Chapter-3

Data and Analysis
Chapter 3: Data and Analysis

3.1 Introduction: -

Magnetic pulsations can be observed in a number of ways. The most commonly used techniques are the following-

(i) The magnetic components of the fluctuations are measured employing rapid run magnetometers. These include the flux gate and Rb-vapour magnetometers.

(ii) The time derivative of the magnetic components of the variations is recorded using induction coils.

(iii) The potential difference induced by pulsation magnetic field between the electrodes buried in the earth is measured.

The application of ground-based magnetometer arrays has proven to be one of the most successful methods of studying the spatial structure of hydromagnetic waves in the earth’s magnetosphere. With a few exceptions, the Pc4 studies undertaken in the past have been confined to middle and high latitudes. The spatial and temporal variations observed in wave occurrence and frequency distribution are of vital importance because they provide evidence which can be directly related to wave generation mechanisms both inside and external to the magnetosphere and propagation modes inside the magnetosphere. The spatial and temporal characteristics of Pc4 pulsations, specially diurnal and seasonal variation of occurrence and frequency at low latitudes, have received very little attention in the past and need to be analysed extensively to understand the generation and propagation mechanisms of these waves [Ansari et al., 2009(a)].

3.2 Data and Analysis: -

The investigations and results reported in the present thesis are based on digitized geomagnetic data recorded at three Indian stations. Geomagnetic data of X (north-south), Y (east-west) and Z (vertical) components of earth’s magnetic field for the duration of the study (01 Jan.
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2005 to 31 Dec. 2005) were recorded using three axis flux gate magnetometer array (Pathan et al. 1999) at the stations Hanle, Nagpur and Pondicherry with one second sampling interval. The stations were situated at almost along the same longitude and at different very low latitudes in India. By analysing the data from these stations, lying along the same longitude, we can observe the latitude dependence of the occurrence and frequency variation of pulsation events. The magnetometer array was established and operated by Indian Institute of Geomagnetism (IIG), Navi Mumbai. The coordinate details of these stations and the schematic representation of their locations are shown in Table 3.1 and Fig. 3:1 respectively. Time is always stated in UT such that Indian Standard Time (IST) = UT + 5:30 hr [Ansari et al., 2009(a)].

The analysis of temporal and spatial variations of the Pc4 pulsations involved several steps. The data, which were calibrated in all respects, are used for carrying out this analysis. The geomagnetic X, Y and Z components of the recorded time series at one second interval were filtered using a zero-phase shift sixth order Butterworth type "band pass" filter for the frequency ranges 5-40 mHz (Otnes and Enochson, 1978). Initially, the dynamic spectra of full day were constructed. These dynamic spectra enabled us to identify the pulsation events. We have detected the pulsation events at all the stations on different dates [Ansari et al., 2009(a)]. Most of the events were detected in the 10 mHz to 30 mHz frequencies ranges. The tables 3.2, 3.3 & 3.4 depict the pulsation events, with time range and frequency range, detected in the month of Jan.-05 for Nagpur, Hanle and Pondicherry recording stations respectively and Fig. 3.2(a), Fig.3.2 (b) and Fig. 3.2(c) provide examples of dynamic spectra of full day for 19th Nov. 2005 at Nagpur, Hanle and Pondicherry respectively [Ansari et al., 2009(b)].
Fig. 3.1: Schematic map representing the locations of the three recording stations. [After Ansari et al., 2009(a)]
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Table 3.1: Coordinate details of recording stations [After Ansari et al., 2009(a)]

<table>
<thead>
<tr>
<th>Recording stations</th>
<th>Geographic co-ordinates</th>
<th>Geomagnetic co-ordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pondicherry (PON)</td>
<td>79.92</td>
<td>11.92</td>
</tr>
<tr>
<td>Nagpur (NAG)</td>
<td>79.00</td>
<td>21.10</td>
</tr>
<tr>
<td>Hanle (HAN)</td>
<td>78.97</td>
<td>32.78</td>
</tr>
</tbody>
</table>

Table-3.2: Pulsation events found at Nagpur (Jan.-05)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time range (x 10) sec</th>
<th>Frequency range (mHz)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-01-05</td>
<td>6.0 – 7.0</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>02-01-05</td>
<td>5.2 – 6.0</td>
<td>5 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>05-01-05</td>
<td>5.6 – 8.0</td>
<td>10 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>06-01-05</td>
<td>5.5 – 7.0</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>08-01-05</td>
<td>6.5 – 7.0</td>
<td>10 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>10-01-05</td>
<td>5.0 – 6.0</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>11-01-05</td>
<td>7.2 – 7.7</td>
<td>7 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>24-01-05</td>
<td>1.5 – 2.0</td>
<td>05 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>27-01-05</td>
<td>6.0 – 7.0</td>
<td>7 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>28-01-05</td>
<td>6.5 – 7.5</td>
<td>7 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>29-01-05</td>
<td>6.0 – 7.0</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>31-01-05</td>
<td>5.5 – 7.0</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
</tbody>
</table>
Table-3.3: Pulsation events found at Hanle (Jan.-05)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time range 4 (x 10 sec)</th>
<th>Frequency range (mHz)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-01-05</td>
<td>6.0 – 7.0</td>
<td>05 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>05-01-05</td>
<td>5.5 – 8.0</td>
<td>10 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>06-01-05</td>
<td>5.5 – 7.5</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>08-01-05</td>
<td>0 – 2.5</td>
<td>7 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>10-01-05</td>
<td>5.5 – 6.5</td>
<td>7 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>11-01-05</td>
<td>7.0 – 8.0</td>
<td>7 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>13-01-05</td>
<td>1.0 – 2.0</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>14-01-05</td>
<td>6.0 – 8.0</td>
<td>5 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>25-01-05</td>
<td>1.0 – 2.0</td>
<td>10 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>26-01-05</td>
<td>6.0 – 7.0</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>28-01-05</td>
<td>6.0 – 8.0</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
</tbody>
</table>

Table-3.4: Pulsation events found at Pondicherry (Jan.-05)

<table>
<thead>
<tr>
<th>Date</th>
<th>Time range 4 (x 10 sec)</th>
<th>Frequency range (mHz)</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>01-01-05</td>
<td>5.0 – 7.0</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>02-01-05</td>
<td>4.0 – 5.0</td>
<td>5 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>05-01-05</td>
<td>5.5 – 8.0</td>
<td>10 – 30</td>
<td>Event observed</td>
</tr>
<tr>
<td>08-01-05</td>
<td>0.0 – 2.5</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>10-01-05</td>
<td>4.0 – 5.5</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>16-01-05</td>
<td>2.0 – 3.0</td>
<td>5 – 15</td>
<td>Event observed</td>
</tr>
<tr>
<td>19-01-05</td>
<td>0.0 – 2.5</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>27-01-05</td>
<td>6.0 – 7.0</td>
<td>7 – 25</td>
<td>Event observed</td>
</tr>
<tr>
<td>28-01-05</td>
<td>6.2 – 7.5</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>29-01-05</td>
<td>6.0 – 7.0</td>
<td>5 – 20</td>
<td>Event observed</td>
</tr>
<tr>
<td>31-01-05</td>
<td>5.0 – 6.5</td>
<td>5 – 25</td>
<td>Event observed</td>
</tr>
</tbody>
</table>
Fig. 3.2(a): Dynamic spectra of full day on 19th Nov. 2005 at Nagpur. Time (UT) is expressed in seconds and frequency in Hz. Relative intensities are indicated by various colours on the right.
Fig. 3.2(b): Dynamic spectra of full day on 19th Nov. 2005 at Hanle. Time (UT) is expressed in seconds and frequency in Hz. Relative intensities are indicated by various colours on the right [Ansari et al., 2009(b)].
Fig. 3.2(c): Dynamic spectra of full day on 19th Nov. 2005 at Pondicherry. Time (UT) is expressed in seconds and frequency in Hz. Relative intensities are indicated by various colours on the right.
The analysis for each day of the whole year was carried out for X and Y components by selecting the events from the full day spectra of that day that were constructed using MATLAB program. After the detection of pulsation events, we selected the data in the narrow time interval and filtered the selected data for the observed frequency range. Filtered time series for selected data filtered between the frequency range 5-40 mHz was also plotted that showed the clear pulsation events. Fig. 3.3 shows the filtered pulsations (in the interval 5-40 mHz) at Nagpur on March 04, 2005.

Fig. 3.3: Filtered pulsations (in the interval 5-40 mHz) at Nagpur on March 04, 2005. The signal amplitudes are expressed in nano Tesla (nT).
We observed the pulsation events at all the stations on different dates that were mostly lying in the 10 mHz to 25 mHz frequency range. The digital dynamic spectra, for events selected with the help of dynamic spectra of full day and filtered time series, were prepared taking the window of 1024 points with the sliding of half the window size for the selected time interval using matlab program. The MATLAB program used for preparing digital dynamic spectra was provided by IIG, Navi Mumbai and is reproduced below. The hourly frequency ranges and the occurrence periods were recorded from these spectra. Analysis of diurnal and seasonal variation in occurrence and frequency was then carried out. The dependence of occurrence of these pulsations on solar wind velocity, and magnitude of interplanetary magnetic field (IMF) was also carried out with these observed hourly occurrence periods and data of solar wind velocity and magnitude of interplanetary magnetic field (IMF) adapted from the websites indicated at the end of list of references [Ansari and Nafees, 2012(a)].
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The MATLAB program used for preparing digital dynamic spectra was provided by IIG, Navi Mumbai and is reproduced below for the sake of completeness. (Curtsey IIG, Navi Mumbai).

**MATLAB program:**

```matlab
clear;
filename=[pathname,filename];
a=load(filename);
th=a(:,1);
tm=a(:,2)/60;
ts=a(:,3)/3600;
tim1=th+tm+ts;
magx1=a(:,4);
magy1=a(:,5);
magz1=a(:,6);
magx2=magx(find(magx<1000 & magy<1000 & magz<1000));
magy2=magy(find(magx<1000 & magy<1000 & magz<1000));
magz2=magz(find(magx<1000 & magy<1000 & magz<1000));
tim2=tim(find(magx<1000 & magy<1000 & magz<1000));
magx_entire=magx2;
magy_entire=magy2;
magz_entire=magz2;
tim_entire=tim2;

figure
subplot(3,1,1);
plot(tim_entire,magx_entire);
title('Time series for full data');
subplot(3,1,2);
plot(tim_entire,magy_entire);
subplot(3,1,3);
plot(tim_entire,magz_entire);
xlabel('Time(U.T.)');
ylabel('Signal Amplitude');

%tim=time2str(tim_entire(find(tim_entire>=17,'nav','hm','hms')));
%str = time2str(time,'nav','hm','hms')
%---------------------------------------------------------------
tim=tim_entire(find(tim_entire>=6 & tim_entire<=11));
magx=magx_entire(find(tim_entire>=6 & tim_entire<=11));
magy=magy_entire(find(tim_entire>=6 & tim_entire<=11));
magz=magz_entire(find(tim_entire>=6 & tim_entire<=11));
magx_dt=detrend(magx,'linear');
magy_dt=detrend(magy,'linear');
magz_dt=detrend(magz,'linear');

figure
```

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```matlab
subplot(3,1,1); plot(tim,magx); title('Time series for selected data'); subplot(3,1,2); plot(tim,magy); subplot(3,1,3); plot(tim,magz); xlabel('Time (U.T.)'); ylabel('Amplitude');
```

```matlab
fs=1; nfft=1024; F=0:0.0001:0.05; [yx,fx,tx,px]=spectrogram(magx_dt,nfft,nfft-20,F,fs,'yaxis'); %title('Dynamic Spectra from 0.0-0.05 Hz'); tsize=size(tx); tx=((tx+t_start)/3600); t_first=tsize(:,1); t_last=tsize(:,2); tx(:,1)=round(tx(:,t_first)); tx(:,t_last)=round(tx(:,t_last)); %title('Dynamic Spectra from 0.0-0.05 Hz');
```

```matlab
[yy, fy, ty, py]=spectrogram(magy_dt,nfft,nfft-20,F,fs,'yaxis'); ty=((ty+t_start)/3600); tsize=size(ty); t_first=tsize(:,1); t_last=tsize(:,2); ty(:,1)=round(ty(:,t_first)); ty(:,t_last)=round(ty(:,t_last));
```

```matlab
[yz, fz, tz, pz]=spectrogram(magz_dt,nfft,nfft-20,F,fs,'yaxis'); tz=((tz+t_start)/3600); tsize=size(tz); t_first=tsize(:,1); t_last=tsize(:,2); tz(:,1)=round(tz(:,t_first)); tz(:,t_last)=round(tz(:,t_last));
```

```matlab
figure subplot(3,1,1) %title('Dynamic Spectra from 0.0-0.05 Hz'); surf(tx,fx,10*log10(abs(px)),'Edgecolor','none'); axis xy; axis tight; colormap(jet); caxis([-40 40]); colorbar; view(0,90); %-------------------------------------
```

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```matlab
subplot(3,1,2)
surf(ty,fy,10*log10(abs(py)),'Edgecolor','none');
axis xy; axis tight; colormap(jet);caxis([-40 40]);colorbar; view(0,90);
ylabel('Frequency(f),(Hz)');

subplot(3,1,3)
surf(tz,fz,10*log10(abs(pz)),'Edgecolor','none');
axis xy; axis tight; colormap(jet);caxis([-40 40]);colorbar; view(0,90);
xlabel('Time(U.T.)');
ylabel('Frequency(f),(Hz)');
title('Dynamic Spectra from 0.0-0.05 Hz');

[c,b]=butter(6,0.04/fs*2,'low');
%magxfilt=filter(c,b,magx);

[d,e]=butter(6,0.005/fs*2,'high');
%magxfiltfinal=filter(d,e,magxfilt);

figure
%plot(tim,magxfiltfinal);
plot(tim,magyfiltfinal);
title('Spectra of filtered data 0.04 Lowpass & 0.005 Hz Highpass');
xlabel('Time(U.T.)');
ylabel('Signal Amplitude');

%title('Spectra of filtered data 0.04 Lowpass & 0.005 Hz Highpass');
%XLIM([5000 10000]);

figure
[pmagxfiltfinal,f]=psd(magxfiltfinal,nfft,fs,'linear');
%pmagxfiltfinal=sqrt(pmagxfiltfinal/fs*2);
%loglog(f,pmagxfiltfinal);

[pmagyfiltfinal,f]=psd(magyfiltfinal,nfft,fs,'linear');
pmagyfiltfinal=sqrt(pmagyfiltfinal/fs*2);
%loglog(f,pmagyfiltfinal);
%subplot(3,1,1)

%plot(f,pmagxfiltfinal);
plot(f,pmagyfiltfinal);
title('Power Spectra from 0.0-.05 Hz');
%xlim([0,5e-2]);
%subplot(3,1,2)
xlim([0,5e-2]);
xlabel('Frequency(f),(Hz)');
ylabel('Power(Wb,nT/sqrt(Hz))');
%--------------------------------------

(Source of the Program: IIG, Navi Mumbai)
```