4.0 SOLAR AND MAGNETIC ACTIVITY DEPENDENCE OF SCINTILLATION

4.1 Solar activity dependence of ionospheric scintillation:

4.1.1 Introduction:

Dependence of ionospheric scintillation with varying solar activity have been reported by many workers well scattered all over the world. But interestingly, this dependence varies rather inconsistently with latitude and longitude. However, a general picture may be obtained from the available reports. The average occurrence of scintillation is higher in a year of higher sunspot number (Aarons et al., 1971; Kullen and Hawkins, 1979; Koster, 1978). From equatorial observations, Koster (1968) reported a six fold increase in summer scintillation at S.I. 50 p.c. level and an eight fold increase at 70 p.c. level from 1965, a period of lowest solar activity to 1967 which was very near to the peak phase of the solar cycle. While analysing the VHF scintillation data over a long period at Huancayo, an equatorial station, Rastogi (1982) observed that average nighttime scintillation index decreases with decreasing sunspot number. But in the Indian sector Pasricha and Reddy (1981) observed inconsistent control of solar activity over scintillation at Ooty, a station very near to the magnetic equator. Again, Rastogi (1982) also reported no definite solar activity control over daytime scintillation at Huancayo. Now at high latitude, as Briggs (1964) observed through radio star scintillation over a complete solar cycle, the mean value of scintillation index is higher at sunspot maximum. He also reported a change in the diurnal occurrence curves of scintillation with varying sunspot number. At sunspot maximum period, scintillations were
observed during day as well as night while in the lowest sunspot number period scintillations were confined mostly within the night-time. Earlier investigations (Chivers, 1960) also showed positive correlation of scintillation activity with sunspot number at high latitudes similar to most of the equatorial observations. Aarons (1977) found that increasing solar activity tends to smooth the latitudinal variation of scintillation activity. Against these mostly positive correlation with solar activity at equatorial and high latitudes, scintillations at some low-mid latitude stations exhibit negative correlation with sunspot number (Tyagi, 1967; Chan, 1970; Dutta et al., 1978). Sometimes no consistent trends were observed with changing solar activity at some low-mid latitude stations (Mullen and Hawkins, 1975; Paulson, 1979, 1980). From Calcutta, a station under the northern crest of the Appleton anomaly belt, Das Gupta et al. (1981) reported significant change in seasonal behaviour of scintillation activity near the equinoxes with varying sunspot number. Thus, it appears at high latitudes correlation between scintillation and solar activity is positive while at the equatorial zone correlation is positive to inconsistent depending upon longitude and perhaps observation period. At low-mid latitudes the relationship between the two events may vary from negative to inconsistent trends.

4.1.2 Solar activity dependence of VHF scintillations observed at Gauhati:

To study the dependence of ionospheric scintillation on solar activity at VHF, the data recorded throughout the period from September, 1979 to December, 1982 have been utilised. This observation period coincided with the peak to declining phase of
the solar cycle No. 21.

Fig. 18 shows the peak p.c. of occurrence of nocturnal scintillation with S.I. exceeding just detectable level, about 2 p.c. (since p.c. of occurrence of scintillation is low at this station) against respective monthly mean values of $R_I$, the international sunspot number. From the figure as a whole no consistent trend of scintillation occurrence with varying solar activity could be ascertained. Still a seemingly positive correlation with sunspot number can be observed in few months, namely, October, November, January and April. In other months (i.e. December, February, May, June, July and August) inconsistent correlation between the two activities may be observed from the figure. The most obvious feature that can be noted from the figure is that the dominant variation of scintillation occurrence is seasonal and is not controlled by solar activity. It is also noteworthy that during local seasonal peak or high activity period of scintillation, sunspot number variation seems to have no definite influence over scintillation occurrence. But during winter months when scintillation activity is very low, its occurrence seems to have positive correlation with sunspot number. This is also noticed in equinoctial month of April, when scintillation occurrence is comparatively low. But during other equinoctial months February and August, when scintillation activity is relatively high, same inconsistent trends as in summer months are observed.

To study the response of daytime scintillation to the variation of solar activity, monthly peak p.c. of occurrence of scintillation events with S.I. exceeding 2 p.c. level during daylight hours are plotted against respective mean values of $R_I$ for each year of observation (Fig.19). From the figure it is seen
Fig. 18: Histograms showing yearly mean p.c. of occurrence of night-time (S.I.>2p.c.) scintillation against yearly mean sunspot number. Blank bars indicate sunspot number while shaded bars indicate scintillation.
Fig. 19: Histograms showing yearly mean occurrence p.c. of daytime scintillation (S.I. > 2 p.c.) against yearly mean sunspot number. Blank bars indicate sunspot number and shaded bars indicate scintillation.
that daytime scintillation occurrence exhibits more or less definite positive correlation with sunspot number except during the months of February, June, July and August. In these months like nocturnal scintillation, daytime scintillation occurrence does not show any consistent trend with sunspot number. Seasonal variation is dominant than solar activity changes in these cases too. It is very difficult to draw any overall conclusion about sunspot number control of daytime scintillation in view of mixed trends as seen from Fig. 19.

Fig. 20 through 23 show the response of scintillation index to the sunspot number and solar flux at 10.7 Cm wavelength (2800 MHz) on a day to day basis. In these representative plots, daily mean and standard deviation of S.I. are plotted against respective sunspot number and solar flux at 10.7 Cm. From Fig.20 it seems that day to day variation of solar activity fails to dictate any consistent trend of variation of S.I. in autumnal equinox (September of 1979). Inspite of this inconclusive nature, occasional positive correlation between S.I. and sunspot number may be observed. Fig. 21 reflects the definite positive correlation of S.I. with sunspot number and also with 10.7 Cm flux (in a rather subdued manner) in the winter month of November of 1979. From Fig. 22, it is seen that during the vernal equinoctial month of February (of 1980), S.I. during nighttime varies with solar activity in an inconsistent manner. Here also occasional positive correlation between the two parameters may be observed. Any influence of 10.7 Cm flux over S.I. cannot be distinguished. The nature of variation of S.I. with solar activity during the summer month of May, 1980 is very interesting as shown in Fig. 23. The correlation was mostly negative during that period between the
Fig. 20: Mean and standard deviation of daily S.I. plotted against 10.7 cm solar flux and sunspot number ($R_1$) during the month of September, 1979.
Fig. 21: Day-to-day variation of S.I. shown against daily sunspot number (RI) and 10.7 cm solar flux during the winter month of November (1979).
Fig. 22: Day to day variation of S.I. shown against daily sunspot number \( R_I \) and 10.7 cm solar flux during the vernal equinoctial month of February (1980).
Fig. 23: Day-to-day variation of S.I. shown against sunspot number (Ri) and 10.7 cm solar flux during the month of May (1980).
Fig. 24: Yearly mean scintillation occurrence (S.I. > 2 p.c.) shown against yearly mean sunspot number ($R_I$).
From the above observations, it may be concluded that during a high solar activity period occurrence and intensity of amplitude scintillation have positive correlation with sunspot number in winter. During equinoctial months no definite relationship between the two parameters could be established. In summer months, occurrence of scintillation may have inconsistent trend with solar activity but intensity of scintillation generally exhibits negative correlation with sunspot number on a day to day basis. But the observation over entire period from September, 1979 to December, 1982 shows that with falling sunspot number one may generally expect to see decreasing scintillation activity on a year to year basis as is evident from Fig. 21. One note of caution about the nocturnal scintillation activity in the year 1979 as shown in Fig. 21, may be raised here. The mean scintillation occurrence for that year includes the month of September, which was a month of very high scintillation occurrence, while in the other years this month is not included due to unavailability of data. However, this imbalance is compensated to some extent as the year 1979 data did not include summer months like the subsequent years. It is recalled that summer months show high scintillation activity. Fig. 21 shows mean nocturnal scintillation occurrence over entire period of observation on a yearly basis.

4.1.3 Discussion:

From the results presented above it has become evident that scintillation activity at this station exhibits a complex sunspot cum seasonal behaviour during a high solar activity period. In winter months scintillation activity as well as S.I. increases with sunspot number, an observation contrary to reports of few
workers (Tyagi, 1967; Walker and Chan, 1970; Lal et al., 1974) who analysed limited data from orbiting satellites received from similar geographic latitudes. These workers observed negative correlation of S.I. and p.c. of occurrence of scintillation with solar activity. Dutta et al. (1978) also reported similar negative correlation. But Das Gupta et al. (1981) from Calcutta (27°N dip) reported increase in scintillation occurrence in winter months, an observation similar to the present finding. At this station with limited data during equinoctial months, solar activity seems to have no definite control over scintillation activity. This is in agreement with some reports from low latitude investigators e.g. Paulson (1979, 1980), Pasricha et al. (1980), Mullen and Hawkins (1975). As for the summer months, the intensity and occurrence of amplitude scintillation exhibit occasionally negative correlation with sunspot number. When the mean scintillation occurrence is considered on a year to year basis it is seen that nocturnal scintillation occurrence is higher in a year of higher sunspot number. For example, from Fig. 24 it is seen that yearly mean nocturnal scintillation occurrence with S.I. exceeding 2 p.c. falls from about 26 p.c. in 1980 to its almost half value of about 13 p.c. occurrence in 1982 as yearly mean sunspot number falls by a factor of 1.5. Thus the solar cycle control of scintillation activity at this station does not emerge as a clearcut relationship at least during a high solar activity period. Future observation during a low solar activity period at similar radio wavelength should be able to clear many confusions.
4.2 Magnetic activity dependence of scintillation

4.2.1 Introduction:

The irregularities which give rise to ionospheric scintillations are generally geomagnetic field aligned in nature. These are elongated along the magnetic field lines in the north-south direction with axial ratio as high as 60:1 (Koster, 1963). Thus geomagnetic field variations play a major role in generation and dynamics of these irregularities. In fact latitudinal and perhaps longitudinal variation of global scintillation zones are believed to be manifestation of magnetic dependence of the scintillation causing ionospheric irregularities.

At high latitudes it has been observed that scintillation activity bears a positive correlation with magnetic parameter $k_p$ (Liszka, 1963; Beynon and Jones, 1964; Yeh and Swenson, 1964; Frihagen, 1971; Aarons et al., 1971). At the geomagnetic equator however, the correlation is negative (Koster and Wright, 1960, 1963). At Legon (geom. lat. 5.63°N), Koster (1971) has observed a negative correlation in night hours but no significant relationship with daytime scintillation. But Mullen (1973) observed increase in scintillation activity during June solstice with increase in magnetic activity at Huancayo, in the equatorial region. Similar to the reports from Ghana (Koster, 1972), observations at Huancayo also showed that the general effect of magnetic activity appears to be a suppression of seasonal variation of scintillation activity with an annual distribution towards uniformity (Mullen, 1973; Mullen and Whitney, 1974). While other studies, analysing long-term data from the same station show statistically insignificant magnetic activity dependence (Bandopadhyay
and Aarons, 1970; Aarons, 1976). A limited study in the Indian sector, observations at the equatorial station Thumba show negative correlation of scintillation with magnetic activity (Chandra and Rastogi, 1974). But another study from Ooty, an equatorial station, at UHF over medium to low sunspot activity revealed insignificant magnetic activity control on scintillation (Pasricha et al., 1982). From observations made at low-mid latitude station Kurukshetra, Lal et al. (1974) reported negative correlation of average S.I. with $k_p$.

4.2.2 Magnetic activity dependence of ionospheric scintillation at VHF over Gauhati:

For the study of magnetic activity control of scintillation, data are divided into three groups - premidnight hours, from 1800 Hrs to 0000 Hrs, postmidnight hours, from 0000 Hrs to 0600 Hrs and daytime hours, from 0600 Hrs to 1800 Hrs. As the Fig. 25 through 27 show the histograms representing each group separately depicting magnetic activity dependence of scintillation occurrence throughout all seasons averaged over entire period of observation. For studying the magnetic activity dependence, the hourly $D_{st}$ index (Sagiura and Poros, 1971; Mullen, 1973) was chosen as a convenient magnetic parameter instead of three hourly index $k_p$. An hour is considered to be disturbed if $D_{st}$ value is less than -20 and for $D_{st}$ greater than -20, it is considered quiet. This arbitrary scale is similar to Mullen's (1973) study.

From Fig. 25 it is seen that scintillation exhibits negative correlation with magnetic parameter in the premidnight hours of winter and equinoctial months in years of high solar activity. Interestingly, in summer scintillation occurrence during
Fig. 25: Histograms showing p.c. of occurrence of premidnight scintillation (S.I.) 2 p.c. during magnetically quiet (Q) and disturbed (D) hours.
Fig. 26: Histograms showing p.c. of occurrence of postmidnight scintillation (S.I. > 2 p.c.) during quiet (Q) and magnetically disturbed (D) hours.
FIG. 27: Histograms showing p.c. of occurrence of daytime scintillation (S.I. > 2p.c.) during quiet (Q) and magnetically disturbed (D) hours.

T - Total p.c. of occurrence
Q - P.C. of occu. in quiet hours.
D - " " " disturbed "

FIG.27: Histograms showing p.c. of occurrence of daytime scintillation (S.I. > 2p.c.) during quiet (Q) and magnetically disturbed (D) hours.
premidnight hours shows slightly positive correlation with magnetic activity, admittedly which is insignificant. The situation becomes even more interesting as Fig. 26 suggests. In the postmidnight hours during winter and equinoctial months scintillation occurrence shows distinct positive correlation with magnetic activity which is just opposite to premidnight characteristic. During same period of summer months negative correlation between the two events is observed as Fig. 26 shows. Now from these findings, if one tries to average the premidnight and postmidnight hours throughout the year, one finds that there is little or no difference between quiet and disturbed period responses of scintillation activity. But from Fig. 27 it is observed that daytime scintillation activity shows positive correlation with magnetic activity clearly irrespective of seasons.

4.2.3 Scintillation activity during severe geomagnetic storms:

Behaviour of scintillation activity during the great magnetic storms of 19-20 December, 1980 and 11-14 April, 1981 is examined in detail. It was observed that both storms triggered intense and long duration amplitude scintillation. Faraday polarization fluctuations were also observed.

Fig. 28 shows the scintillation activity during the 19-20 December, 1980 magnetic storm. This storm was characterized by swing of H value as much as 542 nT as the Hyderabad magnetogram shows (Shrivastava, 1982) or peak Dst value to -248. It may be noted that normally in the month of December, scintillation is scarce even during nighttime. But during the storm period intense to moderate amplitude scintillations were observed over long period up to about local noon. It is seen that (Fig. 28) almost
Fig. 28: Scintillations observed during great magnetic storm of 19 - 20 December, 1980.
Fig. 29: Scintillations observed during great magnetic storm of 11 - 14 April, 1981.
explosive start of scintillation occurred about one hour after the D_{st} peak. Scintillation index reached as high a value as about 82 p.c. during local predawn hours.

Fig. 29 depicts the scintillation behaviour during 11-14 April, 1981 great magnetic storm. This storm was the strongest, after the one of August, 1972. The peak D_{st} value reached as high as -290. The maximum phase of the storm was observed even before the storm fully developed at the equator. This is quite different from the 19-20 December, 1980 storm time behaviour. In this case also intense scintillations were observed with S.I. value exceeding 90 p.c., i.e. peak to peak fade 12 dB during daylight hours of 12 April, 1981 which was well ahead of equatorial D_{st} minor peak at about local noon. Interestingly on 13 April, 1981, when the storm developed to its peak phase (D_{st} value reached -290) at about 1300 Hrs LMT, comparatively less intense scintillations were observed with S.I. about 60 p.c. (6 dB), after about 7 hours from the equatorial D_{st} peak. Towards the dying part of the storm (14-15 April) no significant scintillation activity was observed.

4.2.4 Discussion:

Magnetic dependence of nocturnal VHF scintillation activity at this station appears to be complex. The most obvious effect that has been observed here is that during premidnight hours of December solstice and equinoxes magnetic activity reduces scintillations while during postmidnight hours of same periods, magnetic activity enhances scintillation occurrence. In summer months the situation is reversed in either case. A very nearly similar finding was reported by Rastogi and Mullen (1981) while analysing equatorial data. But little or no significant dependence of
scintillation activity on magnetic variations can be found if one averages the nocturnal data over whole night throughout the year. This is also in agreement with Mullen's (1973) finding at equatorial station, Huancayo. As Fig. 24 shows, daytime scintillation bears positive correlation with magnetic activity all around the year. Apparently anomalous behaviour of nighttime scintillation during summer is difficult to understand. There is nothing in support to Mullen's finding in the equatorial zone that magnetic activity tends to suppress the seasonal variation of scintillation towards uniform annual distribution. From the two magnetic storm associated studies, it has been observed that strong magnetic disturbances can trigger generation of irregularities even during December solstice (when nighttime scintillation itself is rare) giving rise to intense scintillations even during sunrise period. In both the cases it was observed that the onset of scintillation was explosive with high fade rates (4 to 3 fades per minute at times) and it continued over long periods. Towards the end of the activity fade rate fell to less than one fade per minute. Das Gupta et al. (1983) also reported saturated amplitude scintillation during April, 1981 storm in equatorial station, Huancayo. The remarkable feature of the scintillation behaviour during both the storms, was the accompanying phase scintillations and abnormal IEC variations which are discussed in a later chapter. To explain the dawntime scintillation and abnormally high IEC build up rate as observed in the morning of 20 December, 1980, Barbara et al. (1983) suggested injection of plasma from the magnetosphere to ionosphere (Kane, 1976). This generated during magnetic storms are also related to the gravity waves (George, 1968; Thome, 1968) originating at high latitudes.
Considering the lag in the onset time of scintillation from the onset of the main phase of the storm, it is seen that the TIDs responsible for causing scintillations at this station are generated in the auroral zone and then propagated to lower latitude-s with an average velocity of 440 m/s in the case of the December, 1980 storm and corresponding velocity during April, 1981 storm work out to be 350 m/s. Considering this and the observed quasi periodic IEC fluctuations with a period of about two hours, it may be concluded that the irregularities are triggered by gravity waves. Onset of range type spread-F in the case of December, 1980 storm (Fig. 28) along with scintillations indicate that spatial resonance mechanism was effective during that period. Due to unavailability of ionograms during April, 1981 storm the possibility of such a resonance mechanism could not be ascertained.