Chapter 6
Conclusion

The variations in the geomagnetic field recorded on the ground or in the magnetospheric cavity, can yield clues to physical processes at work in (i) the entire magnetospheric cavity, (ii) in interplanetary space, (iii) on the Sun and (iv) within the Earth. The geomagnetic variations can also be used for prospecting for natural resources on the Earth. Singh in 1980 and Arora in 1990 reviewed the methods by which the Earth’s mantle and crust are studied using short-period variations of the transient type. The Magsat observations of the vector geomagnetic field can be utilized to study the Earth’s crust through the extraction of small-scale anomalies, which ride on the main magnetic field (Singh and Rajaram, 1990). The influence of geomagnetism on radio wave propagation is tremendous even during geomagnetically quiet times, more during disturbed times. During a magnetic storm, radio-communication becomes almost impossible.Geomagnetograms can be used to monitor and even forecast the state of the ionosphere and therefore of possible disruptions in radio-communication. Although less dependent on the Earth’s electromagnetic state, even satellite communication is affected by phenomena in the geo-atmosphere (e.g., plasma irregularities which produce scintillation), which are governed by the structure of the geomagnetic field and the upper atmosphere. The detection of magnetic anomalies which are caused by non-uniform distribution of magnetic materials in the Earth’s crust enables to detect the presence of mineral resources within the Earth.
From the Fourier theory, it is well known that a signal can be expressed as the sum of a, possibly infinite, series of Sines and Cosines. This sum is also referred to as a Fourier expansion. The disadvantage of a Fourier expansion however, is that it has only frequency resolution and no time resolution. This means that although we might be able to determine all the frequencies present in a signal, we do not know when they are present. To overcome this problem in the past decades, several solutions have been developed which are more or less able to represent a signal in the time and frequency domain at the same time.

The idea behind these time-frequency joint representations is to cut the signal of interest into several parts and then analyze the parts separately. Analyzing a signal this way will give more information about the when and where of different frequency component, but it leads to a fundamental problem as well: how to cut the signal?

The wavelet transform or wavelet analysis is probably the most recent solution to overcome the short comings of the Fourier transform. In wavelet analysis the use of a fully scalable modulated window solves the signal cutting problem. The window is shifted along the signal and for every position the spectrum is calculated. Then this process is repeated many times with a slightly shorter (or longer) window for every new cycle. In the end the result will be a collection of time-varying frequency representations of the signal, all with different resolutions. Because of this collection of representations it is called a multi resolution analysis.

Wavelet transform enables the detection of extremely weak signals in higher order sub harmonics resulting from the period doubling bifurcations. These signals are either undetected or considered statically insignificant by traditional Fourier analysis. The CWT indicates the presence of multiple time scales which are localized in both frequency and time. Thus the WT is a powerful tool for analysis of phenomena involving multiscale interactions that exhibit localization in both frequency and time. The wavelet transform method gives detailed information on the time localization of each frequency component. In this thesis, the CWT utilized to study the wavelet spectrum provides continuous temporal evolution of the entire range of periods and the time variation of wavelet power for the different period ranges. Morlet wavelet transform is without doubt a powerful tool because of its ability to extract signal information from a non-stationary
signal. Thus to perform a time series analysis with accuracy discrete version of CWT is used which allows a clearer signal representation.

The time series data (Figs. 6.1-6.6) depicts time series, phase spectral image and contours of real part of Dst and AL respectively, from 1 Mar.-30 Apr. (1991)
In Chapter III, the CWT technique is used to identify long period oscillations in $\Delta H$ over Trivandrum (TRD) during the solar maxima 1990-1991 (Oct.-Apr.) and minima 1995-1996 (Oct.-Apr.). The CWT of $\Delta H$ indicates the presence of multiple timescales, which are localized in frequency and in time. This analysis clearly brings out merging of long (~130-180 days) and short period (~1-2 days) oscillations during geomagnetically disturbed intervals. Thus long period oscillations are identified in the ionosphere, though such periodicities have been reported in zonal wind component in the low and middle latitude. Also the merging of long period oscillations with short period oscillations ~1-2 days during geomagnetically disturbed periods is a new observation. The analysis technique is further extended to solar cycle 22 (1986-1996). The periodicities are examined in F10.7 cm, $R_z$ and $Ap$ index for selected intervals. To interpret the merging of long and short period oscillations in $H$, $Dst$ and $AL$ indices are also subjected to similar analysis using 1 Mar.-30 Apr. 1991 data.

The merging of long period oscillations with short period oscillations are observed at the time of storms/substorms as observed in $Dst$ and $AL$ indices when they are subjected to CWT (Figs.6.1-6.6). At the time of geomagnetic storm/substorm the ionospheric electric fields/currents and plasma density in the dip equatorial region depart significantly on different time scales. Major geomagnetic storms represent a significant dissipation of energy by the magnetosphere. The energy is derived from the solar wind flow and the subsequent powerful conversion of that energy takes several different forms. Ring current injection and decay, ionospheric Joule heating, particle precipitation into the atmosphere and several related physical processes are exhibited in large storm events. This work can lead to stimulating analysis and discussions for further understanding of the complexity of geomagnetic storms and its effects on near space environment.

To identify long period oscillations in $H$-component, the CWT technique was extended to two longitudinal zones: Huancayo in South America and Addis Ababa in Africa for the ascending phase of solar cycle-22 (1986-1990) and compared results with Indian zone. The results are presented in Chapter IV. Further, the temporal evolution of wavelet power in $Ap$, for each of the prominent quasi-periods is studied in detail. A long-term and short term analysis of $Ap$ from 1932-2002 using CWT technique and FFT analysis is performed. The amplitude in the
oscillations of $\Delta H$ for different period ranges is high during 1989 and 1990 at the three stations and is low during 1987 except at Huancayo where the amplitude for -170-340 day range wave is comparably high during 1987. Moreover, the amplitude of different period ranges, are high at Huancayo (HUA) as compared to Addis Ababa (AAB) and Trivandrum (TRD) for the year 1986 through 1990.

The wavelet method provides an excellent means of finding the strength of the oscillations in the range of ~8-hours to 2.5-years in $\Delta H$ and from ~7-days to ~37.5-years in $Ap$ and their temporal evolution. Global wavelet spectra of $\Delta H$ at AAB, HUA and TRD indicates the presence of a variety of prominent oscillations from ~2-days to 182-days significant in the analysis of 1-year data and from ~5-day to 913-days in the 5-year $H$-component in the ascending phase of solar cycle-22. Periodicities in $F10.7\text{cm}$ in the ascending phase of cycle-22 are in good agreement with the periodicities in $Ap$ and $\Delta H$ at AAB, HUA and TRD. The similarities of the variations in period in solar and geophysical data provide evidence that the magnetosphere of the Earth is actually a continuation of the heliosphere. The solar background magnetic field determines the variations of the terrestrial magnetic field in the middle heliographic latitudes. However, it was observed that $F10.7\text{cm}$ did not show significant peaks below ~20-day but $Ap$ and the $\Delta H$ showed significant peaks around ~2-20-days. Periodicity around ~2-20-days could be attributed to other sources such as planetary waves.

Chapter V contains CWT of $\Delta H$ from Indian stations - Annamalainagar, Alibag and Sabhawala and the results are compared with that at Trivandrum during ascending phase of cycle-22 (1986-1990). Further, temporal evolution of wavelet power in $R_z$ from 1942-2003 and $F10.7\text{cm}$ from 1947-2003 for each of the prominent quasi-periods are studied in detail. Periodicities of different peaks are identified and related to planetary wave and solar activity phenomena. Here we have seen that planetary waves influence geomagnetic variations. Periodic variations of $\Delta H$ are caused mainly by solar flux variations and due to combination of planetary wave excitation and solar radiation. These waves are not confined to an equatorial station but are equally prominent at stations away from influence of electrojet. Amplitude and power of oscillations were higher during maximum phase of solar cycle but occurrence of oscillations was almost
same at the four stations from 1986 to 1990, indicating that all of these are global in nature but some local effects are obvious.

Cycle-22 is exceptional from 21 solar cycles, containing two peaks, during 1989 and 1991 and having large duration for solar maximum period. Moreover, average geomagnetic disturbances are higher during maximum phase of solar cycle in comparison to solar minimum period for solar cycle-22 at the four-magnetometer stations. This is obvious in the merging of long period oscillations with short period oscillations during conditions of geomagnetic disturbance at the four sites (Molly Issac et al., 2004). Fourier power spectra emphasizes periodic behaviour with the best frequency resolution possible, while a wavelet analysis is able to show at what time intervals a typical time scale dominates the variations in the $\Delta H$, $Ap$, $Rz$ and $F10.7$ cm. Morlet wavelet transform is without doubt a powerful tool because of its ability to extract signal information from a non-stationary signal. Thus to perform a time series analysis with accuracy discrete version of CWT is used which allows a clearer signal representation.