Chapter I
Introduction

1.1. Background

Seismology is the study of seismic sources mostly earthquakes. Earthquakes have many mechanisms to occur and many earthquakes are of dangerous effects on both human lives and constructions; observations showed a disastrous effects done by earthquakes. Hence, to mitigate this natural disaster phenomenon scientists sought for methods of forecasting occurrence of earthquakes. It has been found that many space technologies are useful for recording some parameters that change dramatically during occurrence of earthquakes which was been specified as a good method towards prediction of earthquakes.

1.2. Research Problem

The study history of seismic activity in Africa revealed that there are many major earthquakes which have sever damages effects; this history showed the importance of developing methods to forecast such earthquakes in Africa. The ionosphere in Africa accordingly to maps showed almost a steady distribution of the electron densities contents because the known anomalies are not found in this region, this may infer the importance of checking ionospheric anomalies due earthquakes in the Africa's ionosphere.

1.3. Objective of the research

To rationalize a technique, depends on ionosonde data, of earthquake forecasting that is by checking precursors of ionosphere due earthquake.

1.4. Methodology of the research

We used analysis for the data of (f0F2) to show the phenomena preceding earthquakes for some earthquakes in African continent. We had selected two events on the analyses to confirm precursors of earthquakes within ten days after and before the occurrence. The data of critical frequency in F_2 layers of the ionosphere, i.e. f0F2 were collected from ionosonde station to test the anomalies, and also to more confirmation of anomalies we referred to geomagnetic indices Dst, Kp. We calculate 1-hour medians, and upper quartile of data.

1.5. Scope of the dissertation

This study is formulated as part of studies on applications on space technology usage in disaster mitigation**.**

Chapter II

Background

2.1. The Earth Atmosphere and the Ionosphere

2.1.1 Earth's Atmosphere

The envelope of gases surrounding the earth, which is a stable mixture of several types of gases from different origins, is known as the atmosphere. It is kept in space by gravitational attractions. Nitrogen and Oxygen make up to 99% of the atmosphere at sea level, with the remainder comprising CO_2, noble gases and traces of many gaseous substances .Based on the temperature changes with height, the Earth's atmosphere can be divided into mainly four distinct regions: troposphere, stratosphere, mesosphere and thermosphere. The ionosphere is bounded in the region of thermosphere, and it is a layer under investigation in the research work and shall be discussed in more detail (Folarin 2013/02.13).

2.2. Layers of the Atmosphere

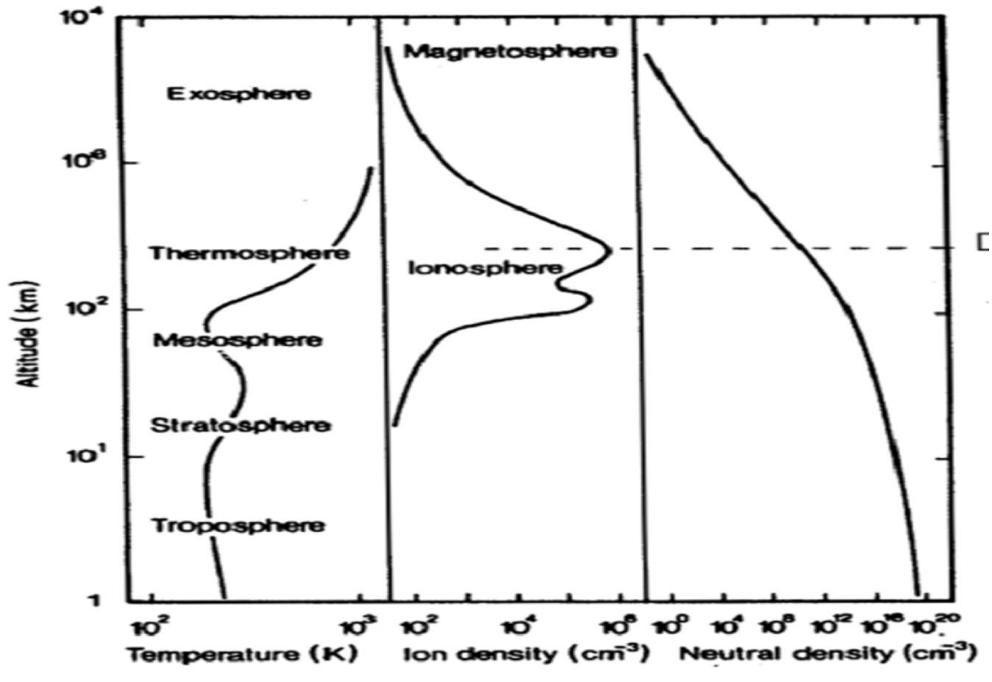


Figure.2. 1.Basic quantities of the atmosphere and ionosphere as a function of height (Bothmer and A.Daglis. 2007)

Troposphere: is the lowest part of the atmosphere and extends to the altitude of 8 km above the poles and 18 km over the equator. The temperature generally decreases with height in the troposphere. The troposphere contains 99% of water vapor in the atmosphere which plays a major role in regulating air temperature because it absorbs solar energy and thermal radiation from the planet's surface (Mohanakumar 2008).

Stratosphere: It is the second layer of the earth's atmosphere, and it starts at an altitude of 8 km - 18 km and extends up to 50 km. It is so named because the stratified layers within it have a temperature profile that increases with altitude The stratosphere holds the ozone that absorbs harmful UV radiation and prevents it from reaching the earth's surface (Mohanakumar 2008)

Mesosphere: is a layer that extend from 50 to 80 km and characterized by decrease in temperature with increasing altitude. The region is considered to be the coldest of Earth atmosphere reaching a minimum of ~180 K at 80 km altitude. The chemical compositions are fairly uniform and pressures are very low. The layer is bounded at the top by the mesopause (Mohanakumar 2008)

Thermosphere: is a region of high temperature and density is very low. The thermosphere includes the ionosphere and extends out to several hundred kilometers. The temperature increase is due to the absorption of intense solar radiation by the limited amount of molecular oxygen present. The thermopause is the level at which the temperature stops rising with height which depend on the solar activity (Mohanakumar 2008)

2.3. The Ionosphere

The Earth’s ionosphere is historically the region of the atmosphere that affects the propagation of radio waves. It is strongly related to the atmosphere; its reservoir of charged particles is created by ionization of atmospheric neutral gaseous compounds at an altitude range of approximately 60-2000 km but the most important contribution lies in the 90–1000 km region. The region above approximately 2000 km can be considered as being in the magnetosphere. And also it plays an important role processes between the Earth’s magnetosphere and atmosphere in the particle, momentum and energy transfer (Kamide and Chian 2007).

2.4. Basic Structure of ionosphere

We can define the ionosphere as the height region of the earth's atmosphere where the concentration of free electrons is so large that it affects radio waves, it comprises of free electrons and ions, generally in equal numbers, in a medium that is electrically neutral. The main sources of ionization are the solar radiations such as extreme ultra violet (EUV and X-ray) radiations (Marković 2014). The ionosphere was discovered when it was observed that radio waves can propagate over large distances, and one therefore had to assume the existence of an electrical conductive layer in the upper atmosphere which could reflect the waves. The electrically conductive region stretches from about 50 km to 500 km above the ground and the concentration of electrons n_e varies from 10^7 particles per m^3at 50 km to a maximum of 10^{12} particles per m^3 at 250-300 km (Moen Sep.13,2004).The ionospheric electron density distribution is logically evaluated first in terms of its height profile comprised of several peaks and valleys, the basis for understanding fundamental properties of the ionosphere comes from a simple picture of an ionized medium dominated by a single region, or layer, having a distinct maximum in electron density (Folarin 2013/02.13).

2.5. Formation of the Ionosphere

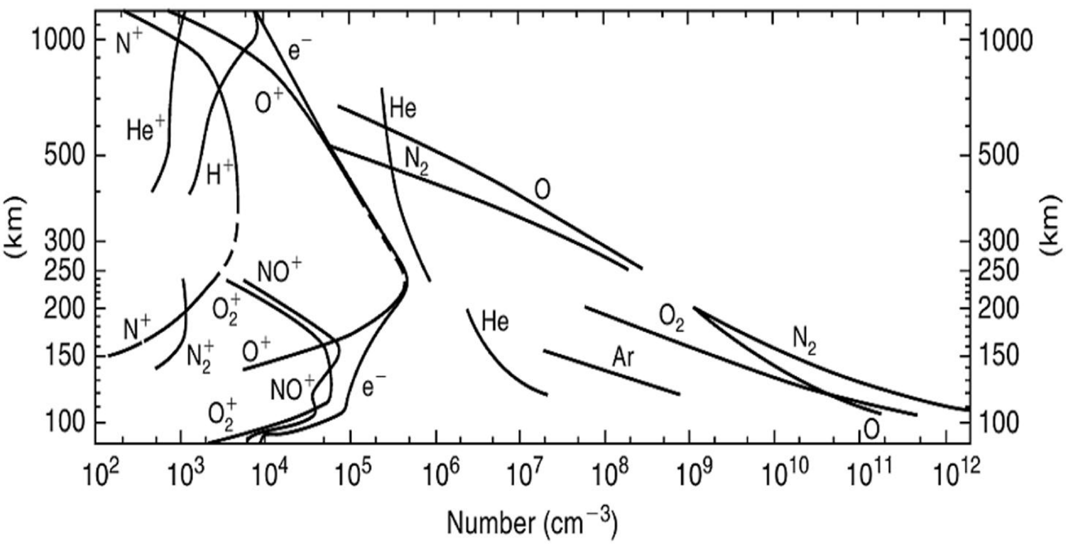


Figure.2. 2 typical vertical profile of the electron ions and neutral densities in the mid-latitude (Folarin 2013/02.13)

The ionosphere is formed when energetic electromagnetic-and particle radiation from the sun and space ionize air molecules, creating plasma in the upper atmosphere (Moen Sep.13, 2004).In the lower atmosphere, species such as N_2 and O_2 dominate the constituent population even though other species such as water vapor, carbon dioxide, nitric oxide, and trace element gases are influential in specific contexts. In the upper atmosphere, however, molecular forms are dis-associated by incoming solar flux into separate atomic components.

2.6. Ionospheric Layering

Ionosphere itself is divided into four smaller layers D, E, F1 and F2, each with special characteristic

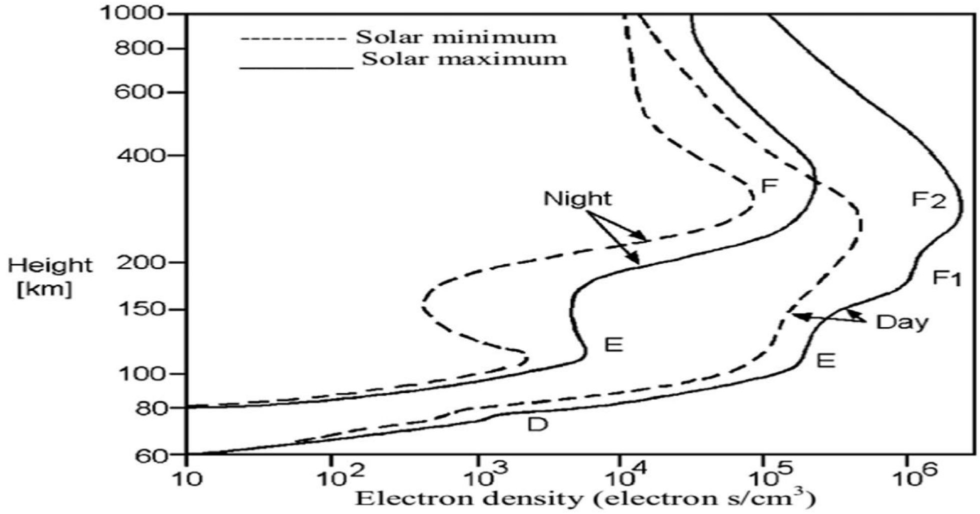


Figure.2. 3 vertical profile of the ionosphere (Folarin 2013/02.13)

2.6.1.D-Region

The lowest region of the ionosphere, is important in the characterization of absorption losses for short-wave systems, but is important as a reflecting layer for long wave communication and navigation systems. It contains the large ion clusters such as $H^+(H2O)_n$, $NO^+(H2O)_n$, $NO^+(CO2)_n$ etc. It is the only region of the ionosphere where the concentration of the positive ions is not equal to the electron concentration due to formation of the negative ions. The diurnal variations of electron concentration in the D-region (difference between the noon and midnight values) can reach 1.5 orders of magnitude for low solar activity and 2.5 orders for the periods of high solar activity (Pulinets and Boyarchuk 2004).

2.6.2.E-Region

The E-region of the ionosphere is formed under action of the solar ultraviolet radiation within the band $80<\lambda<102.8$ nm. The main ionized components are O_2 and N_2, and main ions O_2^+ and NO^+, which are formed from O_2^+ and N_2^+ as a result of ion-molecular reactions (Pulinets and Boyarchuk 2004).

The main mechanism of the charged particles loss is the dissociative recombination of the molecular ions with the electrons. Inside the E-region very thin-patched layers could be formed. This formation is called the sporadic E layer and designated as E_s. The formation of these layers is due to convergence of the vertical flux of long living metallic ions. For the E_s formation the ion transport processes are very important, they are connected with winds, tides, gravitational waves and electric fields (John 2005).

2.6.3.F-Region

The F1 layer appears as a ledge or bending point on the vertical profile of electron concentration between the E and F2 layers at the height 160 – 200 km. Its formation owes to solar ultraviolet radiation. The prevailing ions appearing as a result of ion-molecular reactions are the same as in the E-region, i.e. NO^+ and O_2^+. The processes in both regions are very similar (Pulinets and Boyarchuk 2004).

Spread F: A condition of the F region of the ionosphere caused by patches of ionization that scatter or duct radio signals, characterized on ionograms by a wide range of heights of reflected pulses. In equatorial latitudes spread F is most commonly observed at night and may be negatively correlated with geomagnetic activity. At high latitudes spread F occurs throughout the daytime and is positively correlated with magnetic activity. The latitude of minimum occurrence of spread F is near 30 degrees magnetic latitude (Röttger 2004).

2.6.4.F2-Layer

Is the most dynamical and most dense (from the point of view of plasma density) layer of the ionosphere. Here the main ionosphere maximum is located which, depending on the geophysical conditions.

The F2 region is the most prominent layer in the ionosphere, and this significance arises as a result of its median height (the highest of all the component layers) and of course it's dominant electron density (John 2005).

2.7. Anomalous Features of the Ionospheric F region

The F2 layer of the ionosphere is probably the most important region for many radio wave systems. Unfortunately the F2 layer exhibits the greatest degree of unpredictable variability because of the transport term in the continuity equation. As indicated previously, this term represents the influences of ionospheric winds, diffusion, and dynamical forces. The following subsections indicate the major forms of anomalous behavior in the F2 layer:

Diurnal Anomaly: The diurnal anomaly refers to the situation in which the maximum value of ionization in the F2 layer will occur at a time other than at local noon.

Appleton Anomaly: This feature is symmetric about the geomagnetic equator, magnetic activity is monitored worldwide, and the quasi-logarithmic index Kp is used to represent the level of worldwide activity. There have been suggestions that when Kp is 2 5, the anomaly disappears. But other observations have shown an increased separation of the anomaly crests, a fact that may lead some stations to observe a reduced foF2 value (John 2005).

December Anomaly: This phenomenon refers to the fact that the electron density at the F2 peak over the entire earth is 20% higher in December than in June, even though the solar flux change due to earth eccentricity is only 5% (with the maximum in January) (John 2005).

Winter (Seasonal) Anomaly: These effects are modulated by the 11-year solar cycle and virtually disappear at solar minimum.

The F-Region (High Latitude) Trough: This is representative of a number of anomalous features that are associated with various circumpolar phenomena including particle precipitation, the auroral arc formations, etc.

2.8. Certain Parameters in the Ionosphere

Key parameters for studying the ionosphere are:

2.8.1.Total Electron Content (TEC)

It is an important descriptive quantity for the ionosphere .TEC is the integral of the number of electrons along a ray path between a transmitter and a receiver. Units are electrons per square meter. This number is significant in determining ionospheric effects such as refraction, dispersion, and group delay on radio waves, and can be used to estimate critical frequencies. The TEC is strongly affected by solar and geomagnetic activity (Mosert, et al. 2011).

2.8.2.Critical Frequencies

In ionosphere radio propagation; the frequency capable of penetration just to the layer of maximum ionization under vertical propagation is termed as the critical frequency. Radio waves of lower frequencies are reflected back to the ground; the highest vertically propagated frequency that can be reflected (fully refracted back to the earth's surface) by specific regions or layers of the ionosphere [foE, foEs, foF1, foF2]. The foF2 is equivalent to the maximum density in the vertical distribution of the ionosphere (NmF2) (Mosert, et al. 2011). The critical frequency is an important figure that gives an indication of the state of the ionosphere and the resulting HF propagation. It is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter. The pulse may be reflected back to earth, and the time measured to give an indication of the height of the layer. As the frequency is increased a point is reached where the signal will pass right through the layer, and on to the next one, or into outer space. The frequency at which this occurs is called the critical frequency. The equipment used to measure the critical frequency is called an ionosonde.

2.9. Ionosonde Station

Ionograms are recorded tracings of reflected high frequency radio pulses generated by an ionosonde. Unique relationships exist between the sounding frequency and the ionization densities which can reflect it. As the sounder sweeps from lower to higher frequencies, the signal raises above the noise of commercial radio sources and records the return signal reflected from the different layers of the ionosphere. These echoes form characteristic patterns of "traces" that comprise the ionogram. Radio pulses travel more slowly within the ionosphere than in free space; therefore, the apparent or "virtual" height is recorded instead of a true height. For frequencies approaching the level of maximum plasma frequency in a layer, the virtual height tends to infinity, because the pulse must travel a finite distance at effectively zero speed. The frequencies at which this occurs are called the critical frequencies. Characteristic values of virtual heights (designated as h'E, h'F, and h'F2, etc.) and critical frequencies (designated as foE, foF1, and foF2, etc.) of each layer are scaled, manually or by computer, from these ionograms. As the sounder sweeps from lower to higher frequencies, the signal rises above the noise of commercial radio sources and records the return signal reflected from the different layers of the ionosphere (Arnold 2007).

2.10. What is Space Weather?

The simple definition of space weather: they are the conditions on the Sun and in the solar wind, magnetosphere, ionosphere and thermosphere that can influence the performance and reliability of space-borne and ground-based technological systems and can endanger human life or health (Arnold 2007). And also had a useful definition it is indicated "space weather describes the conditions in space that effect Earth and its technological systems." It goes on to say, "space weather is a consequence of the behavior of the sun, the nature of Earth's magnetic field and atmosphere, and our location in the solar system" (John 2005).

2.11. On the Nature of Solar Activity and Sunspots

One of the most significant solar-terrestrial observables is the sunspot; a phenomenon related to solar activity, the sunspot number has also been a convenient index for many 20" century climatological models of the ionosphere. The number of sunspots has exhibited an eleven-year periodicity for the last 250 years, as shown in Figure it's below.

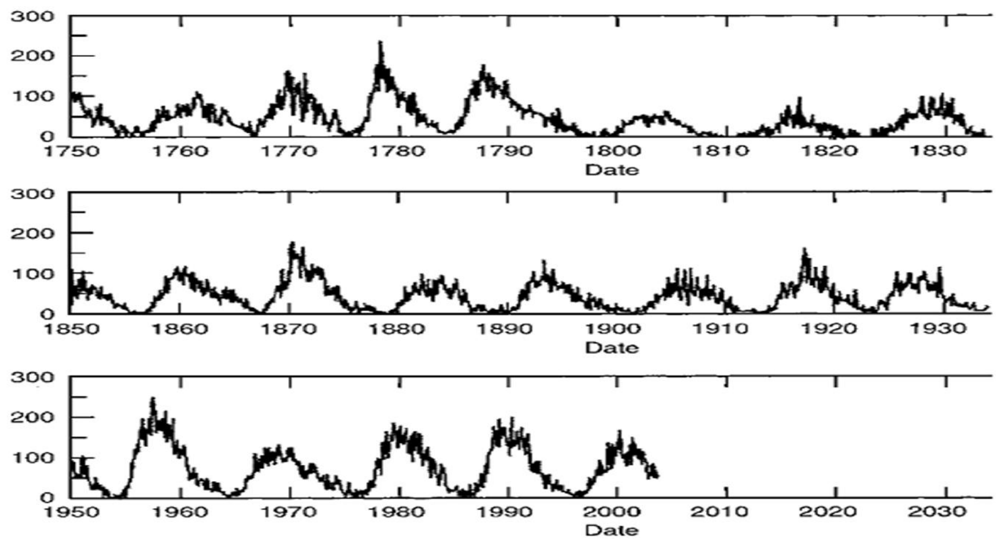


Figure.2. 4 depiction of the sunspot number for the last 250 years (John 2005)

While sunspots are indicative of many space weather phenomena, the role of geomagnetism in understanding the nature of the ionospheric personality is important, if not central, in many radio propagation applications. The impact of the geomagnetic field on earth-space systems can also be significant, since geo-plasma distributions are controlled by the magnetic field, and geophysical phenomena, because, in the absence of the solar magnetic field, current theory does not explain the generation of sunspots or their cyclic behavior (John 2005).

2.12. Geomagnetic Activity Indices

The magnetic activity indices are organized and smoothed in a variety of ways that may have the potential for confusing the user who is not an ionospheric specialist.

K- index: Three-hourly quasi-logarithmic index. It is a measure of the irregular variations of the horizontal field component at a specified station or group of stations. For example Km corresponds to the Fredericksburg site, and Kp is associated with the planetary "average' value. The values of K run from 0-9 with "9" representing the most disturbed condition. Kp is derived from 12 stations between geomagnetic latitudes 48-63 degrees (John 2005).

Dst- index: Hourly Index associated with low latitude magnetic activity. It is designed to be a measure of the ring current in the magnetosphere (i.e., that region above the geomagnetic equator at - 5.6 earth radii). Dst stands for "disturbance amplitude storm time", and its units are nT. Four mid-latitude sites are used in the construction of Dst (John 2005).

2.13. Seismology

2.13.1 What is the Seismology?

Seismology is the scientific study of earthquakes and the propagation of elastic waves through the Earth or through other planet-like bodies. The field also includes studies of earthquake environmental effects such as tsunamis as well as diverse seismic sources such as volcanic, tectonic, oceanic, atmospheric, and artificial processes such as explosions. A seismologist is a scientist who studies earthquakes and seismic waves.

Seismic waves are the waves of energy caused by the sudden breaking of rock within the earth or an explosion. They are the energy that travels through the earth and is recorded on seismographs. Types of Seismic Waves are body waves and surface waves. Body waves can travel through the earth's inner layers, but surface waves can only move along the surface of the planet like ripples on water. Earthquakes radiate seismic energy as both body and surface waves. Body waves arrive before the surface waves emitted by an earthquake. These waves are of a higher frequency than surface waves, and the kinds of body wave are the P wave or primary wave also known as compressional waves and the S wave or secondary wave. Both body and surface waves are traveling waves; however, large earthquakes can also make the Earth "ring" like a bell.

Earthquake occurrence is connected with the Earth' crustal dynamics. The Earth's crust is the rigid external shell of our planet consisting of the continental and oceanic crust. The crust and the upper layer of the mantle form the lithosphere consisting of semi rigid plates of different sizes. The slow movement of these plates over the asthenosphere and ocean floor extension is called plate tectonics Collision of these plates leads to the diving of one plate edge under another (convergent or subduction boundaries) (Pulinets and Boyarchuk 2004).

Earthquakes are the result of the tectonic plates contact; their global distribution is not uniform and is concentrated close to the tectonic plate's boundaries, which is demonstrated in Figure below.

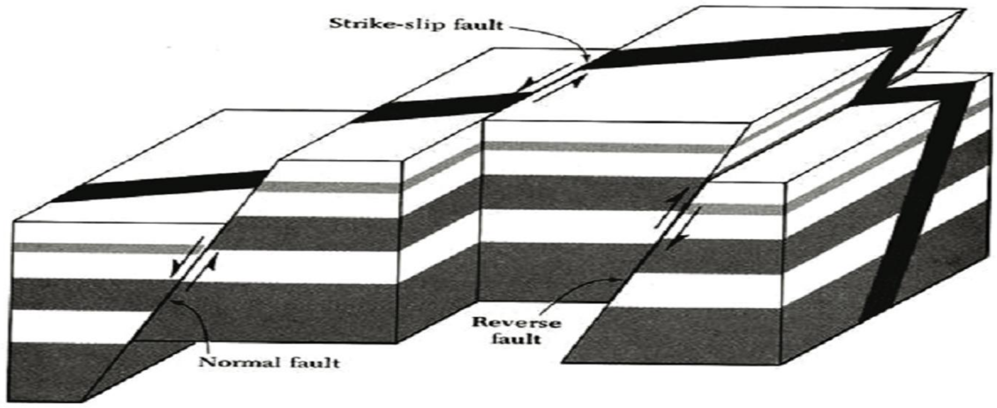


Figure.2. 5 the main types of tectonic fault geometry **(**Pulinets and Boyarchuk 2004**)**

Before we move on to the physical aspects of earthquakes, some introductory information is necessary. Those who are interested in more extended information can find this in recent monographs.

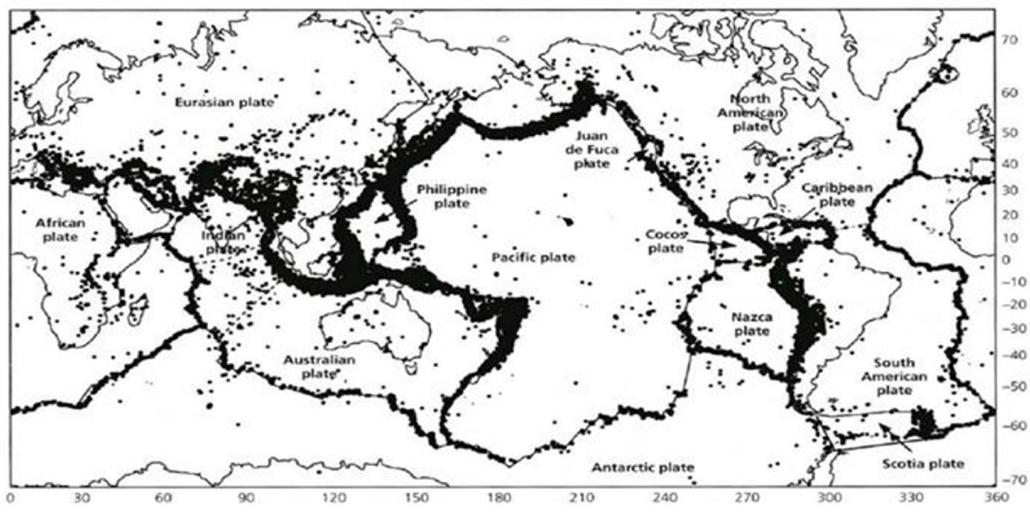


Figure.2.6 global earthquake seismicity in relation to the tectonic plate (Pulinets and Boyarchuk 2004)

The seismic waves are registered by seismographs and the largest vertical displacement A of the seismograph arrow was selected by Charles Richter in the 1930s to characterize the earthquake intensity by a parameter called the “local magnitude” ML

$$ML = Iog10A + 2.56\ 1og10\Delta - 1.67$$

Other determinations of magnitude were proposed for two different types of seismic waves: the body wave named in seismology the P wave, and the surface Rayleigh wave, named the S-wave (Pulinets and Boyarchuk 2004).

2.13.2 Physical Background of Earthquake Prediction

The classical approach to seismic prediction was based on the so-called seismic cycle implying the periodical storing and release of the seismic stress taking into account the continuous tectonic plate movement. Of course, it is difficult to expect from the Earth's crust the ideal homogeneous structure but sometimes the earthquake sequence has a strikingly regular periodicity for the Park-field earthquakes series. Abstracting from the earthquake forecast as an end in itself, we will pay more attention to the physics of the earthquake preparation process, especially its final stage. We will base this regarding the earthquake preparation process and associated physical and chemical transformations within the Earth's crust in the zone of earthquake preparation. The basis of this approach relies on dilatation theory regarding crack formation within the Earth's crust and finally the formation of the main fault in the process of shallow earthquakes preparation.

The process of earthquake preparation within one period of the seismic cycle was divided into five stages starting from the moment of the previous earthquake. Different physical parameters are traced. The first one (which actually put forward the dilatation theory) is the change of the P-wave velocity. The build of dilatation is detected by the velocity diminution in the second stage. Other precursors are ground uplift and tilt, radon emanation, electric resistivity and a number of small earthquakes within the area of earthquake preparation. Basing on present knowledge, we can say that these are not the only precursors registered. Most likely they are representatives of different groups of precursors, namely: mechanical deformation, geochemical and hydrological precursors, electromagnetic precursors, and naturally, the seismic ones (Pulinets and Boyarchuk 2004).

2.13.3 Earthquake Preparation Zone

It is an area, where the local deformations connected with the source of the future earthquake are observed. Naturally, the deformations imply the changes of the crust properties, which could be measured by different techniques. First of all the deformations are accompanied by the strain storing, so the mechanical properties could be measured by strain meters, dephormographs and tilt meters, as well as by a recently developed GPS technique. According to dilatation theory formation of the cracks happens within the preparation zone and will be accompanied by changes in the seismic wave's velocity, density, electric resistivity, ground water level, and geochemical precursors. All these changes can be monitored experimentally. All these physical and chemical changes within the earthquake preparation zone create the physical basis for the earthquake prediction (Pulinets and Boyarchuk 2004).

2.14. Physics of Seismo-Ionospheric Coupling

Actually, the problem of seismo-ionospheric coupling is one of particular cases of the more general problem of electromagnetic coupling of the atmosphere and ionosphere. The traditional precursors of earthquakes among many publications describing the electromagnetic and ionospheric phenomena associated with this earthquake, one can find at least two, where pre-earthquake effects, the first publications dealing with ionospheric parameter variations as seismic precursors the variations of critical frequency (fo) parameter and the ionosphere electron content before the earthquake Concerning the physical explanation, two main hypotheses (with some modifications or options) have competed to describe these phenomena. The first of these was the influence of acoustic gravity waves generated in the earthquake zone on the ionosphere, and the second was anomalous vertical electric fields penetrating from the earthquake zone into the ionosphere, we can consider conductivity changes in the air as an option in the electric field model. Anomalous electric field penetrating of the ionosphere creates irregularities registered experimentally depending on the direction of the electric field on the ground surface (i.e., up or down), negative or positive deviations in the electron concentration may be created, respectively. However, in all cases it is only the perpendicular component, to the geomagnetic field lines, of the anomalous electric field that penetrates into the ionosphere. Due to equi-potentiality of geomagnetic field lines the electric field practically without any decay penetrates at the higher levels of the ionosphere. In the F-region two main effects should be noted. The other, probably main and well-documented effect is formation of the large-scale irregularities of electron concentrations in the F2-region of the ionosphere due to the complex character of particle drift in the F-region in crossed electric and geomagnetic fields, large scale anomalies in the F-region, as well as anomalies connected with AGW propagation may be registered not just over the impending earthquake epicenter, but also shifting in an equator-ward direction (Sergey 2004).

For a better understanding of the magnetic activities in geospace and on the earth's surface storms and substorms are also analyzed by using the Dst index, Kp index, EE index (Equatorial Electrojet) and magnetic pulsation index. In order to monitor these anomalies and forecast change in the lithosphere environment with Electromagnetic (EM) techniques, it is necessary to understand the role of the space environment because ground based magnetometers are more affected by space events than by lithosphere events. Moreover lithosphere signal changes are small in comparison to signal changes caused by the space environment. Numerous studies have already been published on EM precursors and its association with earthquakes and volcanic activity. This type of precursors has been studied with a wide frequency range such as important one Ultra Low Frequency (ULF). There are three models for generation the mechanisms of ULF wave were known shown in figure 9. The first model based on microfracturing, the second is describing the electrokinetic effect and the last one is the changing of the geoelectric conductivity in the lithosphere in the earthquake focal zone.

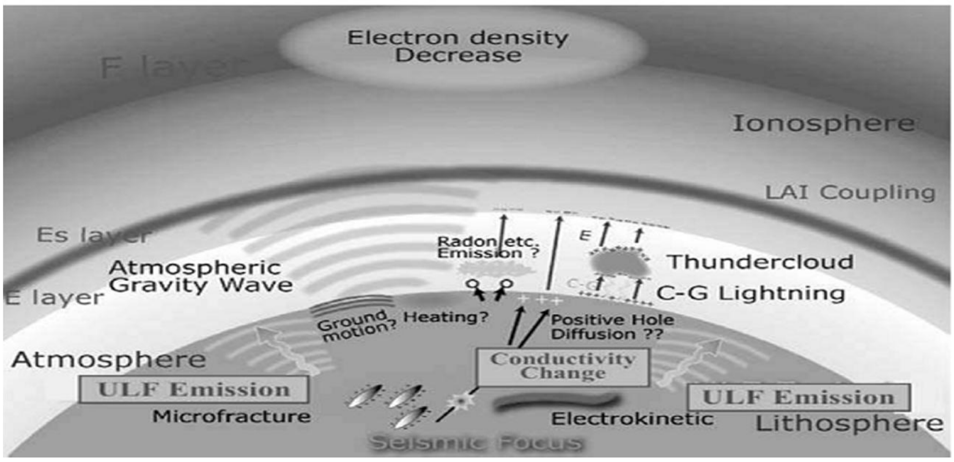


Figure.2. 7 the models of ULF anomalies associated with great earthquakes (yumoto, et al. 2008)

The two first types are the so-called ULF emissions and the third one is ULF polarization and power change caused by the formation of a conductive region. In figure .2.1 we saw the electromagnetic coupling of ULF waves in the plasmasphere, ionosphere, atmosphere and lithosphere. The electric field δE of external ULF waves in the plasmasphere gives rise to an ionosphere current δJ_I which produces magnetic field δB_1 on the ground. This incident magnetic field generates the induced current δJ_L under the ground. The induced current also produces reflected magnetic field δB_L on the ground. The total magnetic field variation on the ground becomes $\delta B_G = \delta B_I + \delta B_L$.

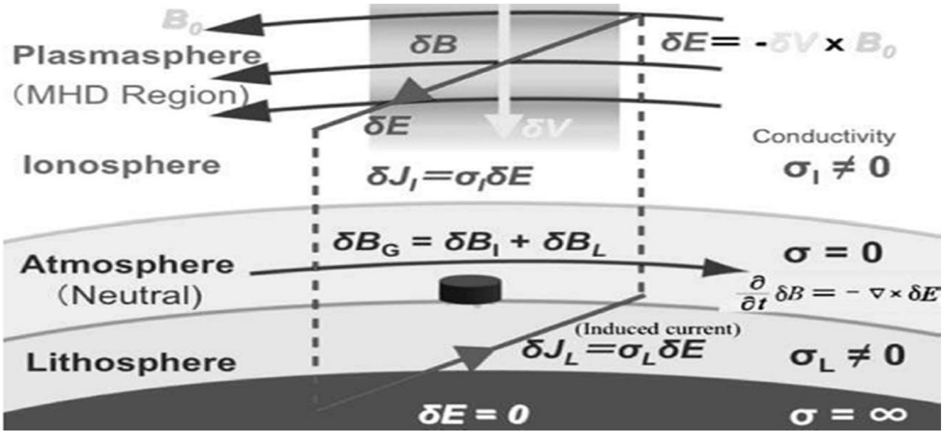


Figure.2.8 electromagnetic coupling of ULF waves in the plasmasphere, atmosphere, ionosphere and lithosphere (yumoto, et al. 2008)

The induced current intensity under the ground depends on the wave period of inducing magnetic fields in the ionosphere and the electric conductivity in the lithosphere.

Chapter Ш

Literature Review

3.1. Theoretical Background:

The history of seismo-ionospheric effects and ionospheric anomalies observed over the earthquake preparation zone counts more than 50 years. Its early stages of development are described in (Pulinets and Boyarchuk 2004).

Anecdotal studies suggest that ionospheric disturbances sometime occur at short term precursors to earthquakes with precursor time of several days. They are different from proposed ionospheric precursor in the literature, in which the anomalies are seen as local variations to the pattern of TEC and f0F2 variation close to the location of forthcoming earthquakes.

There are many ways for prediction of earthquake but in the recent time, GPS based measurements have taken more attention due to its availability around the globe. The measurements of GPS based total electron content (TEC) are giving very interesting results in the relation to earthquakes precursors, the statistical study of TEC have also more attainable due to its significant results. Many researchers have shown the statistical study of TEC and show the very convincing results.

3.2. Study of Ionospheric precursors related to an earthquake (M=7.8) of 16 April, 2013 using GPS-TEC measurements (Devbrat, et al. 2015)

In this study there are analyze the GPS-TEC data observed at Agra station, India (27.2o N, 78o E) and also see the diurnal variations of global ionospheric maps (GIMs) TEC data over the epicenter of this earthquake in Pakistan region use a statistical technique for the analysis of data and identify the significant precursors using 3σ criterion. These precursors are found in form of enhancements on different days in the interval of 5-7 days prior to the earthquake and that have success rate of 80% proves that TEC measurements much effective than the other techniques for the prediction of earthquakes. Show the plot of anomalous variations in the TEC data during the same period in the form of enhancements (in percentage) by histograms.

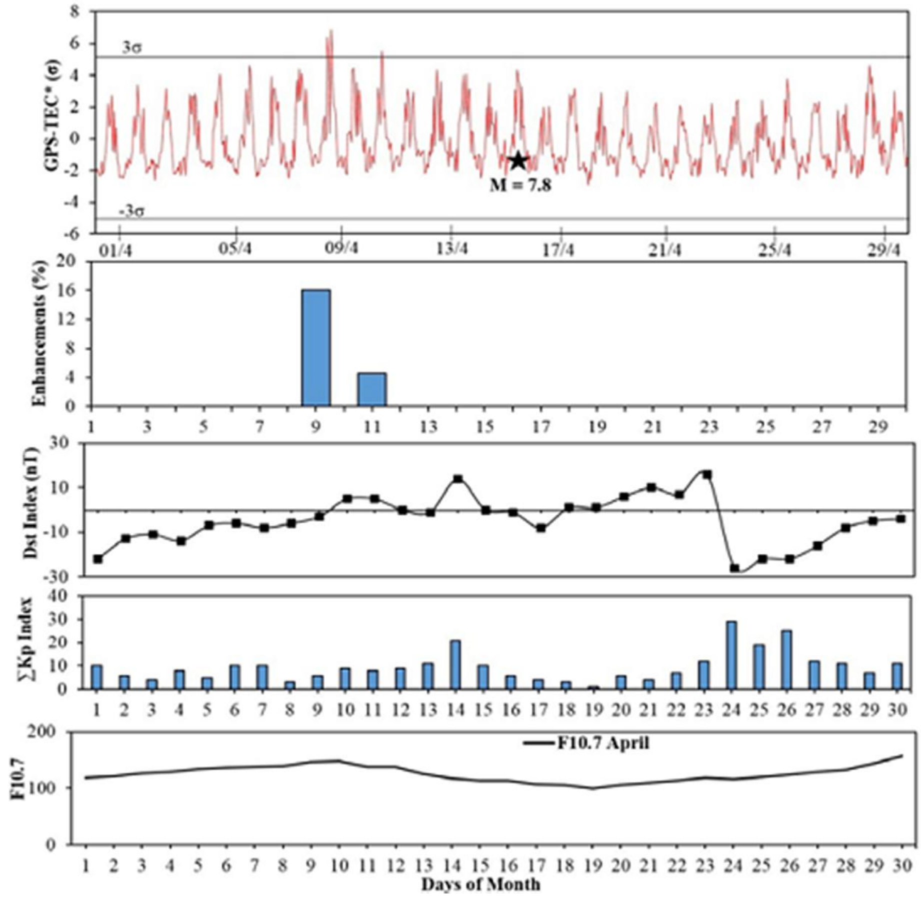
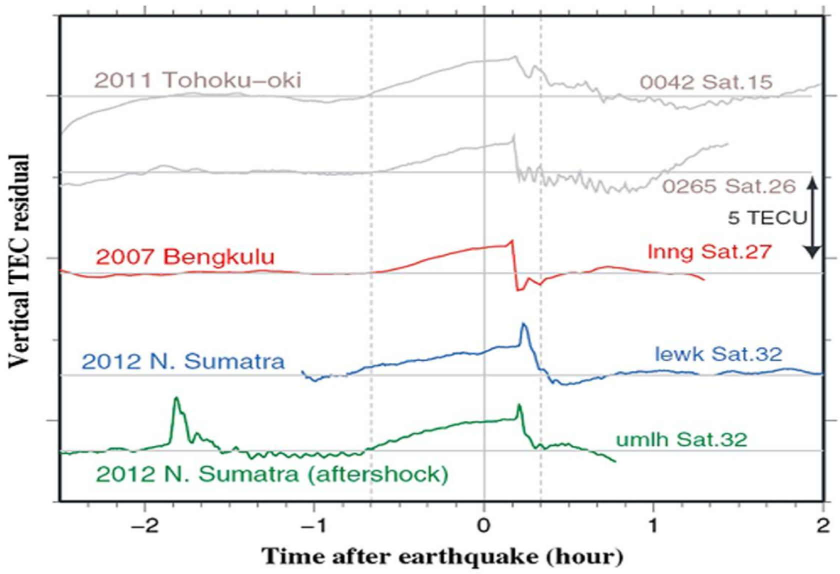


Figure.3. 1Upper panel shows the temporal variations of GPS-TEC observed at Agra station for the month of April, 2013 corresponding to an earthquake of Magnitude M=7.8. The black star shows the day of earthquake. In second panel, the enactments (%) are shown over the upper limit (3σ). The variations of Dst and Kp indices are shown in third and fourth panel. The last panel shows the variation of solar flux F10.7 for the same period (Devbrat, et al. 2015)

They plotted the Kp, Dst Index and solar index F10.7. The plots of magnetic storm parameters (Dst and Kp) are shown in third and fourth panels of Figure. The month of April is magnetically quiet except one isolated storm on 24 April but we have not found the effect of this storm. The last of panel of this figure shows the plot of solar flux F10.7. The solar flux variations are almost quiet during this period of consideration.

3.3. On the onset of ionospheric precursors 40 min before strong earthquakes (Masc, et al. 2015)

Claimed that anomalous, yet similar, increases of ionospheric total electron content (TEC) started 40 min prior to the 2011 Tohoku-Oki, as well as before other Mw>8 earthquakes. Increases of the ionospheric total electron content (TEC) were recently reported just before strong earthquakes including the 2011 Tohoku-Oki earthquake. The TEC enhancements were considered to be possibly linked to the preparatory phase of the pending earthquake. The 9.0Mw Tohoku-Oki, Japan, earthquake of 11 March 2011 05:46:23 UTC occurred under the Pacific Ocean approximately 70 km east of Honshu, Japan (38.32°N, 142.37°E). Time series derived from 30 s GPS data recorded at the same Japan GEONET stations as used by Heki (2011). Astafyeva (2013) demonstrated that stronger earthquakes generate TEC disturbances just after the main shock having longer-lasting depletion and larger amplitude. Perevalova (2014) investigated GPS-TEC time series in correspondence of 38 earthquakes occurred from 1994 to 2012. They found a threshold (nearMw6.5) of the magnitude below which post-earthquakes ionospheric disturbances are difficult to detect.



Fegure.3. 2 VTEC residuals as calculated by Heki and Enomoto [2013, Figure 8] for the 2011 Tohoku-Oki earthquake, the 2007 Bengkulu earthquake (Mw8.4), the 2012 North Sumatra earthquake (Mw8.6) and its largest aftershock (Mw8.2) that occurred ~ 2 h later.

3.4. On long-term variations of foF2 in the mid-latitude ionosphere before strong earthquakes (Liperovskaya, et al. 2006)

The statistical analysis of the variations of the daily-mean frequency of the maximum ionospheric electron density foF2 is performed in connection with the occurrence of (more than 60) earthquakes with magnitudes M > 6:0, depths h < 80 km and distances from the vertical sounding station R < 1000 km, For the study, data of the Tokyo sounding station are used, which were registered every hour in the years 1957-1990. It is shown that, on the average, foF2 decreases before the earthquakes. One day before the shock the decrease amounts to about 5 %. The statistical reliability of this phenomenon is obtained to be better than 0.95. Further, the variations of the occurrence probability of the turbulization of the F-layer (F spread) are investigated for (more than 260) earthquakes with M > 5:5, h < 80 km, R < 1000 km. For the analysis, data of the Japanese station Akita from 1969-1990 are used, which were obtained every hour. It is found that before the earthquakes the occurrence probability of F spread decreases. In the week before the event, the decrease has values of more than 10 %. The statistical reliability of this phenomenon is also larger than 0.95.

3.5. Variations of foF2and GPS total electron content over the Antarctic sector (Mosert, et al. 2011)

There shown a preliminary analysis of the variations of the critical frequency of the F2 region (foF2) and the total electron content (TEC) derived from Global Positioning System (GPS) data. Hourly foF2 values were scaled from ionograms recorded at San Martin (68.1°S, 293.0°E) and the TEC values were derived from GPS observations at O'Higgins (63.3°S, 302.5°E). The database includes measurements obtained under different seasonal and solar activity conditions. The study shows that the daily peak of foF2occurs around local noon in winter and fall, and in spring a secondary peak is observed around midnight. In summer (January) foF2 reaches its minimum value around the noon sector while the maximum in the diurnal variation of foF2 is located in a time sector close to midnight. This behavior is observed at low and high solar activity. The semiannual anomaly appears around noon at high and low solar activity and the winter anomaly is not observed. The effect of the solar activity is generally observed in every season. The analysis of the GPS TEC measurements in the same region indicates that the diurnal, seasonal and solar activity variations are similar to those observed in the foF2 values. They using two Antarctic stations situated close to each other: San Martin (68.1 S, 293.0 E; Geomagnetic 53.0°S) for the foF2 measurements and O'Higgins (63.3 S, 302.5 E; Geomagnetic: 48.6°S) for the GPS TEC values. The foF2 measurements were recorded with an ionosonde (KEL Aerospace) and the TEC values were obtained from Global Positioning System (GPS) data.

3.6. A statistical study of ionospheric earthquake precursors monitored by using equatorial ionization anomaly of GPS TEC in Taiwan during 2001–2007 (Liu, et al. 9 February 2010)

In this study there Examine pre-earthquake ionospheric anomalies by the total electron content (TEC) derived from a ground-based receiver of the global positioning system (GPS). A network of eight GPS receivers is used to construct daily latitude-time-TEC (LTT) plots to monitor the crest of equatorial ionization anomaly (EIA) in the Taiwan area. Three parameters of the strength, location, and formation time of the EIA crest are extracted. A 15-day running medians of the three parameters and the associated upper and lower quartiles are utilized as the references for identifying abnormal signals for all of the 150M≥5.0 earthquakes in the Taiwan area during 2001–2007. Results show that the EIA crest significantly moves equatorward (poleward) and appears in an earlier (later) time of the afternoon period a few days before (after) the earthquakes along the Taiwan longitude. The two parameters of the EIA crest location and occurrence time can be employed to detect ionospheric earthquake precursors.

To further understand seismoanomalies of the three parameters, they statistically examine the EIA crest variations of the GPS TEC associated with the 150M=5.0 earthquakes during 2001–2007.

3.7. Modifications of the ionosphere prior to large earthquakes: report from the Ionosphere Precursor Study Group (Oyama, et al. 2016)

They study of ionosphere precursors (IP) to EQs and aims to prepare for a future EQ dedicated satellite constellation, which is essential to obtain the global morphology of IPs and hence demonstrate whether the ionosphere can be used for short term EQ predictions. Following a review of the recent IP studies, the problems and specific research areas that emerged from the one year project are described. They review that in several steps are to be followed to establish a reliable methodology (including features of EQ disturbance) for the short-term prediction of EQs.

The first step is to find common features of precursor disturbances. Features that are listed as ionosphere disturbances in previous studies are described here. In general, large shallow EQs (M > 6, with depths of less than 30 km) seem to show precursor features in the ionosphere that depend on local time and latitude. It seems that EQs that occur deep in the sea do not show clear variations. There are cases in which we cannot detect ionospheric disturbances, such as the Chuetsu EQ that occurred on October 23, 2004 in Japan. The depth of this EQ was about 30 km. The modification effects of the EQs on the ionosphere seem to be diverse. The second step is to make further efforts to refine event analysis using existing satellite data. The main problems that we encounter include a lack of systematically archived data over a long period of time from satellites as well as ground observations suitable for data analysis. Measurements of TEC and NmF2 are locally limited on land. Japan needs to obtain further data for the ocean, especially in eastern Japan. Systematically archived long-period data over Chile, where EQs occur frequently, are very scarce due to the existence of the Pacific Ocean in the west and a limited number of observation sites in the east. The third step is to determine the mechanism of the EQ-related ionosphere disturbance. Reasonable mechanisms of ionosphere disturbance are far more difficult to identify because no systematic morphology of ionosphere modification has been established regarding latitude, longitude, and local time. The probable source seems to be an electric field. The fourth necessary step is our final goal, that is, to find a feature that can be used to predict EQs. To reach to this goal and find a common feature that appears before each EQ, more event studies are required.

3.8. On Es-spread effects in the ionosphere connected to earthquakes (Liperovskaya, et al. 2006)

The present work, phenomena in the ionosphere are studied, which are connected with earthquakes (16events) having a depth of less than 50 km and a magnitude M larger than 4. Analyzed are night-time Es-spread effects using data of the vertical sounding station Petropavlovsk-Kamchatski (φ = 53°, ʎ = 158:7°) from May 2004 until August 2004 registered every 15 minutes. It is found that the maximum distance of the earthquake from the sounding station, where pre-seismic phenomena are yet observable, depends on the magnitude of the earthquake. Further it is shown those 1-2 days before the earthquakes, in the premidnight hours, the appearance of Es-spread increases. The reliability of this increase amounts to 0.95.In the present work earthquakes with magnitudes of M > 4:0 and depths of up to 50 km. The investigation of such rather weak earthquakes is reasonable as the sporadic E-layers have only a distance of about h 100 km from the surface of the earth, and the seismo-ionospheric effects are apparently stronger than in the case of the F-layer situated at an altitude of about 300 km.

3.9. Comparison of simultaneous variations of the ionospheric total electron content and geomagnetic field associated with strong earthquakes (Naaman, et al. 2001)

Thereinafter they check the perturbations of the ionospheric Total Electron Content (TEC) are compared with geomagnetic oscillations. Anomalies in TEC were extracted using Global Positioning System (GPS) observations collected by GIL (GPS in Israel) and the California permanent GPS networks The purpose of study to capability of GPS measurements as a tool for solid Earth-ionosphere coupling, also sensitivity and accuracy of the ionospheric GPS observations and finally to present some case studies with ionospheric Total Electron Content (TEC) and geomagnetic interrelations. They combine both ionospheric and geomagnetic observations in order to detect a precursor prior to earthquakes.

3.10. Ionospheric phenomena before strong earthquakes (Silina, et al. 2001)

A statistical analysis Deeded of several ionospheric parameters before earthquakes with magnitude M ≥ 5.5 located less than 500 km from an ionospheric vertical sounding station is performed. Data of nighttime measurements of the critical frequencies foF2 and foEs, the frequency foEs and Es-spread at the middle latitude station Dushanbe were used. As the number of earthquakes with magnitude M ≥ 4.5 is rather large, for these events usually a statistical analysis of the phenomena preceding them was performed. But precursor effects of stronger earthquakes with M ≥ 6.0 were analyzed separately, as these earthquakes are rare and a statistical analysis is quite impossible. It should be pointed out that in studies of ionospheric precursors of earthquakes usually the dependence of seismoionospheric effects on the distance from the hypocenter to the vertical sounding station was considered.

Chapter IV

Results, Discussion and Conclusion

4.1. View on the Africa seismology

To give an idea of earthquakes in Africa continent we picked some earthquakes in the magnitude range (5.5 to 8.0), we plot the number of earthquakes per year (occurrence frequency) and magnitude versus years. It is worth taking a look at the following: Figure (4.1) and Figure (4.2).

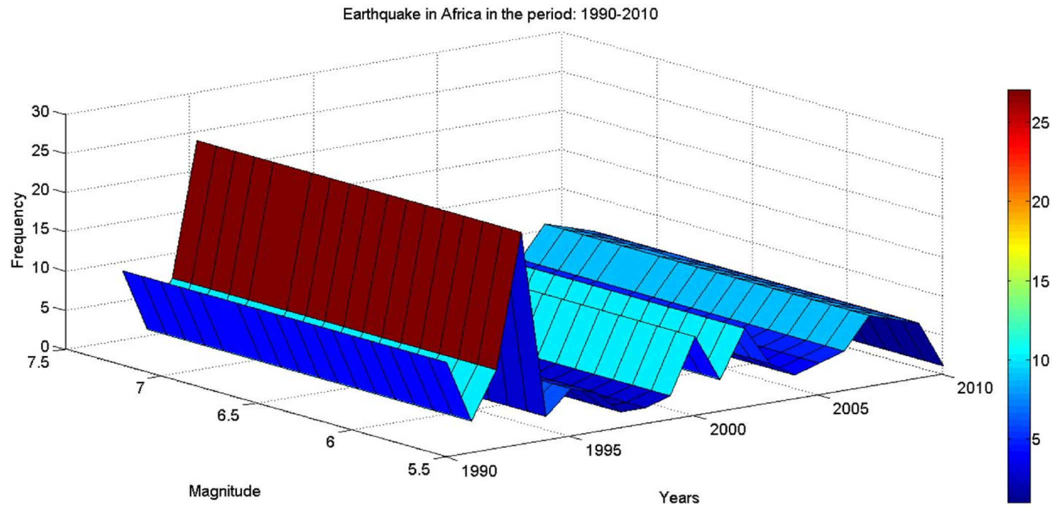


Figure.4. 1as the number of earthquakes in (1990-2010) is rather large, for these event usually a statistical analysis of the phenomena preceding them was performed

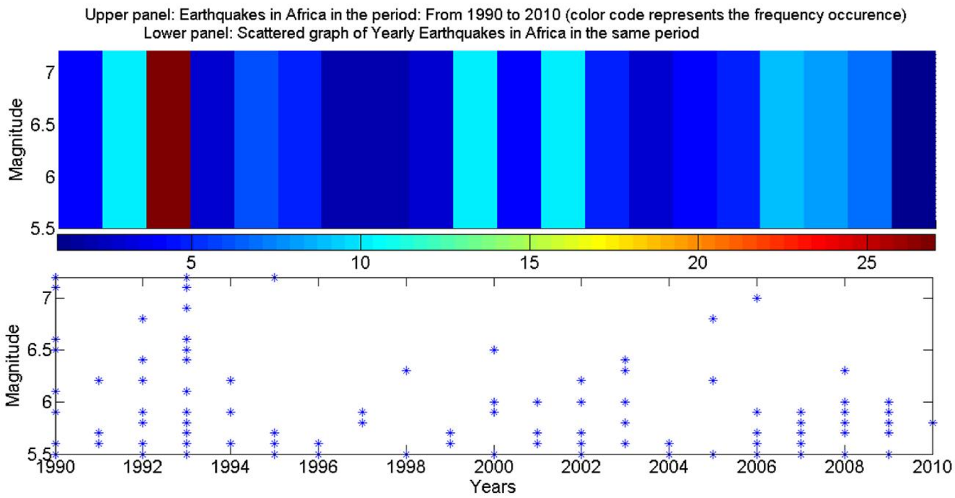


Figure.4. 2 Periodic Earthquakes in 1990-2010 with frequency code and scattering graph

4.2. Results

Time series data of foF2 plots that included times of occurrence of earthquakes are shown down here; and indication of onset of earthquakes events are shown I red for earthquakes that their details were given in attached boxes, respectively as in the figures below.

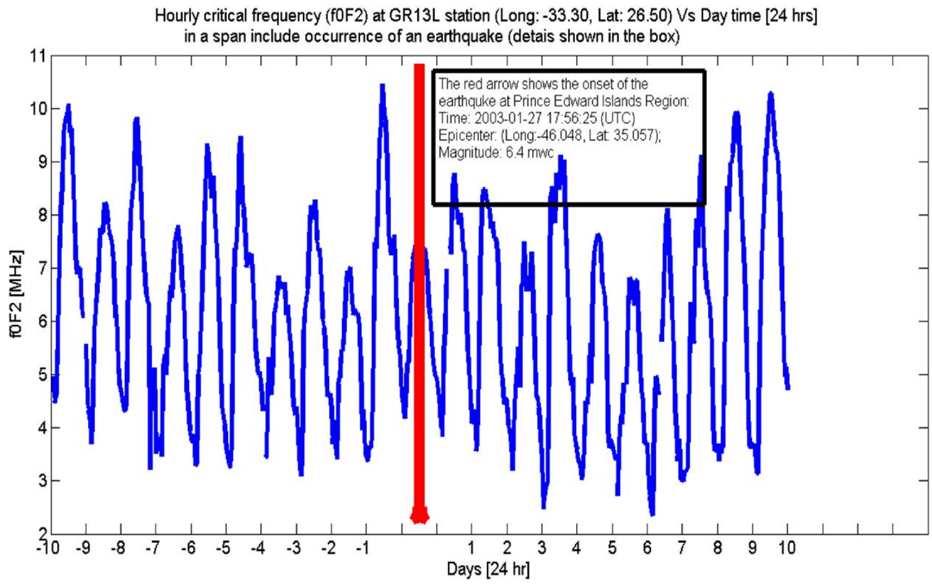


Figure.4. 3 the analysis of Critical Frequency (foF2) for Prince Edward Island Earthquake epicenter (1539.705 Km spherical earth) with magnitude 6.4 in 2003

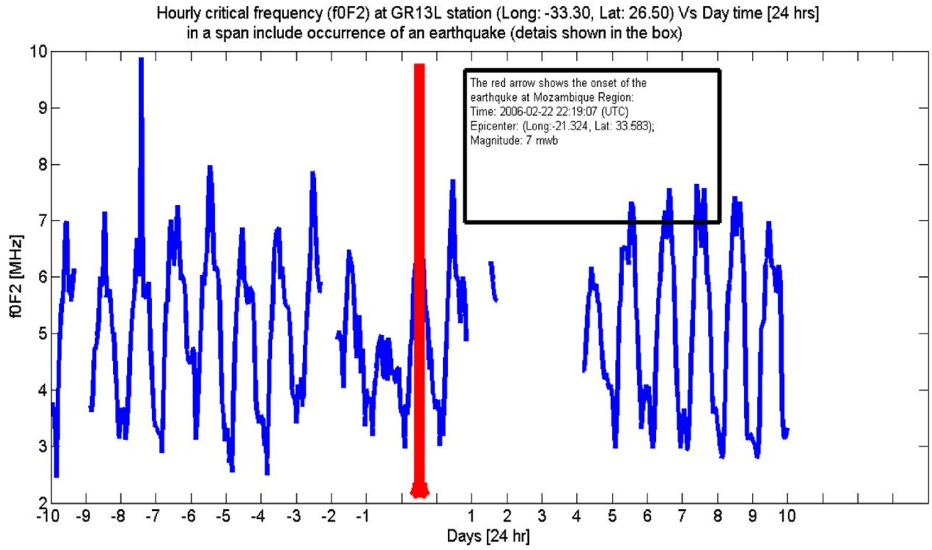


Figure.4.4 the analysis of Critical Frequency (foF2) for Mozambique Earthquake epicenter (1391.39 Km spherical earth) with magnitude 7 in 2006

Furthermore, we considered the geophysical conditions correspond to earthquakes and we plotted similar plots as above with indices Kp and Dst, results of these conditions shown down here, in the following figures

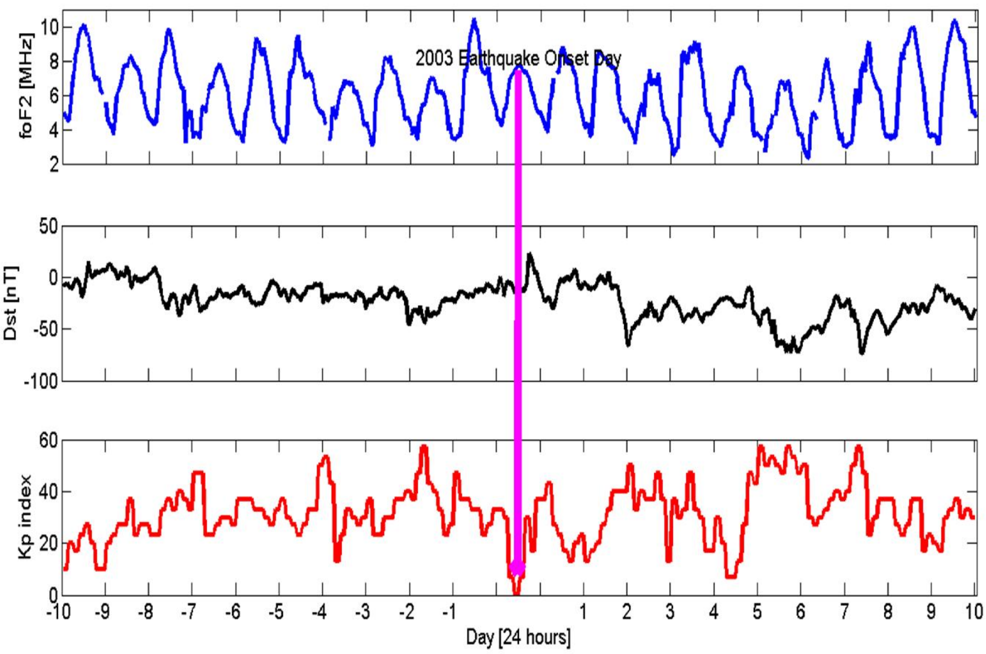


Figure.4. 5clarifies the earthquake onset day 2003 analysis with the variation of the geomagnetic indices (Dst,Kp) if there affects adventitiously

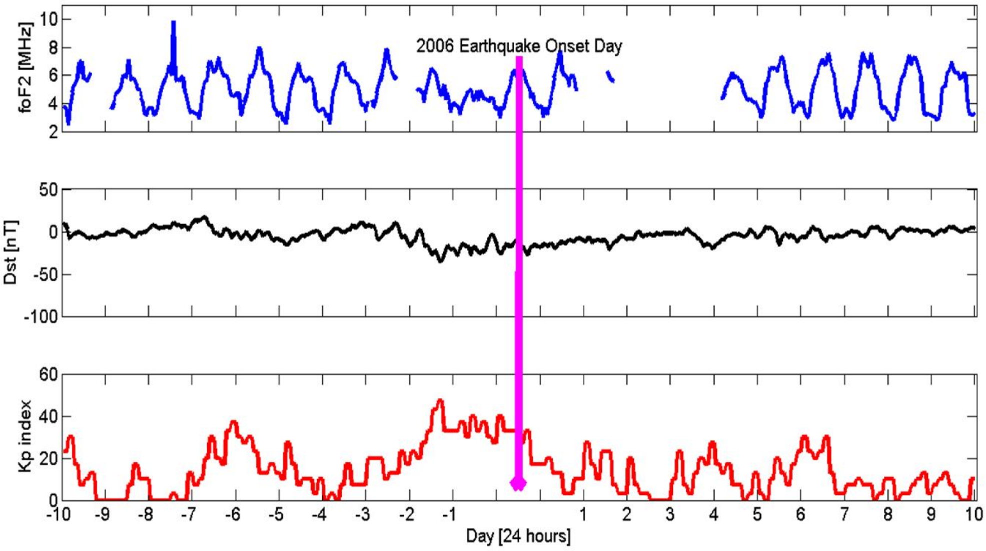


Figure.4. 6clarifies the earthquake onset day 2006 analysis with the variation of the geomagnetic indices (Dst,Kp) if there affects adventitiously

Finally, we carried out some statistical analyses on the data, results of these analyses are shown down here, in the following figures

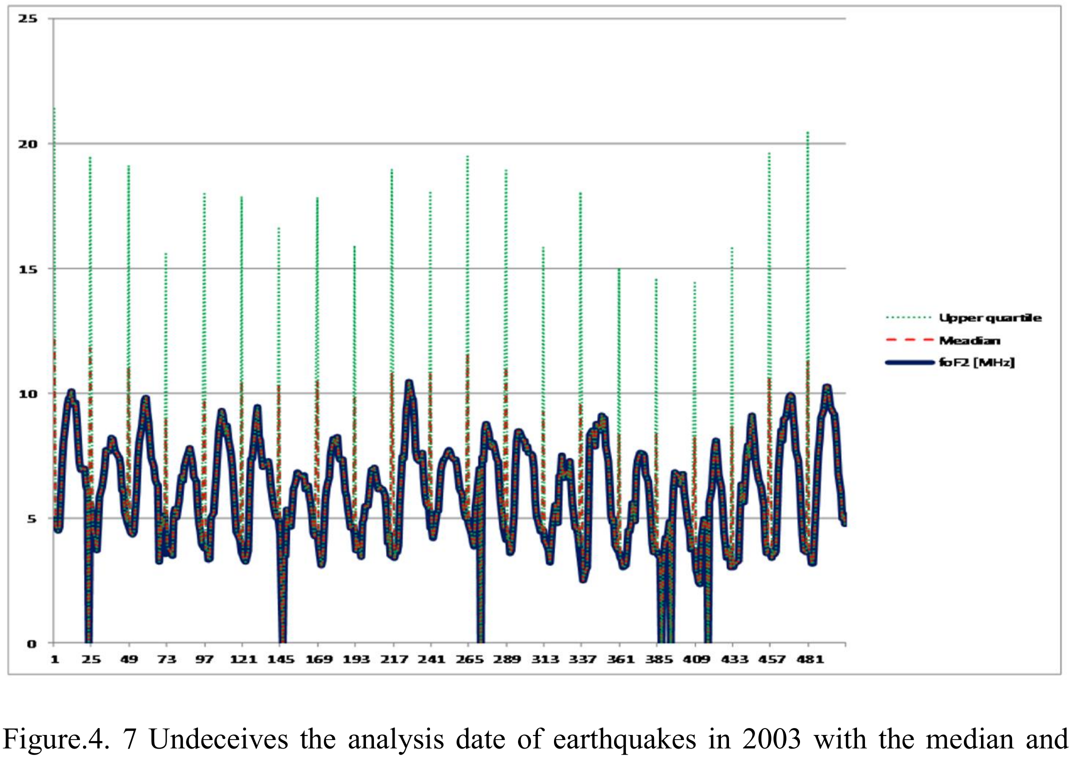


Figure.4. 7 Undeceives the analysis date of earthquakes in 2003 with the median and upper quartile for this data.

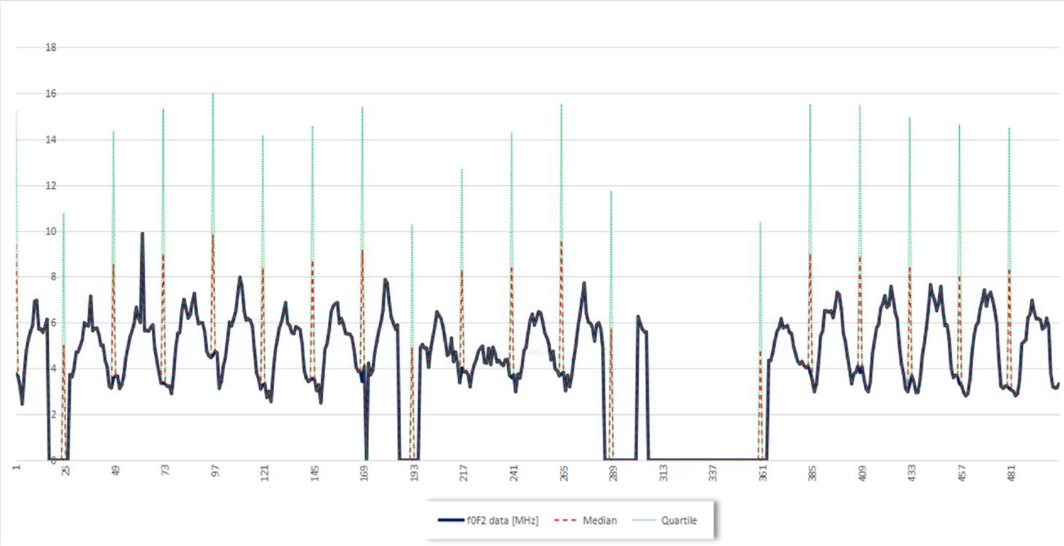


Figure.4. 8 Undeceives the analysis date of earthquakes in 2006 with the median and upper quartile for this data.

4.3. Discussion

We analyzed two earthquakes from different years and regions (2003 event: Prince Edward Island region and 2006 event: Mozambique region) the foF2 data are from Grhamstown station (Bosco 2017). The Prince Edward Island region was far distant about 1539.705 Km from the foF2 observation station (on calculation of the distance see: (Morse 2017)) whereas Mozambique region was far distant about 1391.39 Km from the same foF2 observation station (on calculation of this distance see also: (Morse 2017)). Now, from the above plots figures (4.3_4.4) we observed apparent anomalies in two cases of the study before and after ten days from onset day of the earthquakes. To ascertained these anomalies we get the geomagnetic indices Kp and Dst (Kovalick. 2017) to exclude the magnetic storm effects on the ionospheric layers (F2 region) in these times of anomalies appearance so we found that these anomalies refer to the earthquakes activity as precursor to earthquakes as seen in figures (4.5_4.6). Finally, we carried out a statistical analyses on these data and found the 1- day medians and upper quartile correspond to both events; for Prince Edward Island region the value in the second day before earthquake exceeded the median range and equal to: 10.452 and for Mozambique region the value in the eighth day before earthquake exceeded the median range and equal to: 9.85 as could be seen in figures (4.7_4.8). Hence, we can conclude that those anomalies appeared more likely to be the modulation of the critical frequencies due earthquakes, and referred to the variations of the electromagnetic wave preparations associated with earthquakes occurrence mechanisms.

4.4. Conclusion

Real earthquakes prediction is a great responsibility being based on precise calculation and systematic organization. One component of this system is continuous monitoring of the parameters used to be termed as earthquake precursors. Moreover, to study the ionospheric variability associated with seismic activity face many difficulties, but the most challenging one is that of the identification of this kind of variability. In our study we attempted to categorize the main features of ionospheric variations associated with pre-seismic activity. This classification is based on a lot of cases processed using ground based measurements. It is also based on knowledge of the ionosphere's behavior both under quiet and geomagnetically disturbed conditions as a background for seismoionospheric variability separation. Multi-parameters analyses are also very important. Parameters that identify the precursor as unambiguous should be chosen so as to not confuse the observed variation with variability caused by another source.

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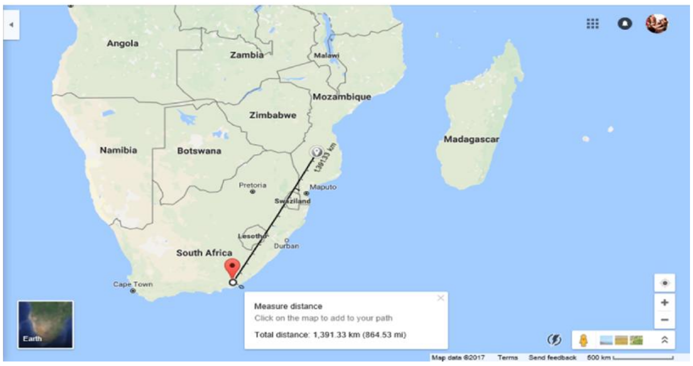
Appendices

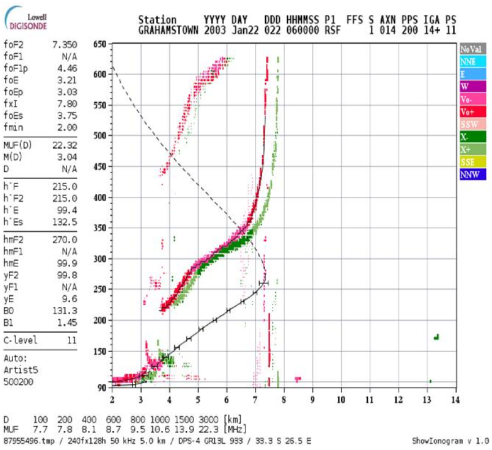
Appendix A

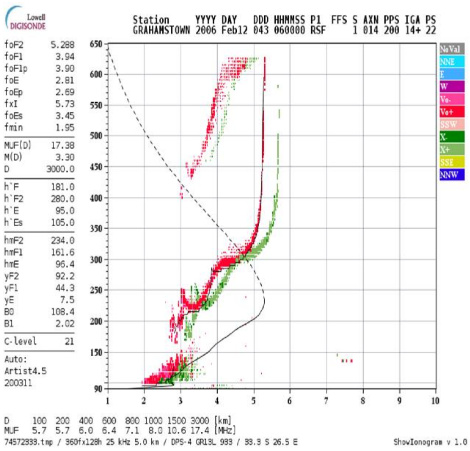
The distance epicenters (Prince Edward Island, Mozambique) to the Grhamstown station.



Appendix B

Sample of the sources of critical frequency data took from Grhamstown station





Appendix C

Sample table of critical frequency f0F2

f0F2	f0F2	f0F2	f0F2
5.775	3.225	6.875	4.488
6.025	3.225	7.275	5.238
6.425	2.9	6.425	6.025
6.875	3.725	5.95	5.863
5.975	4.881	6	6.175
5.875	5.531	5.975	6.512
5.575	5.575	5.625	7.275
5.525	6.525	4.75	7.975

Appendix D

Table Kp index

Kp	*Kp in decimals*	*G-scale*	*Auroral activity*
0	**0,00**	**G0**	**Quiet**
0+	**0,33**	**G0**	**Quiet**
1-	**0,67**	**G0**	**Quiet**
1	**1,00**	**G0**	**Quiet**
1+	**1,33**	**G0**	**Quiet**
2-	**1,67**	**G0**	**Quiet**
2	**2,00**	**G0**	**Quiet**
2+	**2,33**	**G0**	**Quiet**
3-	**2,67**	**G0**	**Unsettled**
3	**3,00**	**G0**	**Unsettled**

3+	3,33	G0	Unsettled
4-	3,67	G0	Active
4	4,00	G0	Active
4+	4,33	G0	Active
5-	4,67	G1	Minor storm
5	5,00	G1	Minor storm
5+	5,33	G1	Minor storm
6-	5,67	G2	Moderate storm
6	6,00	G2	Moderate storm
6+	6,33	G2	Moderate storm
7-	6,67	G3	Strong storm
7	7,00	G3	Strong storm
7+	7,33	G3	Strong storm
8-	7,67	G4	Severe storm
8	8,00	G4	Severe storm
8+	8,33	G4	Severe storm
9-	8,67	G4	Severe storm
9	9,00	G5	Extreme storm