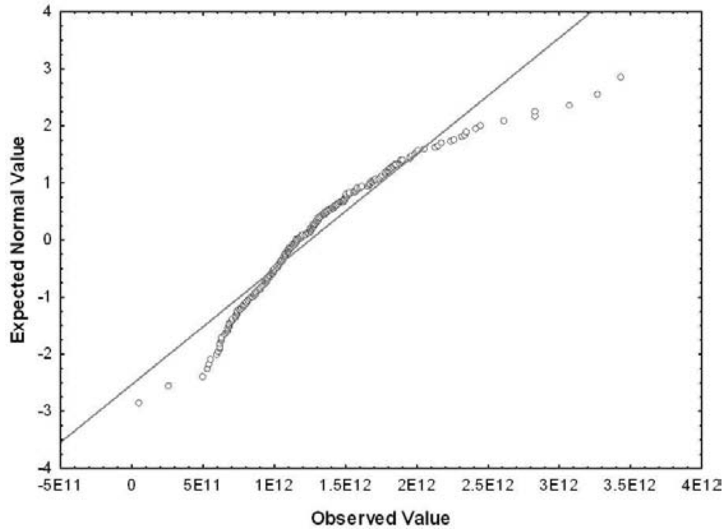
$$n = 0.9493 \quad 8.7723 * 10^{-16} N \qquad (8)$$

The coefficient of correlation, r = -0.7219, and coefficient of determinant, r^2= 0.5212 show negative correlation with intercept 0.9493 and slope of $8.7723 * 10^{-16}$.

4.3. Normal Probability Plot

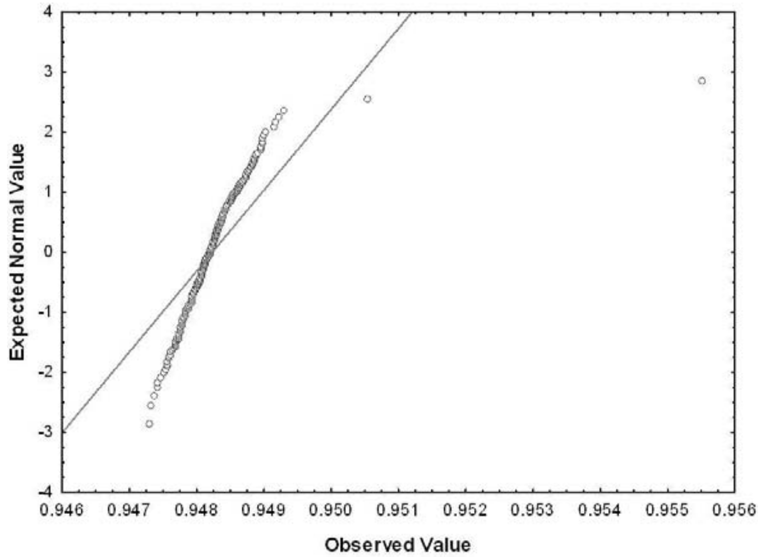
Another graphical display of the data which deals directly with the assumption of normality is the normal probability plot. The concept behind a normal probability plot is to plot the data against some reference that presents a normal distribution (Allan H. Murphy and Richard W. Katz, 1985). The normal probability plots have been plotted for computed parameters for Normal probability plot for electron concentration in Fig-6 presents a non-linear pattern. The lower and upper tails show departures from the fitted line. Normal distribution is not a fair model for the parameter since the S pattern in the middle of graph is mild. To explain further such graph is to generate Tukey Lambda statistical tool.

Fig-6
Normal Probability Plot of Electron Concentration



The normal probability plot for computed values of refractive index of Fig-7 shows for heavy tailed datadistribution. The data seem to be more clumped in the middle but with a few unusual values in the extremes with mentioing two outliers.

Fig-7
Normal Probability Plot of Refractive Index



5. Results and Conclusion

This communication has described physical behavior of ionosphere at Pakistan upper atmosphere region. The hourly recorded ionosphere data has been used to compute parameters of interest discussed in this paper. The computed parameters present good understanding and insight knowledge about variability in the parameter throughout the year 2005. The trends and the data pattern variability are visible in graphical representations and discussed under relevant sub headings histogram and regression. It is evident from the results that varying ion concentration and radio refractivity during day and night plays a vital role in long distance communication via ionosphere. The descriptive statistical tools also conclude towards suitability of investigating methods in respect of variability in ionosphere electron concentration (resulted in varying refractive index)and its effect on the long distance communication has been observed in this study.

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