J. Ind. Geophys. Union (July 2009)
Vol.13, No.3, pp.107-120

Equatorial and low latitude geomagnetic field oscillations in the Indian region

S.K.Bhardwaj
Indian Institute of Geomagnetism, Plot No. 5, Sector –18, Kalamboli (Highway),
New Panvel (W), Navi Mumbai 410 218
E.mail: sandeep@iigs.iigm.res.in

ABSTRACT
Monthly mean hourly values of geomagnetic field components D, H and Z for quiet days at equatorial and low latitude stations in the Indian region are analyzed to study the salient features of geomagnetic field oscillations in magnetic elements. The data used in this analysis is from 1958 to 1993 at equatorial electrojet stations: Trivandrum & Annamalainagar, from 1970 to 1993 at Kodaikanal and from 1927 to 1997 at low latitude station Alibag. From this basic data, geomagnetic Sq ranges and summed ranges are computed and subjected to the data adaptive, noise reducing technique of Singular Spectrum Analysis (SSA). The pair of eigen vectors analyzed through SSA up to order 18 represent different oscillations of the field such as; 11-year, annual, semi-annual, 4-month, 14-month (Pole-tide) and a Quasi-Biennial Oscillation (QBO) etc. The Sq ranges, summed ranges at all the stations and monthly mean sunspot numbers for the same period are also analyzed by a band pass digital filter method in order to identify whether QBO signal at these stations is the result of dynamo winds or due to QBO like signature in the Sun's atmosphere. It is found that, the amplitude of the signal is stronger at equatorial electrojet stations in comparison with low latitude station Alibag and may be due to solar origin.

INTRODUCTION

It is widely accepted that the geomagnetic field oscillations at equatorial and low latitude stations are produced by the electric currents, which are flowing in the ionosphere and magnetosphere with Sun as the primary source. Olson (1970) suggested that the ionospheric dynamo is not the only source of the Sq variations and at least two other magnetospheric current systems, the neutral sheet and ring currents, may also make contributions to the quiet magnetic variations at the surface of the earth. He demonstrated that, a single current system, which flows on the magnetopause, is suffi-cient to produce daily, annual and semiannual variations in the Earth's magnetic field components. The details of these annual and semi-annual variations are given by Bhargava (1970, 1972) and [Bhargava, Rao & Arora 1973]. In addition to the annual and semi-annual variations, the equatorial and low latitude geomagnetic field is also having other periodicities like 4-month, the pole tide signal of 14-months (Rao & Rangarajan 1978) and quasibiennial oscillation (Sugiura 1976; Rangarajan 1985; Rangarajan, Veliz & Arora 1996) etc.

A strong signal with a quasi periodicity of ~ 2 years is known as Quasi-biennial Oscillation (QBO). Many studies have been made for the search of QBO signal in meteorological and geomagnetic parameters and its presence in these parameters as stratospheric winds, temperature and total ozone is already known. The existence of this signal in other parame-ters like sunspot and in geomagnetic field can be found by means of statistical analysis of long series of data. Using spectral analysis Yacob & Bharga-va (1968) examined long series (1905-1965) of Alibag H-magnetic data with corresponding sunspot numbers and found QBO signal in both these parameters. They suggested that the source of this oscillation in Sq(H)-field could well be the Sun. Sugiura & Poros (1977) also analyzed H-field at low and mid latitude observatories using band pass filter and found a periodicity of about 2 years in the geomagnetic field at different latitudes as well as in sunspot numbers. Several authors have analyzed ground based geomagnetic data for the presence of a QBO signal in the geomagnetic field components. Currie (1966, 1973) also reported a 27-month periodicity in the geomagnetic spectrum too. QBO in the geomagnetic field has also been reported by Rajarao & Joseph (1971); Nestrom & Belmont (1976); Sugiura & Poros (1977); Olsen (1994); Kane (1995, 1996); Rangarajan (1985); Rangarajan et al., (1996); Rangarajan & Araki (1997) and Jarvis (1996, 1997).

Also there is a controversy as to whether the source of any QBO signal observed in geomagnetic field components is situated in lower and middle atmosphere or due to QBO-like signal in the Sun's atmosphere. To study the fine structure of QBO signal in the geomagnetic field, Rangarajan (1985) analyzed mean monthly hourly values of H field for both quiet and disturbed days in the Indian region and reported that the amplitude of the QBO signal is large near the dip equator and the signal strength was weak in the quiet day field in comparison with the disturbance field. He suggested that the EUV flux from the Sun is not the main cause for the QBO signal in the geomagnetic field variations. Rangarajan, Veliz & Arora (1996) also reported Strong QBO in geomagnetic field components for all days and suggested that the solar activity can not be the agent responsible for QBO in H-component at low and equatorial latitudes. Recently Jarvis (1996) analyzed long series (37-year) of Argentine Islands Observatory data at Faraday research station (65° S, 64° W), Antarctica. He used monthly mean diurnal range derived from the five geomagnetically quietest days in each month and found a QBO like 27-month periodicity in the Sq daily range. He found that this periodicity is more prominent in the H-component and has a higher significance level in the semidiurnal component then in the diurnal component. The D-component shows no evidence of a QBO in the diurnal Sq component but does show a weakly-significant peak in the semidiurnal component. Jarvis (1997) also, analyzed hourly mean values of H and D-components for the period of 22-years (two solar cycles) at different latitudes for five geomagnetically quietest days in both the northern and southern hemispheres to investigate the variation with latitude of QBO effects in the semidiurnal tide in the lower thermosphere. He found that a QBO like signature is present in the semidiurnal component of the geomagnetic H-field at near equatorial sites and also in the region of 60° latitude in both the northern and southern hemispheres. He also pointed out that a QBO signal can also be present in the D-component of the earth's magnetic field. In the present paper, geomagnetic Sq ranges and summed ranges in all the three elements D, H and Z for quiet days at equatorial and low latitude stations are examined to identify whether the QBO signal at these stations is the result of dynamo winds or due to QBO-like signature in the Sun's atmosphere.

DATA AND TECHNIQUE USED

The data used in this analysis are the monthly mean hourly values of geomagnetic field components D, H and Z for quiet days at a low latitude station Alibag [(ABG) 18° 38′ N; 72° 52′ E] for the 71-year period from 1927 to 1997 and from 1958 to 1993 at equatorial electrojet stations Trivandrum [(TRD) 08° 29′ N; 76° 58′E] & Annamalainagar [(ANN) 11° 22′ N; 79° 41′ E] and from 1970 to 1993 for Kodaikanal [(KOD) 10° 14′ N; 77° 28′ E]. This homogeneous data derived from magnetograms and scaled hourly values is scrutinized for jumps / discontinuities etc. and error free common base mean monthly hourly values are generated. The data for Z-component at Alibag for the years October 1936, December 1942, June, July and August 1943 was not available, which was extrapolated by taking the average of two consecutive months i.e average of preceding and succeeding months. For the year 1921-23 only bi-hourly values were available and from 1924-1926 the values were in local time, only from 1927 the mean monthly hourly values are available in universal time. From this basic data, range for each component is computed by subtracting the base value from its peak value. Summed ranges for all the three elements are computed by adding the absolute departures of hourly values from the daily mean.

The technique of Singular Spectrum Analysis (SSA) is used to isolate different oscillations of the field from the monthly ranges and summed ranges. The major advantage of SSA is that, using the significant eigen vectors as data-adaptive filters on the time series, time evaluation of the corresponding Principal Components (PCs) can be reconstructed and can be graphically seen for further interpretation. This technique is often used to see the spatial and temporal variations of geophysical data. It extracts as much information as possible from short, noisy time series without prior knowledge of the dynamics underlying the series (Broomhead & King 1986; Vautard & Ghil 1989). The mathematical procedure and details of this methodology are given by [Vautard, Yiou & Ghil 1992] and (Rangarajan & Araki 1997), also see in Rangarajan (1994) and Bhardwaj (2006). Only the main points of this method are described here, which are as follows:

For different choices of window length (M), we can generate different trajectory matrices. From this trajectory matrix we generated a correlation matrix by taking the product of each column with all others successively. These are in effect, the lagged auto correlation coefficients and the matrix turns out to be Toeplitz (whose all diagonal elements are equal). The M eigen values of this matrix are then evaluated and organized in descending order of magnitude together with the corresponding M eigen vectors. The magnitude of each eigen value represents the variance due to the corresponding component. If quasi-periodic oscillations are present they will correspond to pairs of nearly equal eigen values with the eigen vectors in phase quadrature. As the matrix is positive symmetric Toeplitz, the number of non-zero eigen values will correspond to the number of independent variables in the system. In the presence of noise in the data, the other eigen values will be close to zero defining a noise floor [Sharma, Vassiladis & Papadapoulous 1993]. The square root of the eigen values are called 'singular values' and their set is called 'singular spectrum'. The successive singular values can be arranged in monotonically decreasing order and the noise level then appears in the singular spectrum as a flat 'floor' at its tail. Eigen vectors significantly above the noise level provide the principal components as the projection of the time series along the directions defined by each of the significant eigen vectors. In other words, the eigen vectors serve as data adaptive filters. Subramaniam (1993) pointed out that if the eigen vectors appear as even and odd pair in phase quadrature, it is indicative of pure oscillations in the time series with the periods less then the viewing window of length (M). As the principal components are filtered versions of the original time series with the M elements of the eigen vectors serving as appropriate filter weights, the resulting series would only be of length (N-M+1). Vautard, Yiou & Ghil (1992) have given a method to extract a series of length N corresponding to a given set of eigenelements which they call as Reconstructed Components (RC). The points lost in this computation are reconstructed by the relevant formulae given in (Rangarajan & Araki 1997). To identify the source of quasi-biennial oscillation, Sq ranges, summed ranges and the monthly mean sunspot numbers for the same period are also analyzed by a band pass digital filter method with unit response for 24 ± 4 months.

RESULTS AND DISCUSSION

In the use of monthly mean hourly values, the fluctuations shorter than one hour are automatically suppressed (Hibberd 1985) and as the ranges and summed ranges are the input for singular spectrum analysis the long term trends will also be automatically removed from the data. Plots of ranges and summed ranges from 1927 to 1997 for each component D, H and Z at Alibag are shown in Figs.1

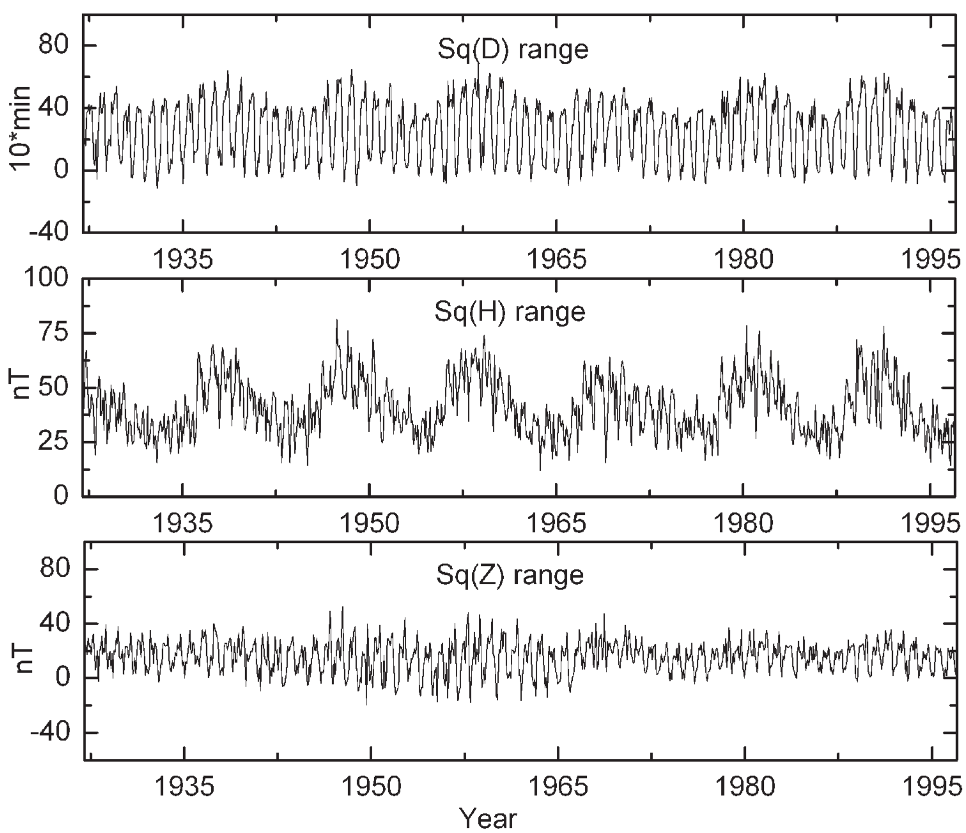

Figure 1. Monthly mean Sq ranges in D, H and Z components at Alibag from 1927 to 1997.

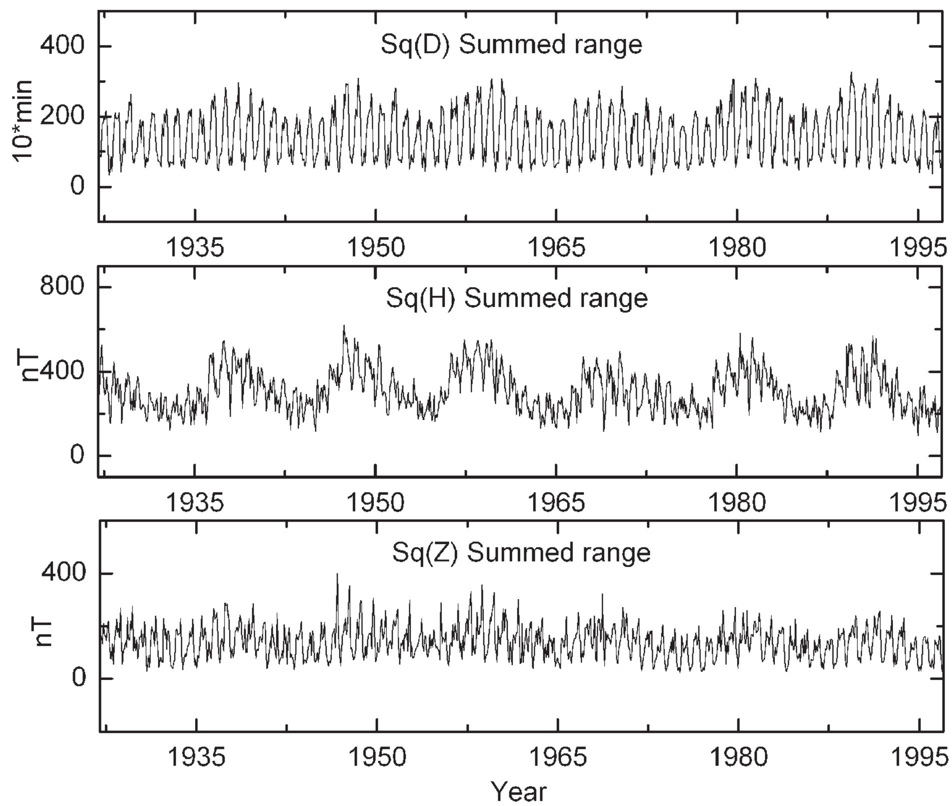

Figure 2. Monthly mean Sq summed ranges in D, H and Z components at Alibag from 1927 to 1997.

and 2. The Sq ranges, which are the maximum amplitude of geomagnetic variation under quiet geomagnetic conditions, show strong annual and 11-year solar cycle variations. These annual and 11-year solar cycle variations can be seen in both the plots of ranges and summed ranges for all the three components D, H and Z for the period from 1927 to 1997 (Figs.1 and 2). Chapman & Bartels (1940) also reported 11-year periodicity in the monthly mean summed ranges in all the three components D, H and Z at Bombay for the period from 1845 to 1905. Olsen (1994) also found these variability's in the monthly means of the daily range of the H--component at the observatory Honolulu.

In Figs.1 and 2 the 11-year solar cycle component can be seen more clearly in Sq(H) ranges and summed ranges in compression with Sq(D) and Sq(Z). This is because the H-component of the earth's magnetic field is affected more by sunspot cycle compared to D and Z. Long term trend in the field values of D, H and Z are shown in Fig.3. D-field changes at Alibag from 1927 with the broad minimum around 1965, while H showing a long period cyclicity with a minimum prior to 1927 and attained a maximum by about 1965 and is consistence with the results reported previously by Bhargava & Yacob (1969, 70) and (Bhardwaj & Rangarajan 1997). Z-field showing a near-sinus-oidal variation with a periodicity ~ 80-year the so-called Gleissberg cycle (Gleissberg 1965) with maximum around 1930 and minimum near 1970.

As the most dominant oscillation in Sq ranges is the 11-year sunspot cycle; hence a viewing window of size 144 months is chosen for the singular spectrum analysis, which is much less than one-third of the data length, the upper limit, for M recommended by Vautard, Yiou & Ghil (1992). The singular spectrum (square root of the individual eigen values) for D-component on logarithmic scale for M upto 40 are shown in Fig.4. Here we use M = 40 and the corresponding singular spectrum shows a noise floor beyond M=18. The first eighteen eigen vectors (ev) are computed for order M = 144 and are shown in Figs. 5(a) and 5(b). The percentage of variance accounted by these first eighteen eigen vectors together is 91.85 % of the total variance. The remaining 8.15 % is accounted for by several subsequent components none of which is significant individually. We therefore, plotted only first eighteen eigen vectors and by considering these eigen vectors in pairs (even and odd

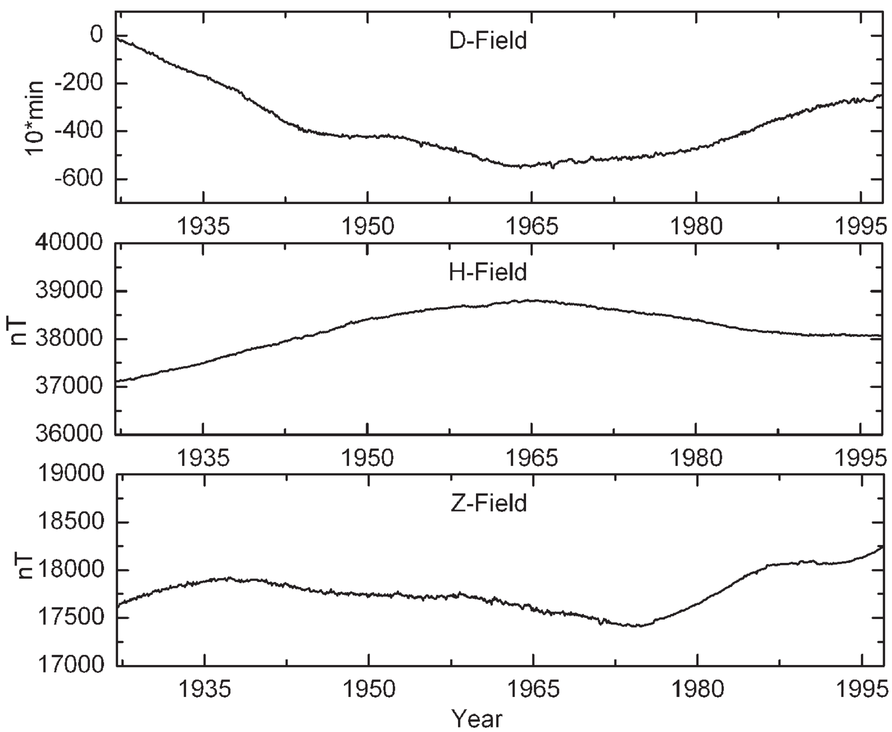

Figure 3. Long term trend in the field values of D, H and Z components at Alibag from 1927 to 1997.

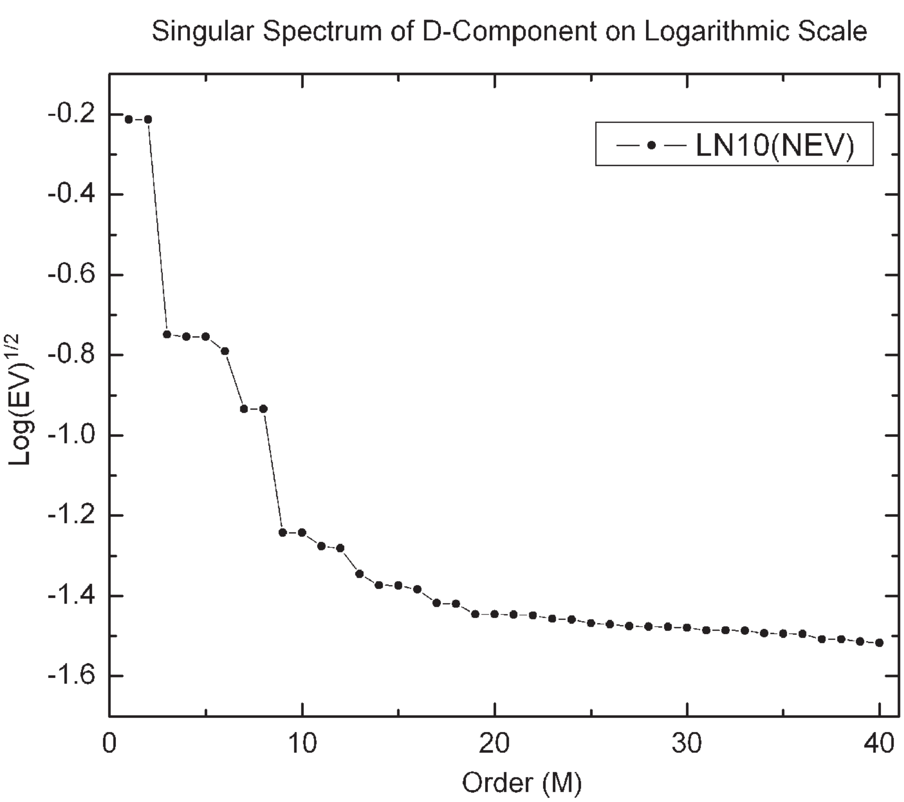

Figure 4. The Singular Spectrum defined by the square root of the eigen values [$(EV)^{1/2}$] in descending order on logarithmic scale corresponding to the time series of monthly mean Sq (D) ranges with maximum lag M = 40.

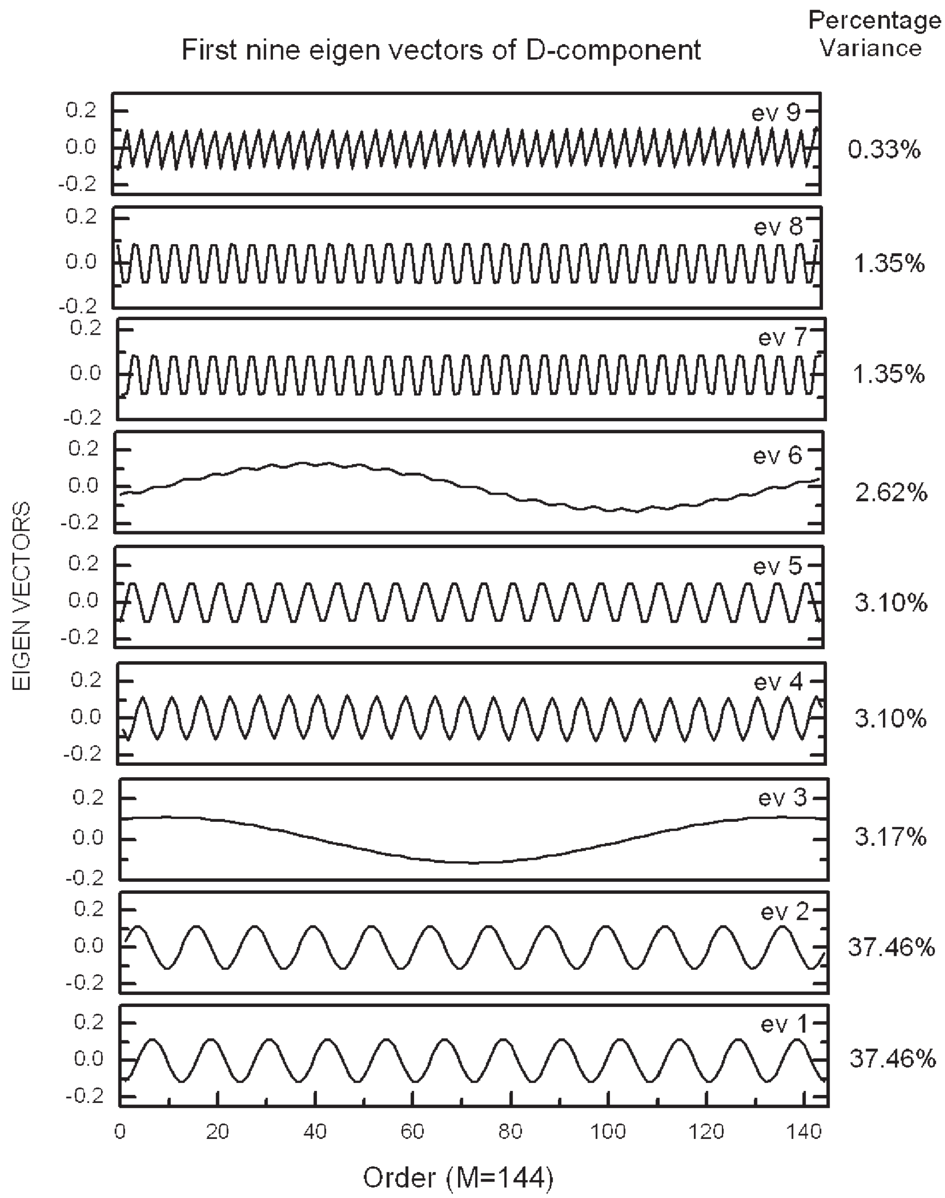

Figure 5(a). First nine eigen vectors computed through singular spectrum analysis at Alibag for D-component (monthly ranges on quiet days).

parts) the first 10 significant reconstructed components (RCs) are generated and time variation plots of first 10 reconstructed components of D for quiet days at Alibag are shown in Fig. 6. From figures 5(a) and (b) it can be seen that the seven pairs of eigen vectors (1 & 2), (4 & 5), (7 & 8), (9 & 10), (11 & 12), (14 & 15) and (17 & 18) are in near phase quadrature indicating that they represent well defined oscillations of the Sq field. From the number of cycles completed over the embedding space it is clear that the first pair of eigen vectors (1 & 2), which accounts most of the variability of the data (74.92 %) shows annual variations, the second pair of eigen vectors (4 & 5) account 6.2 % variance represents semi-annual variations, the third pair (7 & 8) having 2.7 % variation shows 4-monthly (tri-annual) component, fourth pair (9 & 10) 3-month for 0.66 %, fifth pair (11 & 12) ~14-month for 0.55 %, sixth pair (14 & 15) represents quasi-biennial oscillation for variance 0.36 % while seventh pair of eigen vectors (17 & 18) again shows nearly semi-annual (~ 6.25-months) variations for percentage variance 0.30 %. The combination of eigen vectors 3 & 6 shows an 11-year solar cycle variation for 5.79 %, whereas eigen vectors 13 (variance 0.20 %)

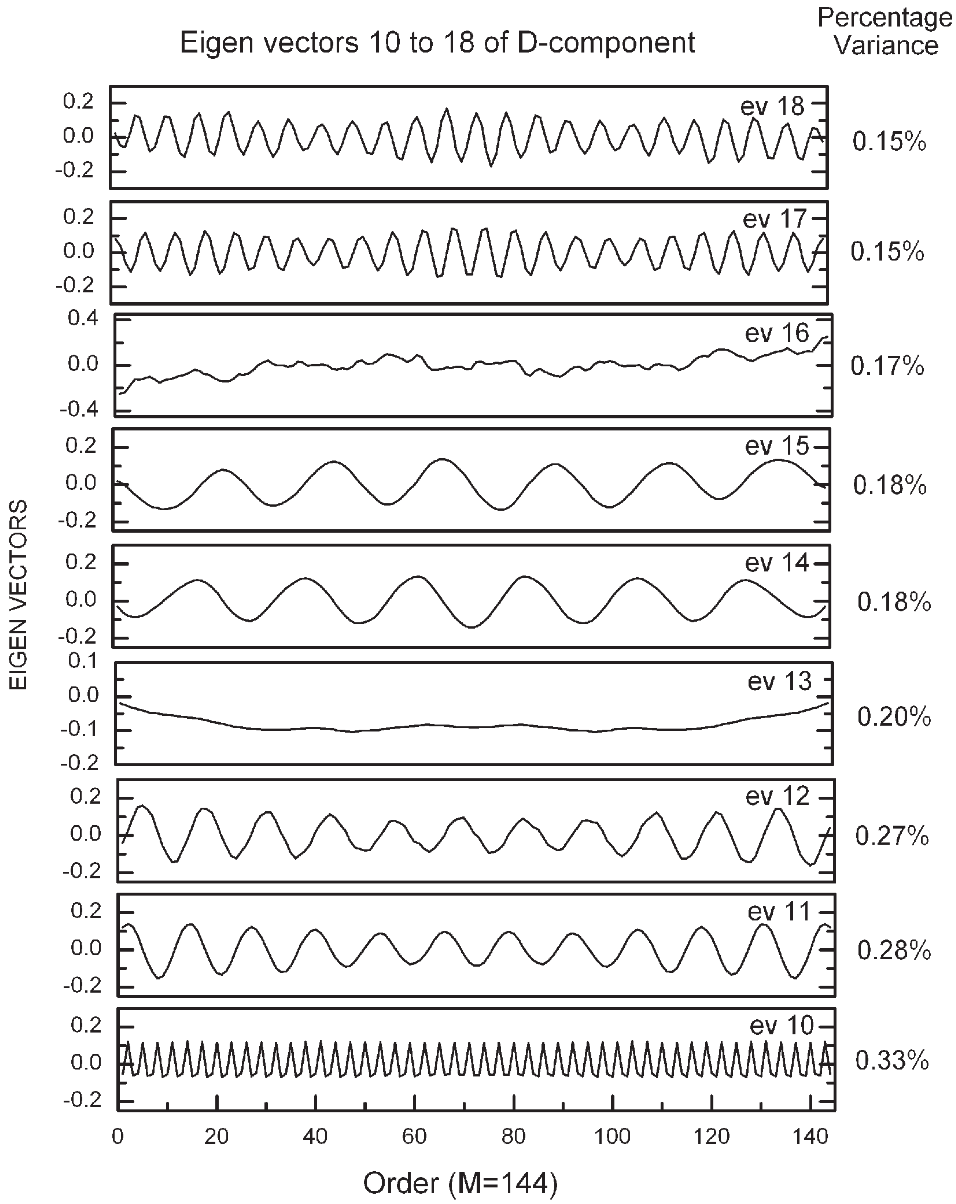

Figure 5(b). Eigen vectors 10 to 18 computed through singular spectrum analysis at Alibag for D-component (monthly ranges on quiet days).

and 16 (variance 0.17 %) show aperiodic and 35.2-months variations respectively. The daily range of Sq (D) possesses both annual and semi-annual variations as can be seen in figure 6. The annual variation arises from the annual variation in the electrical conductivity of the E-region of the ionosphere, whereas the semi-annual variation arises from the semi-annual variation in the thermospheric neutral temperature that gives rise to the driving force for the Sq dynamo [Hibberd 1985]. The variation of Sq-ranges with solar cycle has long been known and is, of course, directly related to the effects of solar activity on the ionosphere. As shown in Fig.1 the monthly range of Sq (H) for quiet days also shows large variations with solar activity and the amplitude of Sq (H) are larger for higher solar activity. After combining principal components 3 and 6, an 11-year solar cycle is noticed in Sq(D) range spectrum as shown in figure 6. In Fig.6 the reconstructed component corresponding to sum of Principal Components 14 and 15 generated through SSA, represent a QBO like signal with a quasi-periodicity of ~ 24-month in Sq (D)-range spectrum at Alibag. As in figure 6 the annual, semiannual, solar cycle and other variations are dominated on QBO, after

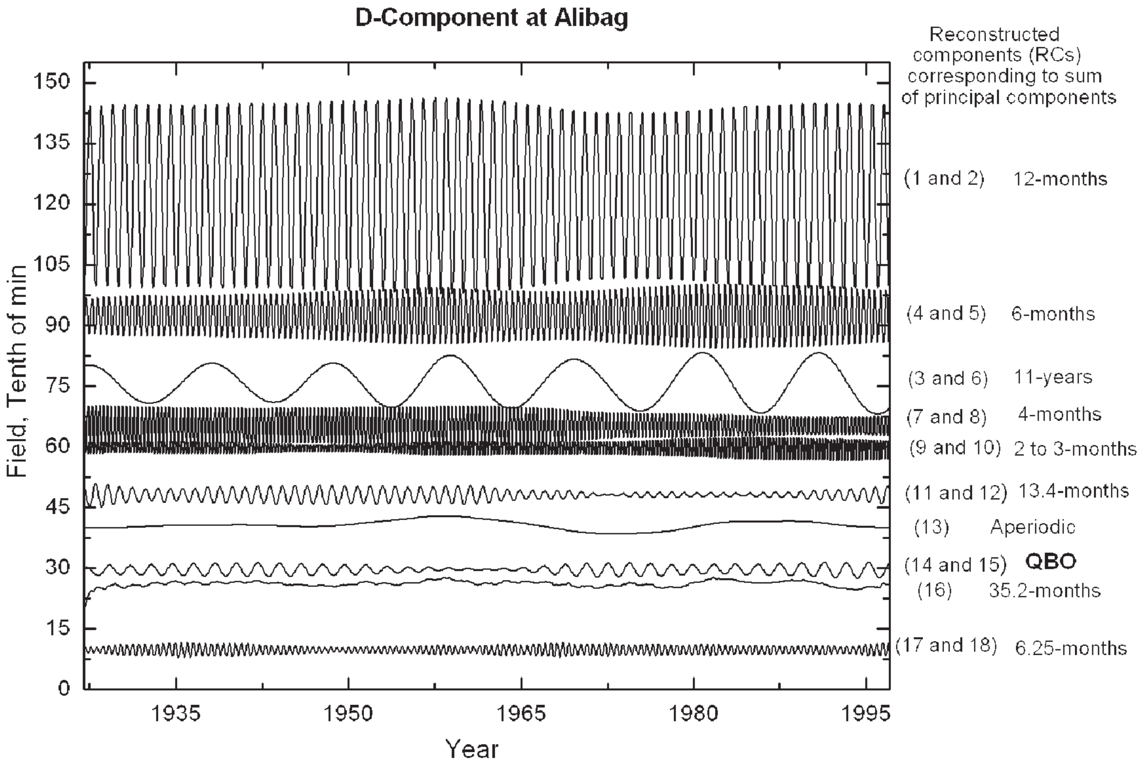

Figure 6. Time variation plots of first 10 Reconstructed Components (RCs) provided by the pairs of normalized eigen vectors at Alibag for D-component.

removing the first seven reconstructed components the QBO like wave can be seen more clearly in D-component and are shown in Fig. 7. No body has reported QBO like signature in the D-component of the earth's magnetic field till now, whereas Jarvis (1997) pointed out that, the QBO like wave can also be present in the D-component of the earth's magnetic field and our results are supporting his statement and that is why we have shown the spectrum only for D-component (Fig.6).

The technique of SSA provides relative significance (in the decreasing order of their contribution to the total variance of the time series) of different dominant oscillations. In identifying 'significant' oscillation the two governing aspects are (i) The pair nearly equal eigen values should be clearly above the noise floor seen in the spectrum and (ii) the corresponding pair of eigen vectors should be in phase quadrature.

The reality of QBO in the data analyzed passes these two guidelines without ambiguity. The time variations of the strength of the QBO signal which is almost absent in certain years (Fig. 7) just before 1965 and is significantly present over certain periods of time as seen around 1980 in Sq(D) range. Also, the presence of QBO in the data sets analyzed has been brought out by an alternate approach of digital filtering.

Time evolutions of QBO signal analyzed by a band pass digital filter at Trivandrum, Kodaikanal, Annamalainagar and in sunspot numbers for Sq (H) ranges and summed ranges are shown in figures 8 and 9 in which Kodaikanal having lack of data available only from 1970. A QBO like periodicity with varying amplitude of ~ 26-months in the Sq (H) ranges, summed ranges at all these stations and in sunspot numbers is observed. The signal is stronger at Trivandrum as compared to Kodaikanal and Annamalainagar in both the Sq(H) ranges and summed ranges and is consistence with the solar cycle variations. As Alibag having long series of data (71 years) we therefore, analyzed it separately and the time evolutions of QBO signal in sunspot numbers, Sq ranges and summed ranges for D, H and Z are shown in Figs.10 and 11. Once again a QBO like periodicity of ~ 26-months is detected in the monthly mean quiet day ranges and summed ranges of all the three components D, H and Z and in sunspot numbers at Alibag. From figures 10 and 11 it is clear that the signal is stronger in D and H as compare to Z in both the ranges and summed ranges and is consistent with the solar cycle variations. The largest signal can be seen before 1930 in all the three ranges of D, H and Z, which was also reported by Rangarajan, Veliz & Arora (1996) in the H-component at Huancayo

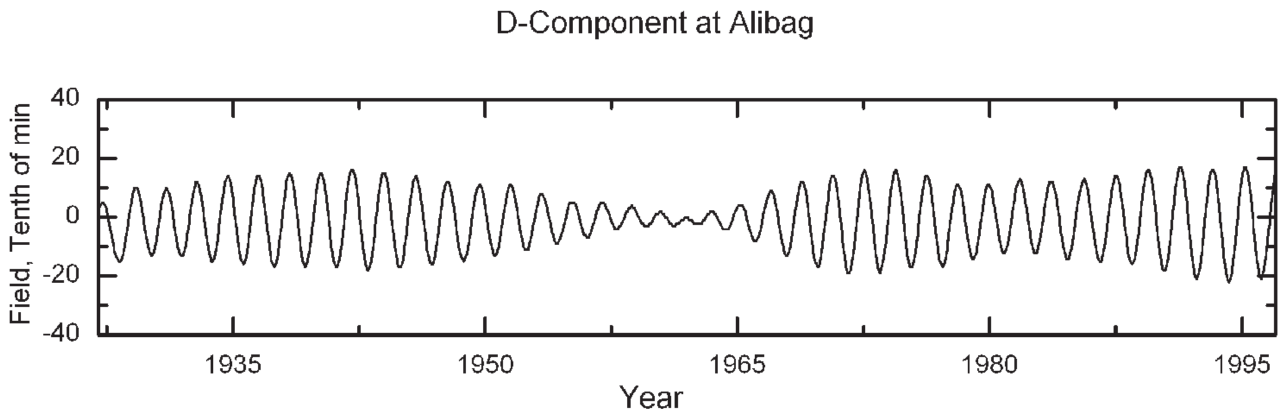

Figure 7. Quasi-biennial oscillation in D-component at Alibag after removing first seven Reconstructed Components.

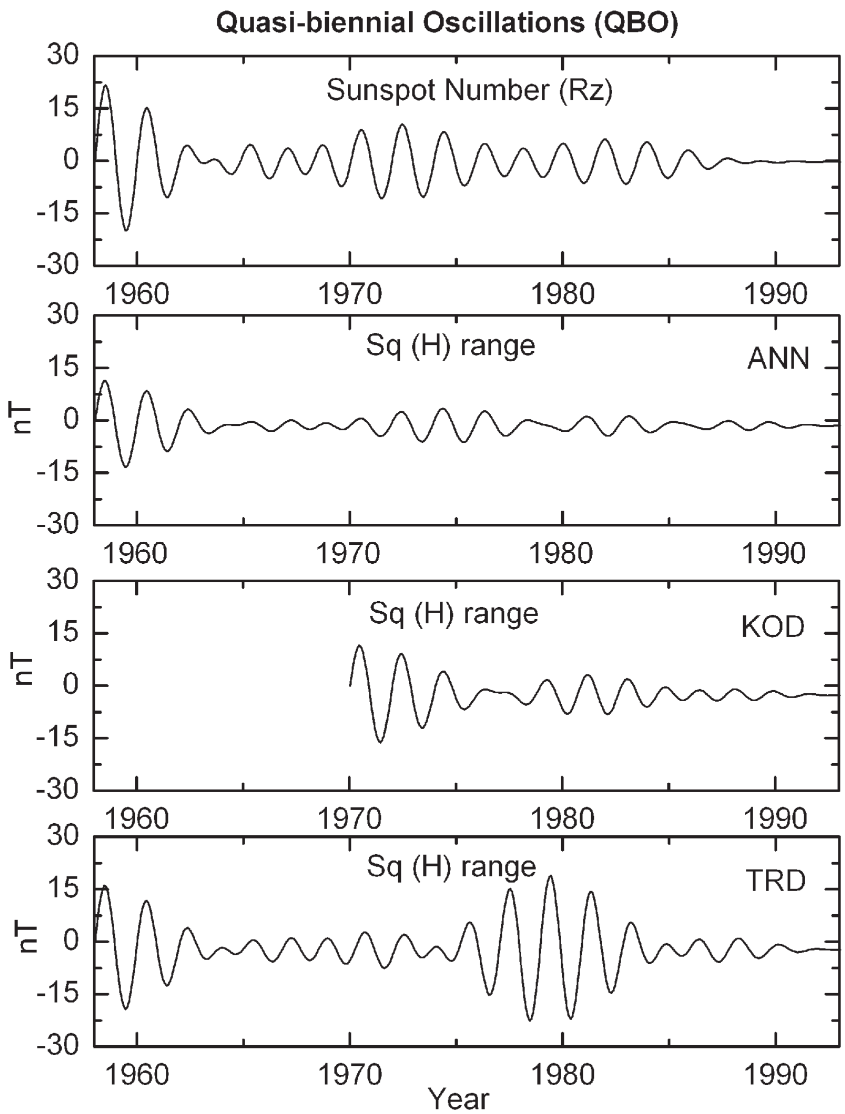

Figure 8. Quasi-biennial oscillation in monthly mean Sunspot numbers (Rz) and in Sq(H) range at Trivandrum, Kodaikanal and Annamalainagar from 1958 to 1993 computed through bandpass filter (24 ± 4) months.

and Alibag. However in the present study, the signal strength is small in Sq (Z) ranges with varying amplitude of about +2 nT to -3 nT (Fig.10). This is significant and real as it is computed by band pass digital filter method using Sq ranges, also its amplitude is more than the experimental error which is around ±1 nT in recording geomagnetic data. Similar variation in amplitude of QBO (Z-component) at Huancayo was observed by Rangarajan, Veliz & Arora (1996). The experimental error in recording geomagnetic data may be more than ±1 nT but as we used ranges so most of the variations are removed. Thus it is no matter whether the amplitude is 2 nT or less as reported by Raja Rao & Joseph (1971). These authors observed QBO with amplitude ~ 0.4 nT at Kakioka which is very small in comparison with 2 nT. The trend in the QBO signal for both the ranges and summed ranges for all the three components are similar but the amplitude of the signal is stronger in summed ranges compared to ranges. The occurrence of the same periodicity in Hq-range and in sunspot numbers was also suggested by Yacob & Bhargava (1968), which we also observed here in both the ranges and summed ranges, which suggests that the source of this QBO like signature is located in the Sun's atmosphere.

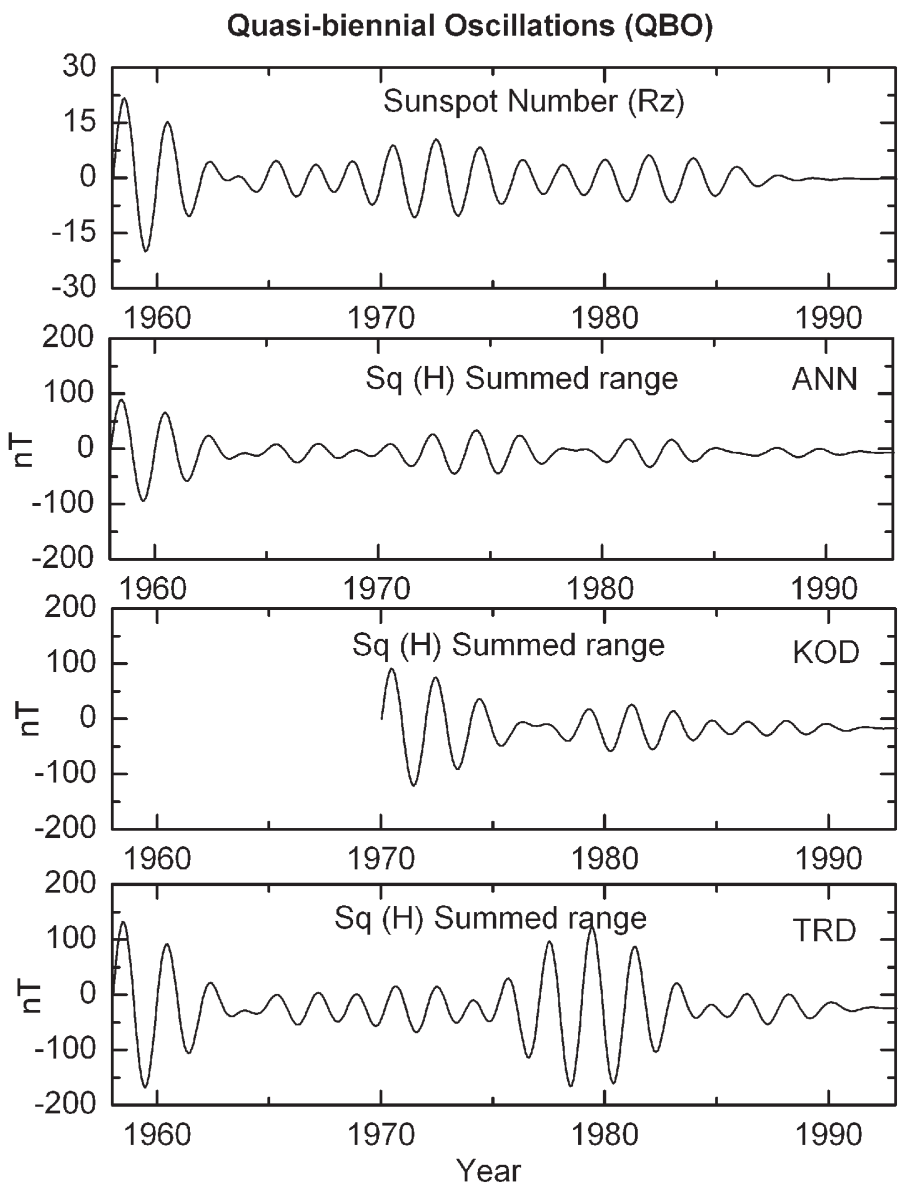

Figure 9. Quasi-biennial oscillation in monthly mean Sunspot numbers (Rz) and in Sq(H) summed range at Trivandrum, Kodaikanal and Annamalainagar from 1958 to 1993 computed through bandpass filter (24 ± 4) months.

SUMMARY AND CONCLUSIONS

After combining Principal Components 14 and 15 a QBO like signal with a quasi-periodicity of ~ 24-month has been detected in Sq (D)-range spectrum at a low latitude station Alibag. This signal is identified more clearly after removing the first seven reconstructed components as shown in Fig.7. In order to explain the source of this oscillation, Sq ranges, summed ranges at all the stations and monthly mean sunspot numbers are also examined by band pass digital filter method. Results show that a QBO signal with varying amplitude (period 24 to 26-months) occurs at all the stations in Sq ranges and summed ranges and also in the monthly mean sunspot numbers. The signal is stronger at Trivandrum in comparison with other stations. However at Alibag the peak to peak variations are not seen in sunspot numbers and Sq (D) and Sq(Z) ranges, but Sq(H) ranges show clear peak to peak variation with sunspot

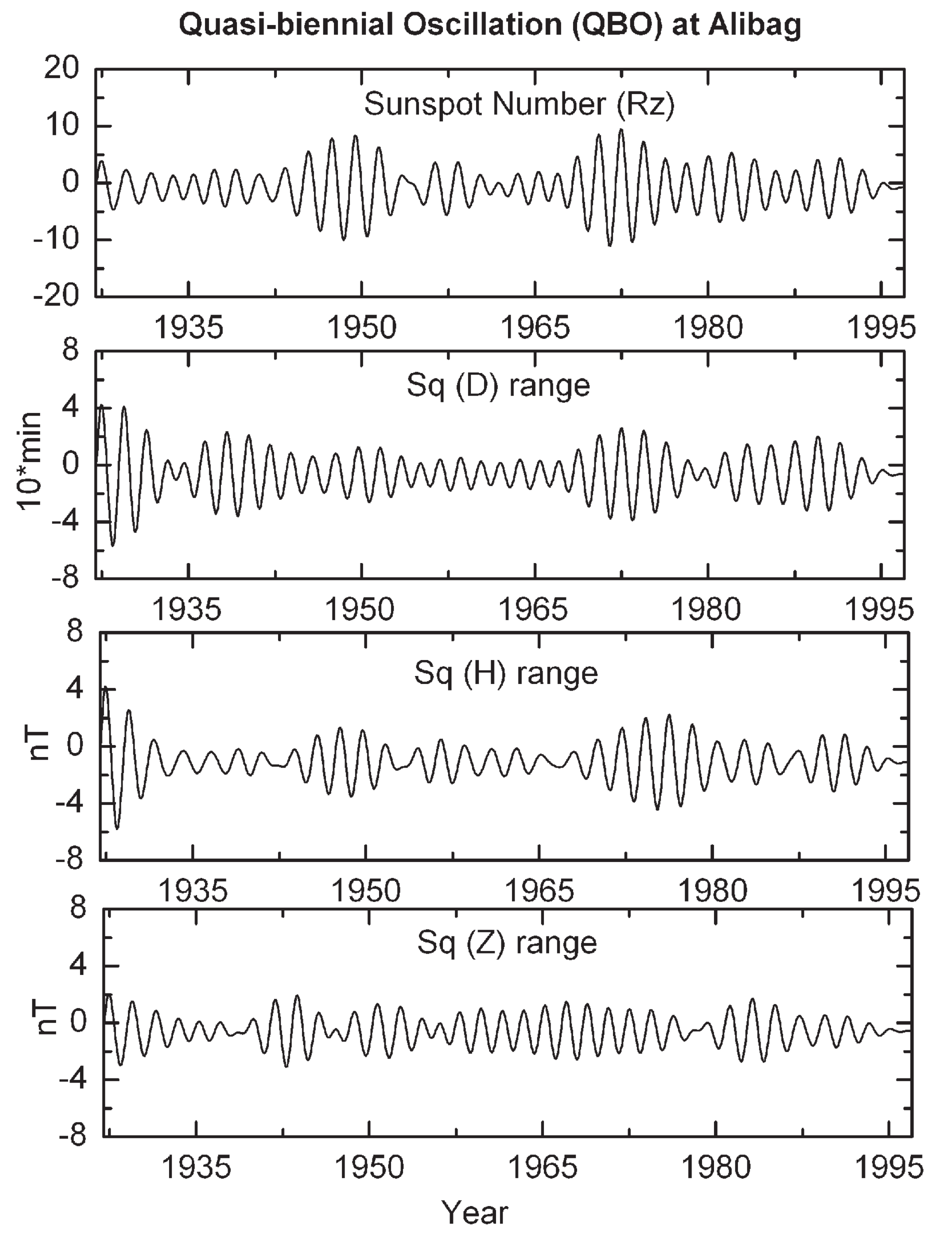

Figure 10. Quasi-biennial oscillation in monthly mean Sunspot numbers (Rz) and Sq ranges in D, H and Z components at Alibag from 1927 to 1997 computed through bandpass filter (24 ± 4) months.

numbers at all the equatorial and low latitude stations with maximum amplitude near 1930, 1950 and before 1980. It is noticed that the signal is stronger at equatorial stations in comparison to low latitude station Alibag, also at Alibag the signal is stronger in D and H than in Z and is consistence with the solar cycle variations. Our results are in disagreement with the results of Rangarajan et al., (1996) in which they reported that the QBO signal at Huancayo and Alibag do not show overall coherence with QBO in sunspot numbers and the solar activity is not the sole cause for the observed QBO in H at low and equatorial latitudes. However, these results were for all day field and not for quiet day field. They also pointed out that, the signal should be stronger in the quiet day field than in the disturbance field which we also observed here in quiet day field and in agreement with the results reported by (Yacob & Bhargava 1968).

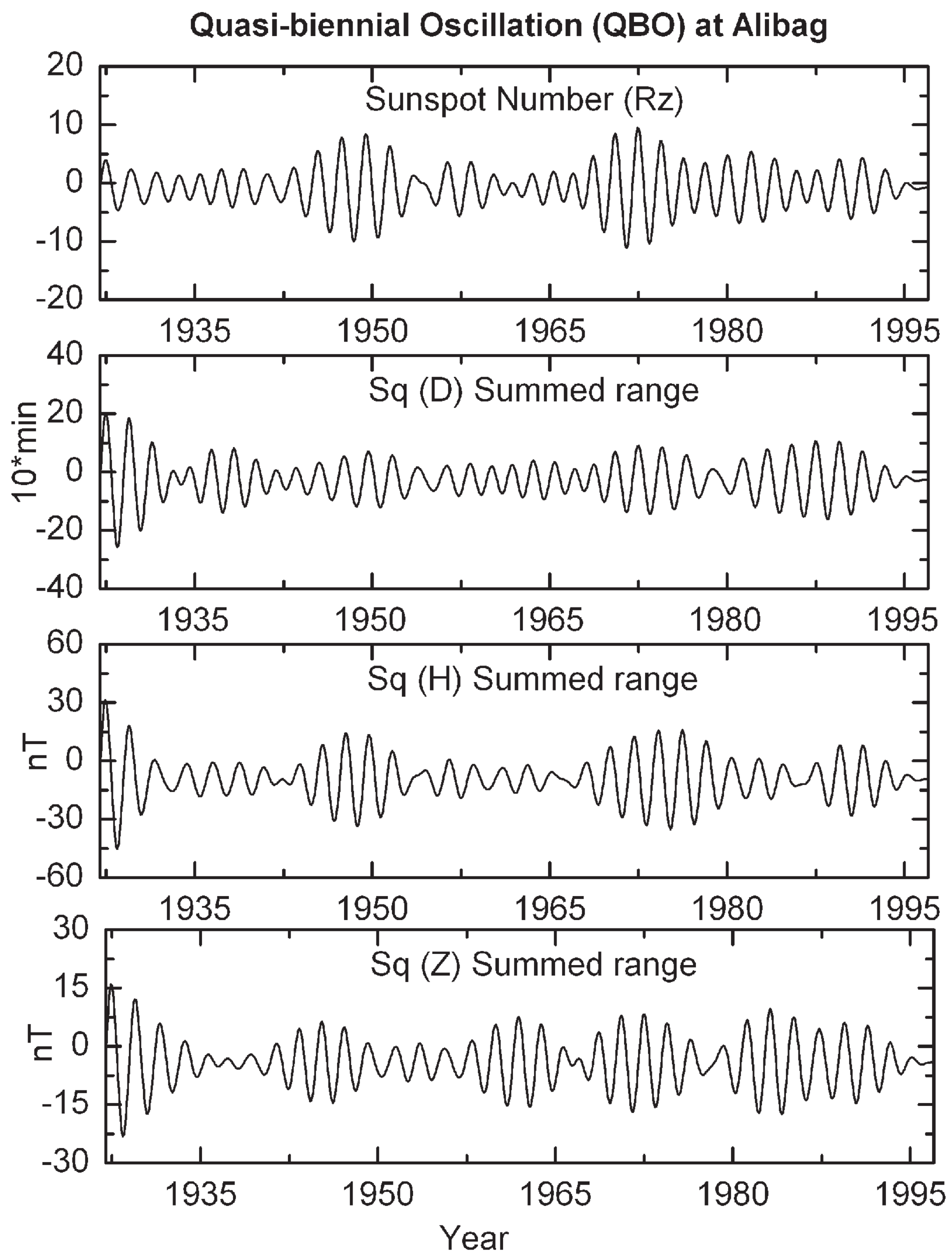

Figure 11. Quasi-biennial oscillation in monthly mean Sunspot numbers (Rz) and Sq summed ranges in D, H and Z components at Alibag from 1927 to 1997 computed through bandpass filter (24 ± 4) months.

ACKNOWLEDGEMENTS

The author is thankful to Prof. G. K.Rangarajan and Prof. B.R.Arora, Director, Wadia Institute of Himalayan Geology, Dehradun, India for many fruitful discussions and suggestions. I thank Prof. Harish Chandra for his helpful comments and suggestions for improvement of the manuscript.

REFERENCES

Bhardwaj, S.K., 2006. Parameterization and sources of equatorial and low latitude geomagnetic oscillations, Ph.D thesis, Mumbai University, 37 – 40.

Bhardwaj, S.K. &. Rangarajan., G.K., 1997. Geomagnetic Secular Variation at the Indian Observatories, J. Geomag. Geoelectr., 49, 1131-1144.

Bhargava, B.N. & Yacob, A., 1969. Solar cycle response in the horizon-tal force of the earth's magnetic field, J. Geomag. Geoelectr., 21, 385-397.

Bhargava, B.N. &Yacob, A., 1970. The secular variation of the magnetic field and its cyclic components, J. Atmos. Terr. Phys., 32, 365-372.

Bhargava, B.N., 1970. The semi-annual oscillation in the horizontal intensity of earth's magnetic field, J. Atmos. Terr. Phys., 32, 1849-1893.

Bhargava, B.N., 1972. Semi-annual component of the earth's magnetic field and its generating mechanism, Indian J. RadioSpace Phys., 1, 9-11.

Bhargava, B.N., Rao,D.R.K.& Arora, B.R., 1973. Semi-annual modulation of earth's magnetic field in the equatorial electrojet region, Planet. Space Sci., 21, 1251-1255.

Broomhead, D.S. &King, G., 1986. Extracting qualitative dynamics from experimental data, Physica (D)., 20, 217-236.

Chapman, S. & Bartells, J., 1940. Geomagnetism, Vol. 1, Oxford Univ Press, London.

Currie, R.G., 1966. The geomagnetic spectrum- 40 days to 5.5 years, J. Geophys. Res., 71, 4579-4598.

Currie, R.G., 1973. Geomagnetic line spectra- 2 to 70 years, Astrophys. Space Sci., 21, 425-438.

Gleissberg, W., 1965. The eighty-year cycle in auroral frequency numbers, J. Brit.Astr.Assoc., 75,227.

Hibberd, F.H., 1985. The geomagnetic Sq variation- annual, semi-annual and solar cycle variation and the ring current effects, J. Atmos. Terr. Phys., 47, 341-352.

Jarvis, M.J., 1996. Quasi-biennial oscillation effects in the semidiurnal tide of the Antarctic lower thermosphere, Geophys. Res. Lett., 23, 2661-2664.

Jarvis, M.J., 1997. Latitudinal variation of quasi-biennial oscillation modulation of the semidiurnal tide in the lower thermosphere, J. Geophys. Res., 102, 27,177-27,187.

Kane, R.P., 1995. Quasi-biennial Oscillation in ionospheric parameters measured at Juliusruh (55° N, 13° E), J. Atmos. Terr. Phys., 57, 415-419.

Kane, R.P., 1996. Quasi-biennial Oscillation in quiet-day ranges of low latitude geomagnetic H component, Ind. J. Radio Space Phys., 25, 101-105.

Nastrom, G.D. & Belmont, A.D., 1976. The influence of long-period dynamo region winds on the surface geomagnetic field elements, J. Geophys. Res., 81, 4800-4804.

Olsen, W.P., 1970. Variations in the Earth's surface magnetic field from the magnetopause current system, Planet Space Science., 18, 1471-1484.

Olsen, N., 1994. A 27-month periodicity in the low latitude geomagnetic field and its connection to the stratospheric QBO, Geophys. Res. Lett., 21, 1125-1128.

Rajarao, K.S. & Joseph, K.T., 1971. Quasibiennial oscillation in the geomagnetic Sq field in the low latitude region, J. Atmos. Terr. Phys., 33, 797-805.

Rangarajan, G.K., 1985. Quasi-biennial oscillation in geomagnetic disturbance field, Proc. Indian Acad. Sci. (Earth Planet. Sci.), 94, 29 – 34.

Rangarajan, G.K., 1994. Singular spectral analysis of homogeneous Indian monsoon (HIM) rainfall, Proc. Indian Acad. Sci. (Earth Planet. Sci.), 103, 439 – 448.

Rangarajan, G.K., Veliz, O. & Arora, B.R., 1996. Geomagnetic secular variation and field oscillations of the external origin at Huan-cayo, Peru. Brazilian J.Geophys. 14(1), 29-40.

Rangarajan, G.K. and Araki, T., 1997. Multiple timescales in the fluc-tuations of the equatorial Dst index through singular spectrum analysis, J. Geomag. Geoelect., 49, 3-20.

Rao, D.R.K. & Rangarajan, G.K., 1978. The pole tide signal in the geomagnetic field at a low latitude station, Geophys .J .R. Astr. Soc., 53, 617-621.

Sharma, A.S.,Vassiladis, D. &. Papadapoulous. K., 1993. Recostruction of low dimensional magnetospheric dynamics by singular spectral analysis, Geophys. Res. Lett., 20, 335-338.

Subramaniam, M., 1993. Multiple time scales in rainfall variability, Proc. Indian Acad. Sci. (Earth Plant. Sci)., 102, 249-263.

Sugiura, M., 1976. Quasi-biennial geomagnetic variation caused by the Sun, Geophys. Res. Lett., 3, 643-647.

Sugiura, M. & Poros.D.J., 1977. Solar generated quasi-biennial geomagnetic variation, J. Geophys. Res., 82, 5621-5628.

Vauatard, R. & Ghil.M., 1989. Singular spectrum analysis in nonlinear dynamics, with applications to

paleoclimatic time series, Physica (D)., 35, 395-424.
Vautard, R., Yiou, P. & Ghil. M., 1992. Singular spectrum analysis: A toolkit for short, noisy chaotic signals, Physica (D)., 58, 95-126.
Yacob, A. & Bhargava, B.N., 1968. On 26-month periodicity in quiet day range of geomagnetic horizontal force and in sunspot number, J. Atmos. Terr. Phys., 30, 1907-1911.

(Revised accepted 2009 July 10; Received 2008 October 25)

Dr. S.K.Bhardwaj joined the Indian Institute of Geomagnetism, Bombay (presently Mumbai) in July 1990 and is currently working as Technical Officer-III. He was born in 14th June 1962 at Bareilly, Uttar Pradesh. He obtained his first class B.Sc in 1981 and first class M.Sc (Physics) degree in 1983 from Rohilkhand University, Bareilly (U.P). He was awarded Ph.D. (Science) Degree in physics from Mumbai University, Mumbai in 2006 under the supervision of Prof. B. R. Arora. His areas of research interest are geomagnetic field variations such as: Secular variations and current systems in the ionosphere, especially Sq current system and equatorial electrojet. Before joining IIG, he has worked as a lecturer at different colleges in U.P and taught theory and practical to B.Sc and M.Sc classes with ~3 years teaching experience of Undergraduate and ~2 years of postgraduate students. He joined as a Research Scholar in 1988 under the guidance of Prof. R. K. Rai in UGC Special Assistance program and worked on the problems of absorption of Radio waves in the Ionosphere in the College of Science, Sukhadia University, Udaipur (Raj). He has published 4 papers in National and International journals and ~ 24 papers were accepted in National and International conferences in which ~ 17 papers were presented. He also attended and presented a paper in XXIII IUGG General Assembly during June 30 - July 11, 2003 at Sapporo, Japan. He is having ~ 20 years of research experience in the field of Ionospheric absorption, Scintillations and Geomagnetic field variations.