CHAPTER II

A review on techniques and approaches relevant to the work under study

2.1 Introduction

Over the past few decades electromagnetic techniques are found to be very promising in earthquake (EQ) prediction studies. The chapter gives the description of available techniques with main focus on electromagnetic modes generally adopted in precursor study of earthquake.

With emerging evidences of electromagnetic (EM) emission prior to earthquakes, importance of utilizing the relevant frequency spectra of EM radiation for uncovering earthquake precursor has gained momentum. The chapter therefore gives description of EM techniques used by different workers around the globe for understanding earthquake induced features in the atmosphere. A few such methods brought under discussion are monitoring technique of Low and Very Low Frequency (LF and VLF) signal, Very High Frequency (VHF) noise observation, Anomalous Propagation and Reception of over-horizon VHF signals propagation character and TEC measured by ground based GPS observation. Among these techniques two basic methods are used in the present study. These are anomalous propagation of over-horizon VHF signals and TEC measured by ground based GPS observation. A brief description of the techniques is discussed below.
2.2 EM techniques for EQ precursor study

2.2.1 Monitoring of Low and Very Low Frequency signal

Use of LF and VLF signals for understanding earthquake induced effects on the atmosphere has been made for the last few decades. However as the thesis work does not cover this frequency range as a study for earthquake induced effects at the atmosphere, a very brief discussion is only referred here.

Hayakawa used three-axis induction type magnetic receiving system i.e. 3-component high sensitive magneto meters for monitoring Low Frequency (LF) to Ultra Low Frequency (ULF) signals say 0.1 mHz - 4 Hz with a sampling frequency of 10 Hz from all three orthogonal sensors (two horizontal components, \(H_x\) and \(H_y\), and the vertical component \(H_z\)) (Hayakawa et al., 1996, 1999, 2000; Kopytenko et al., 1993, 2002). From the ratio of “vertical component to horizontal one” of magnetic field the magnetic gradient vectors and phase velocities of ULF waves propagating along the Earth’s surface have been calculated. These workers have shown that this ratio sharply increases just before strong seismic activity. They have also pointed out that future center of seismic activity before an earthquake event can be obtained by the magnetic gradient vectors (~1-5 pT/Km) using horizontal component data (amplitude ~ 0.03-0.06 nT) from the network of a number of magnetic stations. By using spectral component of ULF magnetic data, Hattori (Hattori et al., 2002) have observed variations of magnetic field intensity and polarization. It was suggested that the anomalies seen are associated with two moderate earthquakes (M = 6.5 and M = 6.3). The apparent increase of the vertical component of magnetic field, \(H_z\) has been observed a few weeks before the first earthquake of March 26, 1997. Hobara (Hobara et al., 2002) working with same type of three-axis wide-band ULF/ELF induction-type magnetic sensors have shown
significant increase in $H_z/H_x$ starting about 20 days before a series of large seismic events ($M > 6$) near Izu Islands (source-observer distance is less than 100 km), where $H_x$ is the vertical component of magnetic field. The Izu Islands are a group of volcanic islands stretching south and east from the Izu Peninsula of Honshu, Japan. This anomaly is seen mainly in the frequency band ranging from 0.01 to 0.022 Hz, suggesting a clear precursory signal of large seismic activities near the observation site. Yagova (Yagova et al., 2002, 2004) has used ULF observations at two nearby stations KAG and KNY in Kyushu Island, Japan and extracted ULF noisy component to associate co-relation between such signal and earthquake event. Miyaki (Miyaki et al., 2002) have continuously monitored signal amplitude and phase from LF transmitter, JG2AS (frequency = 40 kHz) at distances from 224 km to 533 km from the transmitter and utilized these data for understanding role of earthquake and generation of atmospheric gravity waves. The data during one year from June 1999 to May 2000 used by them indicated association between fluctuations in the above frequency range with earthquakes and they discuss the role of gravity waves due to the pre-seismic activity in the lithosphere - ionosphere coupling.

2.2.2 Very High Frequency (VHF) noise observation

There are large numbers of reports on the abnormal increase of electromagnetic noise intensity before or during earthquakes (Hayakawa et al., 1994, 1999, 2006). It has been observed that noise in the television images and radio broadcasting increases after the South Hyogo Prefecture earthquake ($M=7.2$) in western Japan which struck at 5:46 AM JST on January 17, 1995. It was also noted that those electromagnetic noises were generated by seismo radio emissions related to distraction and friction of rocks (Ogawa

Ruzhin (Ruzhin et al., 1999, 2000, 2002, 2007) have reported generation of natural noise phenomena around 50 MHz and investigated the correlation between generation of such noises and earthquakes. Yamada (Yamada et al., 2002) has observed electromagnetic noises at VHF band at Tateyama observatory transmitted at 48.25 MHz and 49.75 MHz. They noted that the reception of electromagnetic interference or artificial signals at 48.25 MHz and 49.75 MHz prior to earthquake is coupled to the TV signals from Thai and China stations respectively.

2.2.3 Anomalous Propagation and Reception of over-horizon VHF signals

Using the anomalous propagation character of TV or FM signals the short-term earthquake predictions are also now offered. Fukumoto and Hayakawa (Fukumoto et al., 2002; Hayakawa et al., 1994, 1999) have observed over-horizon signals on the basis of the measurements by differential antenna systems transmitting at 77.1 MHz from a distant station at Sendai. They noted that over-horizon signals are mainly observed about 7 days before an earthquake. The signals are found to have small elevation signal (~10°), which implies that the signal is due to tropospheric effect. Experiments on monitoring long-distance TV channels were also conducted by Takano (Takano et al., 2004) in an observatory located at the south end of the Boso Peninsula, Japan. Their selected frequencies covered the ranges (a) 47.5 - 52.5 MHz and (b) 50 - 76 MHz; measurements were taken for a 2-year period from 1999. The system consisted of a horizontally polarized five-element Yagi for frequency range (a), and a log periodic dipole antenna (LPDA) setup for frequency range (b). They noted that the
characteristics of anomalous appearances varied with the season; TV broadcasts from China were received in the frequency range of 49.75 - 64.25 MHz, mainly during summer daytime, whereas in the case of programmes from Malaysia and Philippines (from 45 to 70 MHz), detection was from pre-noon to midnight hours, and mainly in spring. They tried to associate the long hop appearances with impending EQs (Takano et al., 2004). The distance traversed for the Malaysian hop was found to be around 5,200 km and that from China was 1,800 km (Sakai et al., 2003). Both values indicate significantly larger distances as compared with those that Fukumoto et al., (2002) had observed.

Table 2.1: Magnitudes, epicentre position and radius of preparatory zone for the EQ

<table>
<thead>
<tr>
<th>Event (no.)</th>
<th>Date</th>
<th>Latitude, $^0$N</th>
<th>Longitude, $^0$E</th>
<th>Magnitude</th>
<th>Characteristic radius of preparation zone (km)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>24.06.83</td>
<td>21.70</td>
<td>103.28</td>
<td>6.1</td>
<td>445.8</td>
</tr>
<tr>
<td>2</td>
<td>13.04.84</td>
<td>11.85</td>
<td>95.01</td>
<td>6.0</td>
<td>403.4</td>
</tr>
<tr>
<td>3</td>
<td>24.04.84</td>
<td>22.05</td>
<td>99.14</td>
<td>5.9</td>
<td>365.0</td>
</tr>
<tr>
<td>4</td>
<td>06.05.84</td>
<td>24.26</td>
<td>93.54</td>
<td>5.7</td>
<td>298.9</td>
</tr>
<tr>
<td>5</td>
<td>18.05.84</td>
<td>29.58</td>
<td>81.87</td>
<td>5.6</td>
<td>270.4</td>
</tr>
<tr>
<td>6</td>
<td>19.11.96</td>
<td>24.50</td>
<td>92.64</td>
<td>5.5</td>
<td>244.7</td>
</tr>
<tr>
<td>7</td>
<td>03.05.01</td>
<td>12.28</td>
<td>93.50</td>
<td>5.2</td>
<td>181.3</td>
</tr>
</tbody>
</table>

(Devi et al., 2012)

The Gauhati University group in their study on reception of VHF TV signals (54-70 MHz) had received and recorded TV programme from distances for beyond the
normal radio horizon. Such signals make their appearance at the GU location as a weak
noise and reception shows gradual increase for some days to well defined quality when
it disappeared at that point. For example on June 20, 1983 a signal appeared as a noise
and its quality improved daily to June 23, 1983, when the signal disappeared totally on
June 24, 1983. They could detect seven such events (table 2.1) that were subsequently

2.2.4 Appleton Anomaly Effect on TEC: application potentialities of anomaly
features in EQ precursor study

TEC signifies the total columnar electron content of ionosphere from the satellite
to ground. This parameter is calculated by using Faraday Rotation (FR); a rotation
suffers by a signal while traversing through ionosphere because of the anisotropic
properties of the ionospheric medium. TEC is calculated from the FR by using the
following equation:

\[ \Omega = \frac{k}{f^2} \int NB \cos \theta ds \]  \hspace{1cm} (2.1)

Where \( k \) is a constant, \( N \) electron density, \( B \) earth magnetic field, \( f \) frequency of the
signal and \( \theta \) angle between geomagnetic field and the ray path.

As the basic source of ionization density is the sun and its energy sources, total
columnar electron content also shows maximum during noon time. However there are
situation when TEC does not attain maximum at noon, but the maximum value reach
two to three hours after noon time. This feature is generally observed at off equatorial
stations situated at \( \pm 15^\circ \) from equator. This features developed due to the Appleton
anomaly effect. A few anomaly effects which can be seen from TEC diurnal plot is shown in Figure 2.1.

![Graphs showing TEC pattern](image)

(a) (b)

*Figure 2.1: Typical TEC pattern obtained from GPS*

The Figure 2.1 (a) shows the diurnal TEC variation with its peak at noon hrs as in the normal situation. But Figure 2.1 (b) shows that diurnal TEC reaches its maximum not at the local noon but one or two hours from it. This feature is the result of equatorial anomaly. The basic physics and dynamics of development of this anomaly are described below:

The concentration of ions and electrons governs the electrical conductivity of ionospheric layer specially at the E-layer height. The conductivities present are-

- Longitudinal conductivity that determines the current parallel to the magnetic lines of force,
- The Pedersen conductivity indicates the current parallel to the electric field which is perpendicular to the magnetic field and Hall current is perpendicular to both electric and magnetic field. Due to the E-layer current system, an electric field is produced from west to east direction over the equator. On the equator the earth magnetic field is horizontally along north south direction. Due to these two crossed electric and magnetic
field the electrons are pumped along the vertical direction to about $\pm 15^\circ$ geomagnetic off equatorial zone. Therefore, though the crest of the electron density should be obtained over the equator due to solar radiation, it is obtained over $\pm 15^\circ$ geomagnetic latitude. This region is called anomaly crest and the phenomenon is known as Appleton anomaly. Past studies show that TEC profiles reflect Appleton anomaly effect prior to an EQ, depending on magnitude of the event and epicenter status. However, ionization density as suffers changes with solar and geomagnetic conditions, different approaches are adopted (Devi et al., 2001, 2004, 2010a, b; Liu et al., 2002) to extract seismic induced ‘anomalous TEC’ values. The thesis works on this frame work as discussed in the following sections:

2.3 Techniques adopted in this present work for analyzing and understanding EQ induced effect on signal propagation

2.3.1 Monitoring of Very High Frequency (VHF) anomalous propagation

2.3.2 Analysis of TEC data from GPS receiver installed at GU and from global TEC data: Use of Appleton Anomaly features

2.3.3 Monitoring of Lower atmospheric variabilities like temperature, pressure data: extraction of pre-seismic induced anomalous features

2.3.4 Model computation of lower atmospheric parameters: extraction of EQ induced features

A brief description of each method is discussed below:
2.3.1 Monitoring Very High Frequency (VHF) anomalous propagation

For receiving VHF anomalous signal, it is necessary to monitor signal propagation character from stations beyond the normal LOS path distance. In normal situations, when a transmitter location is more than 100 km away, we do not receive any signal, but in special situations, signal received from distant stations and these we identify as anomalous VHF receptions. Therefore for analyzing the role of EQ preparatory processes of anomalous propagation we select Chukha FM transmitter (frequency 98 MHz) of Bhutan (27.05ºN, 89.58ºE) which is 300 km away from the receiving station. For this purpose a receiving setup consisting of polarized antenna, receiving unit and data analysis modules are designed and developed. The details description of the setup is discussed in chapter III.

2.3.2 Analysis of TEC data from GPS receiver installed at GU and from global

TEC data: Use of Appleton Anomaly features

To understand the role of lithosphere to atmosphere coupling it is essential to measure not only the lower atmospheric variabilities, but also the ionospheric parameter like TEC. Because the electric field generated by pre EQ preparatory processes could enhance the existing electric field at the ionospheric height, thereby significant modification in the ionization density may be expected around an EQ epicenter zone. In order to analyze the role of EQ in the development and growth of equatorial anomaly, TEC data measured at Guwahati by dual frequency global positioning system is installed. In this work, along with the TEC data taken over Guwahati, global TEC data
are analyzed to understand how an anomaly seen at the ionospheric height could affect the signal propagation status.

2.3.3 Monitoring of lower atmospheric variabilities like temperature, pressure data: extraction of pre-seismic induced anomalous features

To identify the sources associated with EQ induced signal propagation over the horizon, the lower atmospheric variabilities such as temperature, pressure and humidity data are recorded and analyzed at the transmitter and receiver site as well as the epicenter site. For this purpose round the clock data of temperature and humidity are recorded from high sensitive sensor, radiosonde and also from website. A few representative data outputs are presented below:

2.3.3.1 High resolution sensitive continuous temperature and humidity data from embedded system installed at GU

Ground based data on temperature, humidity are taken from high sensitive sensor installed at Gauhati University with time resolution of 1 minute. The temperature resolution is 0.1°C and humidity resolution is 0.1%. Representative profiles of daily temperature and humidity data are shown in Figure 2.2.
2.3.4 Model computation of lower atmospheric parameters: extraction of EQ induced features

2.3.4.1 VARSHA Model

VARSHA Flosolver MK7, developed at Flosolver Unit, NAL, run at Gauhati University, is a parallel processing hydrostatic spectral general circulation model developed specially for forecasting atmospheric variabilities such as precipitation, humidity, wind velocity and direction, temperature etc. at 120 spectral modes, a horizontal grid of 512x256 (approx 80 km at equator) and 18 vertical layers. The system is based on distributed memory concept and built around Pentium processors, which acts as processing elements (PEs). Communication between processing elements is very important, which is done through hardware switch called Floswitch. Floswitch supports both message passing as well as message processing. Message processing is a unique feature of Floswitch. The initial conditions are prepared using the Final analysis (FNL)
dataset of NCEP which is available at 1 degree resolution. FNL data is in gridded format and on pressure levels. All these data needs preprocessing before feeding in to the model. Representative outputs from model VARSHA is shown in Figure 2.3.

Figure 2.3: Representative profile of Temperature, Humidity, Wind and Precipitation forecast from model Varsha.
2.4 Supporting data

Supporting inputs like temperature, pressure, humidity and dew point are collected from IMD (Indian Meteorological Department), also round the clock data of temperature and humidity are taken from website www.wunderground.com, www.weather.uwyo.edu. The wind, temperature and pressure parameters are further computed from VARSHA model run at Gauhati University, an eight processor Flosolver machine. The Radiosonde data over various stations are collected from Wyoming University, China Atmospheric Soundings Data division. A brief description of radiosonde technique adopted for procuring atmospheric data is given below:

2.4.1 Radiosonde data

The radiosonde carries a small radio transmitter together with sensors to measure pressure, temperature and humidity and the entire assembly is made to go up by a free flying balloon released from surface at 0000 and 1200 UTC daily. The transmitter produces a carrier wave which is amplitude modulated by signals from thermistor, hygristor sensors. The released balloon rises at a rate of 5 m s\(^{-1}\), and can reach heights of about 20 km to 30 km above the mean sea level. While an aneroid capsule measures pressure, temperature and humidity are measured by a thermistor and hygristor respectively. A small electric motor turns the switch, which couples the individual oscillators to the transmitter circuit, while a small battery provides power for the assembly. Thus a series of information of air temperature, humidity and pressure at various upper levels of the atmosphere are measured in situ and transmitted to the ground receiving station. The receiver consists of computer controlled processor, which
measure the signal and decodes the information. The sensors in the radiosonde are calibrated before the launch and these calibration factors are used to derive the values of the meteorological / atmospheric parameters. A few representative outputs obtained from Radiosonde are presented below:

![Figure 2.4: Representative profile of (a) temperature (b) humidity (c) potential temperature obtained from radiosonde data](image)

2.5 Approaches adopted for achieving the aims of the thesis

Taking all these aspects into the ambit of working modules, the following procedures and approaches are adopted to achieve the aims and objectives of the work:

I. A setup consisting of polarised antenna with low noise, high sensitive receiver coupled with data logger and analyzer is designed and developed for monitoring reception of VHF signals received from sources beyond the normal LOS horizon.

II. Analyses of lower atmospheric parameters as temperature, pressure, humidity, RRI and structure constant parameter (Cn²) are performed to identify any features that are modified by EQ induced processes.
III. Analyses of latitudinal, longitudinal and diurnal variations of global TEC values are routinely performed and GPS-TEC round the clock data is received at GU. EQ time shifts in location of noon time TEC peaks due to equatorial anomaly effect are analyzed for identification of pre EQ time preparatory processes.

IV. The phenomena of EQ time extension of radio horizon seen through appearance of larger number of GPS satellite passes and azimuthal status of GPS satellite are processed in search of consequent effect of increase in radio horizon in modification of signal propagation.