ABSTRACT

The main purpose of the study is to determine the parameters used to identify the variability of the ionospheric region in Malaysia. In order to contribute to the development of a model of ionospheric variability, the behavior of the ionospheric critical frequency, f_oF_2 was analyzed on diurnal variation basis at different solar activity conditions and during earthquake occurrence. The Canadian Advanced Digital Ionosonde (CADI) is a low cost, flexible, full featured ionosonde ideal for both routine ionospheric monitoring and research. The ionosonde uses basic radar techniques to detect the critical frequency of the ionosphere. Simulation using Matlab was utilized to fit the critical frequency of the ionosphere. The observation data was obtained from the Ionogram that has been stationed in WARAS Centre, UTHM. Overall, the solar activity can affects the value of critical frequency at the daytime more than during night time. Other than that, the relationship between the Earth's movement and the variation of the critical frequency in the ionosonde data can be determined.

ABSTRAK

Tujuan utama kajian adalah untuk menentukan parameter yang digunakan bagi mencari kepelbagaian rantau ionosfera di Malaysia. Dalam usaha untuk menyumbang kepada pembangunan, kebolehubahan model bagi lapisan f_oF_2 dianalisis pada asas variasi yang berbeza pada waktu siang dan malam bergantung kepada aktiviti isyarat solar dan kejadian gempa bumi. *Canadian Advanced Digital Ionosonde* (CADI) merupakan alat yang berteknologi tinggi, ekonomi dan sesuai untuk pemantauan serta penyelidikan lapisan ionosfera. Ia menggunakan teknik radar asas untuk mengesan ketumpatan elektron pada lapisan ionosfera. Nilai kritikal frekuensi yang sesuai disimulasi menggunakan perisian *Matlab*. Data yang diambil diperolehi daripada ionogram yang ditempatkan di Pusat Rujukan WARAS, UTHM. Secara keseluruhannya, aktiviti solar boleh memberi kesan kepada nilai frekuensi kritikal pada siang hari berbanding pada waktu malam. Selain daripada itu, berdasarkan nilai kritikal frekuensi pergerakan Bumi menggunakan data CADI dapat dikenal pasti.

CHAPTER 1

INTRODUCTION

1.1 General Review

This research was carried out to study on the ionogram variation at difference solar activity and earthquake occurrence. The main purpose of the study is to determine the parameters used to search the variability of the ionospheric region in Malaysia. The data from the ionograms recorded by the Ionosonde at Wireless and Radio Science (WARAS) Centre, University Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor.

The Earth's upper atmosphere is ionized by radiation, both electromagnetic and corpuscular from the Sun. Ionosphere is topside of the atmosphere that contains high concentration of electron and ions. The free electrons and ions are produced via ionization of the neutral particles both by extreme ultraviolet radiation from the Sun and by collisions with energetic particles that penetrate the atmosphere.

The ionosphere is a part of the upper atmosphere, comprising portions of the mesosphere, thermosphere and exosphere. It can also reflect the radio waves in the ionosphere due to the refraction.

Ionospheres vary latitudinal, longitudinally and attitudinally where many atoms are ionized. The ionosphere is also responsible for absorbing the most energetic photons from the Sun and for reflecting radio waves. The structure of the ionosphere is strongly influenced by the charged particle wind from the Sun, which is in turn governed by the level of solar activity.

The ionosphere is formed when extreme ultraviolet (EUV) light strips the electrons from the neutral atoms of the Earth's atmosphere. The Earth's magnetic field has important effects on both the ionosphere and high frequency (HF) propagation. In this research, HF propagation was used, which is in the frequency range of 3 to 30 MHz.

The purpose of this research is to determine the critical frequency, f_c of the ionosphere. The f_c is equal to the maximum frequency which can be reflected from the ionosphere at vertical incidence. The f_c closely correlates with the solar activity and actually is the measure of the maximum electron density in the ionospheric layer. This means the absolute daytime value of the f_c increase with the increase in solar activity.

This project uses Canadian Advanced Digital Ionosonde (CADI) to measure the f_c of ionosphere. Ionosonde is pulse radar that can function at frequency range varies from 1 MHz to 20 MHz. An ionosonde is used to monitor and find the optimum operation frequencies in the high frequency range.

An ionogram is an output from ionosonde receiver, which is the plot of the tracings of high frequency ionospheric reflected radio pulses. It varies greatly in appearance upon a several factors such as geographic location, sunspot number, season, local time and others. Sample of conventional ionogram can explained on its variation at daytime and night time. At daytime, only ordinary wave traces with reflection from the layer of ionosphere. At night, only F-layer echoes are present and the virtual height increases steadily with frequency up to penetration at the ordinary wave.

1.2 Problem Statements

This problem statement come out with the variation of the ionosphere is very drastic over the equatorial region. So, by using the ionosonde data, which is the critical frequency, the relationship between the ionospheric variation and f_c can be determined over the equatorial region. On top, the f_c variation also can be used to determine or predict the occurrence of the Earthquake.

1.3 Project Objectives

The major objectives for this project are:

(i) To determine the variation of the f_c over equatorial region.

(ii) To obtain a relationship with diurnal variation f_c with solar activity.

(iii) To analyze possible relationship between the Earth movement and the variation of the f_c in the ionosonde data from WARAS Centre, UTHM.

1.4 Project Limitation

The limit of this project:

1) Ionogram data taken from WARAS Research Centre. So, the area of research is only at the top of WARAS.

1.5 Expected Result

(i) Ionogram's observation is to identify f_c that can recognize the physical nature of the ionosphere.

(ii) Determine relation between the f_c and solar activity and occurrence of the Earthquake

In the following chapter, the literature review of the theoretical studies that was carried out to conduct this research has been given.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The project begins with the literature review of the ionospheric layer behaviour over the equatorial region. By doing so, the theoretical knowledge about the ionospheric layer and the presence of the layer can be learnt. Apart from that, a brief introduction about Ionosonde that was used to measure the f_c was also given here. On top of that, review on some of the previous research works from the same area of research topic has also been look into in this chapter.

2.2 Previous Study

In the early stage of the project, the information from the various sources are discussed in this section.

Table 2.1: Previous Project

No.	Title	Explanation
1	F_2 layer variation in the equatorial region associated with Earthquake [15].	(i) Investigate the probability of using the F_2 Layer variations f_c which happen prior to the great earthquake that occur in Southeast Asia Region.
2	Ionosphere Properties and Behavior, Part 2 [13].	(i) The Earth's ionosphere and photographic studies of the aurora (ii) Covers the physical processes operating in stratosphere, mesosphere, thermosphere, ionosphere, magnetosphere and the Sun
3	Day to day variability in the critical frequency of F_2 layer over the anomaly crest region [11].	(i) Study the variability in the critical frequency region from mean and standard deviations at each hour. (ii) Study the data day to day variability of ionospheric data
4	Observations of F-Region Critical Frequency Variation over Batu Pahat, Malaysia, during Low Solar Activity [14].	(i) This work analyses the dependence of the fc during the solar minimum of Solar Cycle 23. (ii) The median fc value is used to develop a model using regression and polynomial approaches because it is more accurate than using average values.

5	Analysis of Ionospheric Variability Associated With a Seismic Event and a Space Weather Event [19].	(i) The seismo ionospheric variations begin to appear five days before the shock. (ii) Data observed during the geomagnetic storm event. (iii) The pattern recognition technique should be used with the help of statistical analysis of the ionospheric precursors in every region.

2.3 Ionosphere

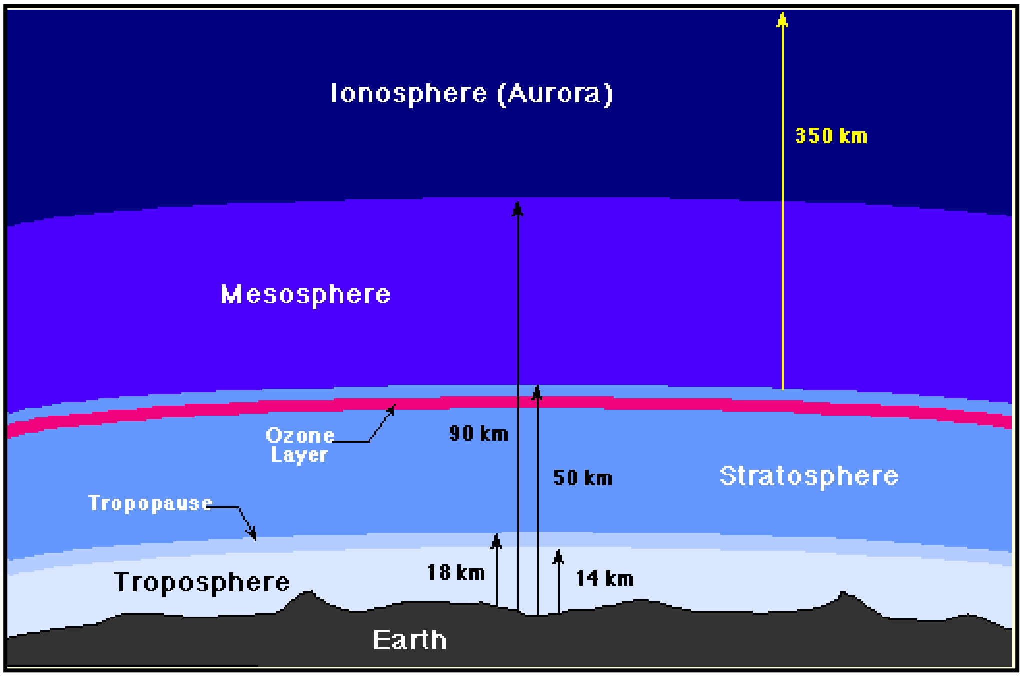

Figure 2.1 : Atmospheric Layer [4]

The ionosphere is a part of the upper atmosphere from 50 to 1000 km, comprising portions of the mesosphere, thermosphere and exosphere. Ionosphere can vary latitudinal, where many atoms are ionized. The ionosphere is very thin, but it is where aurora takes place, and is also responsible for absorbing the most energetic photons from the Sun and for reflecting radio waves [4].

The structure of the ionosphere is strongly influenced by the charged particle wind from the Sun, which is in turn governed by the level of solar activity. One measure of the structure of the ionosphere is the free electron density, which is an indicator of the degree of ionization. In ionosphere, a collection of ionized particles and electrons in the upper most portion of the earth's atmosphere which is formed by the interaction of the solar wind in the very thin air particles that have escaped the earth gravity. These ions are responsible for the reflection or bending of radio waves occurring between certain f_{cs} with these f_{cs} varying with the degree of ionization. Ionosphere is composed of the D, E, and F layers.

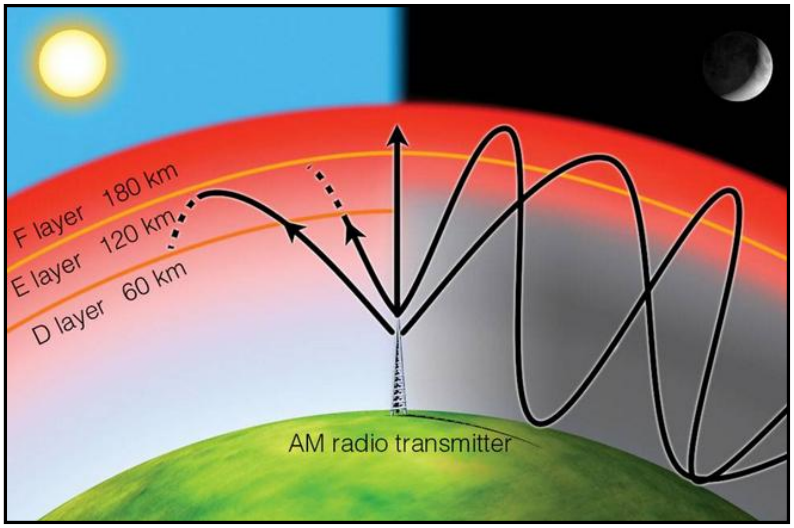

Figure 2.2: Ionospheric Layer [7]

Table 2.2: Layers in the ionosphere

Layer	Approximate Altitude	Existence
D	50-90 km	Day time only
E	90-120 km	Always –very weak at night
F	120-400 km	F_1- stronger during day time F_2- at day and night time

2.4 Overview of Ionospheric Structures

2.4.1 D layer

The D layer is the lowest part of the ionospheric layer, which lies from about 50 to 90 km of altitude above the surface of the Earth. It develops shortly after sunrise and disappears shortly after sunset. Ionization here is due to Lyman series-alpha hydrogen radiation at a wavelength of 121.5 nanometer (nm) ionizing nitric oxide (NO). In calm conditions this region is present only during the day. While in conjunction with high-energy electrons and protons from the Sun, associated with geomagnetic disturbances in nature, additional layers of ionization can be produced at any time of day or night. The ionization of this region is very low. In fact, the HF radio waves are not reflected by it. This region is in fact primarily responsible for the absorption caused by the fact that electrons set in motion by the electric field wave that propagates, collide with neutral molecules present in high concentrations, so by subtracting the energy waves [2].

2.4.2 E layer

The E layer is the middle ionospheric layer about 90 to 120 km above the surface of the Earth. This layer can only reflect radio waves because it only absorbs radio waves having frequencies about 10MHz due to the partial absorption of these higher frequency radio waves [8]. The vertical structure of the E layer is determined by the competing effects of ionization and recombination. The E layer develops shortly after sunrise and it disappears a few hours after sunset. The maximum ionization is reached around midday and the ions in this layer mainly due to soft x-ray (1-10 nm) and far UV solar radiation ionization of molecular oxygen (O_2).

The Es-layer also called as sporadic E-layer. Its altitude may vary anywhere between 80 km and 120 km. This extraordinary part of the ionosphere is capable of reflecting radio waves well into the VHF band (30-300 MHz) and into the lower part of UHF band (300-3000 MHz). This layer develops clearly mostly during the summer months and briefly at mid-winter with the peak occurring in the early summer. Furthermore, it can be appear at any time of the day with a preference for the late morning and early evening [8].

2.4.3 F layer

The F layer is the highest part of the ionosphere, located between 250 km and 500 km in altitude. This layer is the topside ionosphere which is the layer before radio signals release into the space. It also contains the highest concentrations of electron density. At night, this layer may reflect radio waves up to 20 MHz and occasionally even up to 25MHz.

The F layer consists of two layers at day time F_1 layer and F_2 layer remains at day and night responsible for most sky wave propagation of radio waves, facilitating high frequency (HF, or shortwave) radio communications over long distances [2].

The F_1 layer occurs during daylight hours. Before the sunrise, the Sun begins to shine on the upper part of the atmosphere containing the F-layer. Due to an unclear physical mechanism, the sunlight causes this F-layer to split into two distinct layers called F_1 and F_2 layers. The maximum ionization of the F_1 layer is reached at mid day and it reflects radio waves about 10MHz.

The important layer of the ionosphere is the upper most part of the Earth's atmosphere which is termed as F_2 layer. It's located between 250 km and 450 km with occasionally altitudes extending beyond 600 km. At this layer, about an hour before sunrise, this layer starts to develop as the F layer begins split. The maximum ionization of the F_2 layer is usually reached one hour after sunrise and it typically remains at this level until shortly after sunset. However, this layer shows variability with peaks in the maximum ionization occurring at any time during the day, displaying its sensitivity to rapidly changing solar activity and major solar events. Most importantly, this layer can reflect radio waves up to 50 MHz during a sunspot maximum and Maximum Usable Frequencies (MUF) can extend beyond 70 MHz on rare occasions [7].

2.4.4 Formation of the ionosphere

The ionosphere is formed when extreme ultraviolet (EUV) light from the Sun strips electron from the neutral atoms of the Earth’s atmosphere. The more familiar ultraviolet light has a shorter wavelength than visible light, and is more energetic. Extreme ultraviolet light is even more energetic. When a bundle of EUV light called a photon hits a neutral atom such as an oxygen atoms, its energy is used to transfer an electron in the neutral atom which can escape from the atom and dart freely around. The neutral atom thereby becomes positively charge because it has lost a negatively charged electron and known as positive ion. The process which indicates the photon strips an electron from neutral atoms, thus creating a positively charged ion, known as photoionization [2].

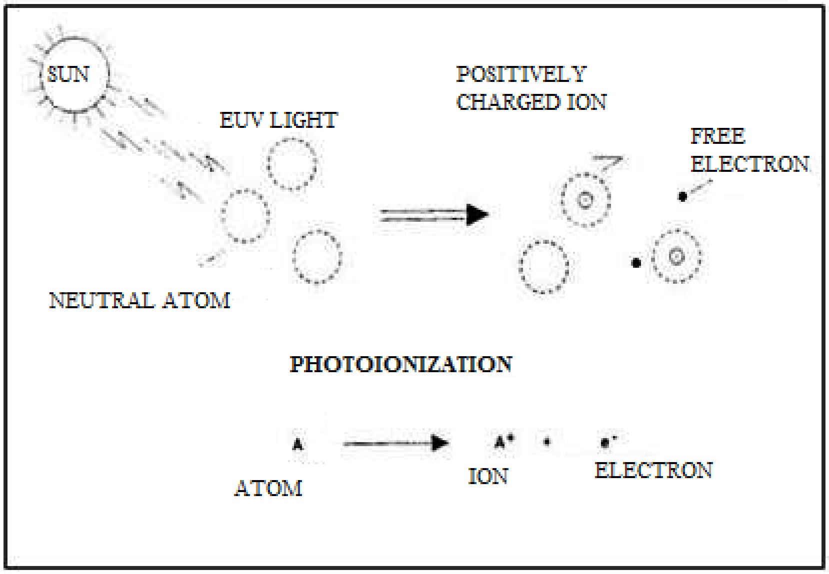

Figure 2.3: Photoionization of a neutral atom, A by extreme ultra light from the sun [1]

That part of the atmosphere in which the ions are formed is called the ionosphere. The ion are over 20,000 times heavy as the electrons and just too massive to respond to the rapid oscillations of a radio wave.

Recombination is the reverse of photoionization, which negatively charged electrons and positively charged ions combining together again to produce neutral atoms. This is the main process by which electrons are lost in the higher parts of the ionosphere. There are two types of recombination, called as radiative and dissociative. The process of radiative and dissociative illustrated in figure 2.4 below.

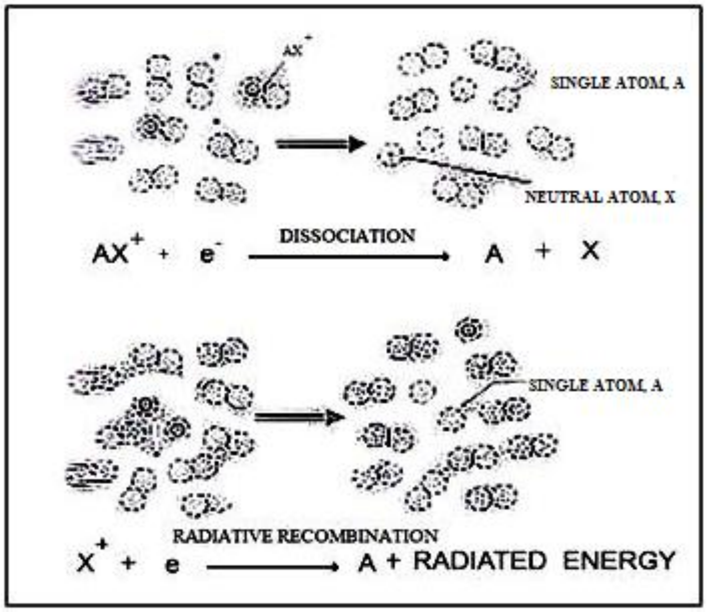

Figure 2.4: Radiative and dissociative recombination of an electron, e^- with positively charged ion [2]

In radiative recombination, the electrons combine directly with positively charged ions, converting them into neutral atoms and losing their own freedom. While dissociative recombination occurs by a two stage process and is much more efficient. In the first stage, positive ions, X^+(formed by photoionization), interact with the numerous neutral molecules, A_2(such as oxygen and nitrogen), replacing one of the atoms in the molecule.

$$X^+ + A_2 \rightarrow AX^+ + A \tag{2.1}$$

In the second stage, electrons combine with the positively charged molecule AX^+, giving two neutral atoms and again losing their freedom.

$$AX^+ + e^- \rightarrow A + X \tag{2.2}$$

In the lower levels of ionosphere, electrons are lost by the process of attachment in which they are attached to neutral atoms which thus become negatively charged ions. Like the positively charged ions, the negative ions are much heavier than electrons and do not respond to the electromagnetic oscillations of radio waves.

2.5 Recombination

Recombination is the reverse process of ionization. It occurs when free electrons and positive ions collide, combine, and return the positive ions to their original neutral state. Recombination begins to take place when a free electron is captured by a positive ion if it moves close enough to it. As the gas density increases at lower altitudes, the recombination process accelerates since the gas molecules and ions are closer together. The high variability in the electron content of the Ionosphere is based on the constant movement of free electrons at any direction due to electric fields, Earth’s magnetic lines of force and neutral winds [2].

Like ionization, the recombination process depends on the time of day. Between early morning and late afternoon, the rate of ionization exceeds the rate of recombination. During this period the ionized layers reach their greatest density and exert maximum influence on radio waves. However, during the late afternoon and early evening, the rate of recombination exceeds the rate of ionization. It causes the densities of the ionized layers to decrease. Throughout the night, density continues to decrease, reaching its lowest point just before sunrise.

2.6 Variation of the Ionosphere

The regular variations are like the daily, seasonal and solar cycle variations [8]. The electron density in the ionosphere is greatest in summer, in the middle of the day and near the equator. The ionosphere also varies significantly with solar activity and the amount of EUV radiation from the Sun [1].

The five main variations are:

(i) Diurnal Variation - These variations occur only throughout the day, following the apparent movement of the sun. The f_c reaches their greatest value at noon. They affect the D, E and F1 layers depending on the solar activity, and the solar zenith angle over the location. The E-layer does not completely vanish at night and stays around a f_c but one often considers that its drops to zero and vanish at night as it as little consequence on radio propagation. The F_1 layer becomes a separate layer only at daytime and mainly during 3 to 4 hours before and after local noon. It disappears after sunset leaving the place to the F-layer located higher in altitude. The F_2 layer variation is more complex. Its f_oF_2 reaches is the lowest level (about 2-4 MHz), just before dawn, after the recombination process eliminated all electrons. The f_oF_2 rises rapidly after sunrise due to the photoionization, amplifies during the day then decreasing at sunset but it never vanishes. Surviving the night, the F_2 layer is the most important layer for HF communications.

(ii) Seasonal variation- the ionosphere varies also with seasons. In winter for example, the sun is always lower over the horizon than in summer. This affects the f_c of the D, E and F_1 layers that is greater in summer than in winter. But this is the opposite for the f_oF_2 at mid-latitudes that shows are greatest variation in winter. This difference is known as the mid-latitude seasonal anomaly and finds its root in seasonal changes in the relative concentrations of atoms and molecules.

(iii) Latitudinal variations- related to Geographic and geomagnetic. f_c of each layer are not superposable and show considerable difference at low, mid and high-latitudes.

(iv) Solar activity due to solar radiation can also affect the value of the f_c. It can be absorbed or reflected by elements of the atmosphere and Earth surface. Solar radiation refers to the total electromagnetic energy radiated by the Sun. The Sun's shortwave radiation is eventually returned to space as long wave radiation. The transition from short to long wave occurs because the energy is absorbed, becomes heat energy and then radiated.

(v) Variations from day to day. In this variation, the air temperature varies following the 24 hour cycle and from day to day, so the f_c of the ionosphere in response to the change of EUV radiation from the Sun. The changes occurring at a very fast rate in the low atmosphere (within 5 minutes) at each of the 24-hours of the day. They affect the D, E and F_1 layers depending on the solar activity, and the solar zenith angle over the location. The E-layer does not completely vanish at night and stays around a critical frequency f_oE = 0.6 MHz, but one often considers that its drops to zero and vanish at night as it as little consequence on radio propagation.

The Earth-Sun relationship is continually going through four periodic cycles that affect propagation at any given location on the globe:

(i) 24-hour diurnal (night/day) cycle: rotation of the Earth on its axis, producing daily ionospheric changes.

(ii) Solar axial rotation: cycle of approximately 27 days, resulting in the likelihood of a repeat of the current conditions 27 days later.

(iii) Earth's seasonal cycle: as the Earth orbits the Sun, due to the change in the annual shifting of the solar angle or altitude of the Sun. Sunlight illuminates the globe as a result of the tilt of the Earth's axis with respect to the plane of orbit, the level of solar exposure rises and falls.

(iv) The Sun's 11-year seasonal Cycle. The Sun, a ball of extremely hot gases, has equatorial storm seasons much the same as occur in the tropical regions of the Earth, except that the increase and decrease in the solar storm season spans approximately 11 Earth years. During this period, every 11 years, the Sun moves through a period of fewer, smaller sunspots, prominences, and also flares called a solar minimum and a period of more, larger sunspots and prominences called a solar maximum [7].

(v) Solar maximum is the term for the maximum in solar activity that takes place approximately every eleven years. Solar minimum is the lowest point of solar activity. The last solar maximum was in 2001. Solar events can interact and interfere with each other, creating a very complex system. The smaller flares tend to follow the eleven year cycle and peak at several tens of flares per day. The largest flares usually occur only a few times during solar maximum. Sunspots increase with solar maximum and are relatively rare during solar quiet times [7].

2.7 Critical Frequency

The ionosphere has own f_c that depends on the maximum electron density. It varies with time of a day, altitude, season and location. The f_c is equal to the maximum frequency which can be reflected from it at vertical incidence [1]. It also defined as the highest frequency signal that will reflect directly back to its transmission location.

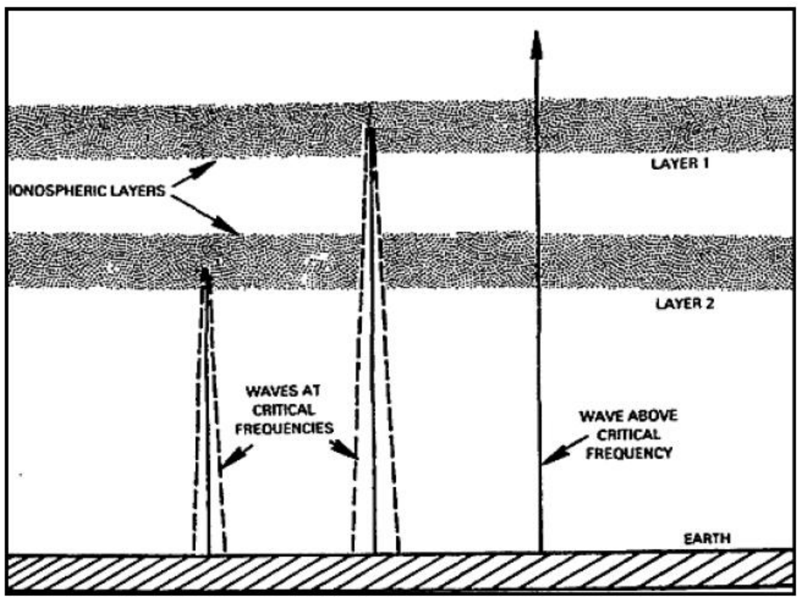

Figure 2.5: Critical frequency definition

The signal will be reflected from the higher F-layer if the operating frequency is near the f_oF_2 (frequency of the Ordinary wave reflected from the F_2 layer) critical frequency. The f_c is dependent on the intensity of the ultra-violet (UV) radiation from the Sun and varies with the time of day and day of the sunspot cycle. Increased UV radiation will increase the f_c of the F-layer. The f_c closely correlates with the solar activity and measure of the maximum electron density in the ionospheric layer. f_c for radio wave transmitted vertically and reflected to Earth.

Measurements of the height and density of the ionospheric layers that reflect signals back to Earth are periodically made at various sites [11]. The equipment used to measure the f_c of the ionospheric layers is called an ionosonde. An ionosonde measures the structure of the ionosphere directly overhead by transmitting a sequence of varying frequency pulses and then analyzing the strength and delay time of the echoes.

An ionosonde sweeps a range of frequencies, usually from 0.1 to 30 MHz, transmitting at vertical incidence to the ionosphere. For ordinary mode waves, this occurs when the transmitted frequency just exceeds the peak plasma, or f_c of the layer [3].

By varying the frequency and studying the change in time interval by using ionogram the electron density as a function of height can be determined. If the frequency is too high, the index of refraction remains finite and no vertical reflection occurs. Therefore, for the minimum at which the vertical reflection just disappears determines the maximum electron density in a given ionospheric layer. For ionosondes, that is a problem because it is more difficult to transmit a good signal at low frequencies and a very large antenna is needed. Other than that, there are usually a lot of radio transmitters at that frequency.

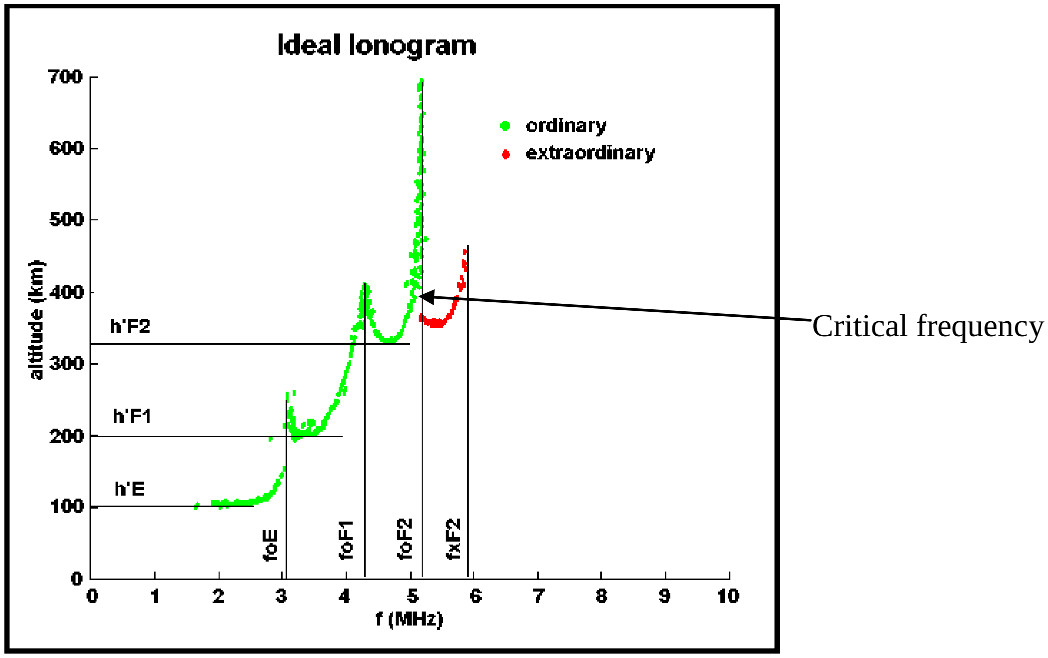

Figure 2.6: Ionosonde interpretation for selection of f_c

The height of reflection is determined by the frequency of the RF signal and the electron density [2]. The vertical asymptote of the selected analytical function corresponds to the critical frequency f_oF_2.

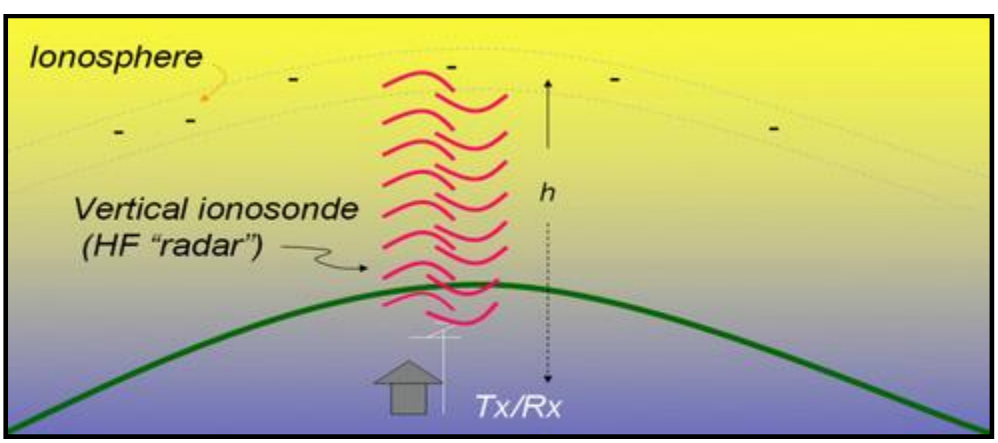

Figure 2.7: The f_c of the different refracting ion regions

Each of the ionospheric layers has its own value of f_c. It depends on the maximum electron density, Nmax on the ionospheric layer which varies with time of a day, season and location.

For the relationship:

$$fc = 9\ x\ 10^{-6}\sqrt{Nmax} \qquad (2.3)$$

Where f_c = in MHz,

$N_{max} = N_mF_2$ = electron per m^3

Another way to determine the variability of the critical frequency is through a comparison of the measurement observation values between the IRI models [20].

2.8 Canadian Advanced Digital Ionosonde (CADI)

Canadian Advanced Digital Ionosonde (CADI) is a modern digital ionosonde. An ionosonde is special radar for studying the ionized part of the Earth's upper atmosphere (ionosphere). It consists of a transmitter, four receivers, and the antenna system. The transmitter antenna is a delta antenna, and the receiver antenna array consists of four dipoles arranged as a square [4]. Ionosonde works on the principle of reflection of radio waves .

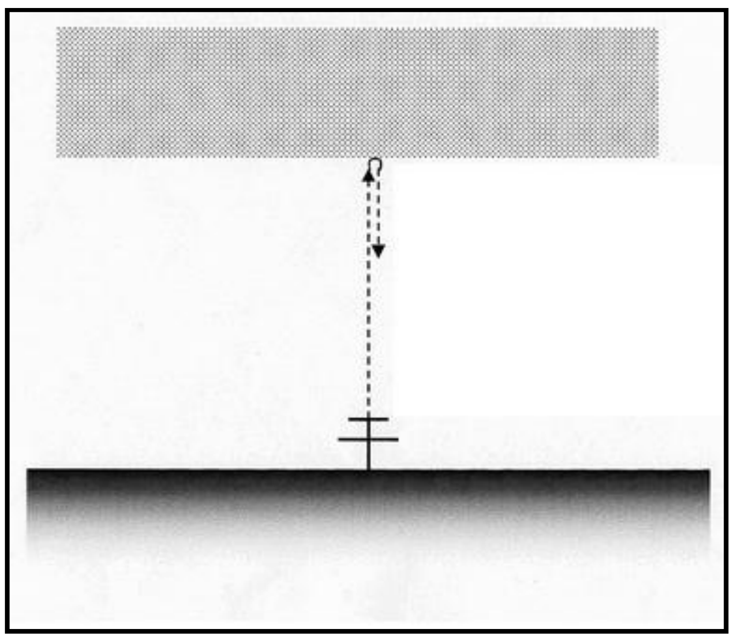

Figure 2.8: Ionospheric reflection [20].

The path of a radio wave is affected by any free charges in the medium through which it is travelling. The refractive index is governed by the electron concentration and the magnetic field of the medium and the frequency and polarization of the transmitted wave. These lead to some important properties for waves propagating in the ionosphere [5]:

(i) The refractive index is proportional to the electron concentration.
(ii) The refractive index is inversely proportional to the frequency of the transmitted wave.
(iii) There are two possible ray paths depending on the sense of polarization of the transmitted wave. This is a result of the magnetic field. The two rays are referred as the ordinary and extraordinary components.

The ionization in the atmosphere is in the form of several horizontal layers, and so the electron concentration and therefore the refractive index of the ionosphere vary with height. By broadcasting a range of frequencies and measuring the time it takes for each frequency to be reflected, it is possible to estimate the concentration and height of each layer of ionization. An ionosonde broadcasts a sweep of frequencies, usually in the range of 0.1 to 30 MHz. As the frequency increases, each wave is refracted less by the ionization in the layer, and so each penetrates further before it is reflected. The sweep frequency record produced by an ionosonde is called an ionogram [5].

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