Ionospheric scintillation and associated total electron content fluctuations at Tokyo

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The phenomenon of TEC fluctuations (Faraday polarization fluctuations) associated with strong amplitude scintillations is investigated for a station outside the equatorial anomaly belt. It is shown that the two phenomena are well correlated in the nocturnal variation as well as in the seasonal variation of their occurrence. The scintillation index is found to vary linearly with TEC fluctuation amplitude. An attempt is made to interpret the Faraday polarization fluctuations in terms of the mechanism proposed by Lee et al. [Radio Sci (USA), 17 (1982) 399].

1 Introduction

Fluctuation of Faraday rotation angle of received transionospheric VHF signal associated with amplitude scintillation at an equatorial station, Ghana, was first reported by Amankwah and Koster. Several workers have subsequently reported association between TEC depletions and scintillations in the nighttime equatorial and low latitude ionosphere particularly during high sunspot year and identified these depletions with the plasma bubble or plume phenomena in the equatorial ionosphere, first reported by Woodman and LaHoz. Many workers have reported intense and fast fluctuations of the Faraday rotation angle in association with strong amplitude scintillations at stations near the crest of the equatorial anomaly and their absence at stations close to the magnetic equator. These two phenomena even coexisted with L band scintillations at Ascension Island (31°S dip). An explanation for these fast Faraday polarization fluctuations (FPFs) at VHF has been advanced as due to scattering by small scale (< 200 m) density irregularities with a power law spectrum. Similar FPFs associated with strong amplitude scintillations have been reported by Sinno and Kan for a lower midlatitude station Tokyo (subionospheric geomagn. lat. 23.5°N) which may be beyond the crest of the equatorial anomaly. In this paper this phenomenon has been investigated in more detail for the station Tokyo and an attempt has been made to examine its origin in the mechanism proposed by Lee et al.

2 Data and method of analysis

Published data of ionospheric electron content and scintillations at 15-min intervals at Koganei, Tokyo (geographic lat. 35.71°N, geographic long. 139.49°E, and subionospheric geomagn. lat. 23.16°N) for the year 1979 have been used in the present study. This location is outside the equatorial anomaly region and hence outside the region of equatorial bubble phenomena. Whenever fluctuations of Faraday rotation angle took place, they were converted into corresponding electron content fluctuations categorized into A, B, C, D and E types as follows:

- A: \(1.49 \leq \Delta \text{TEC} < 2.99\)
- B: \(2.99 \leq \Delta \text{TEC} < 5.98\)
- C: \(5.98 \leq \Delta \text{TEC} < 12.00\)
- D: \(12.00 \leq \Delta \text{TEC} < 23.90\)
- E: \(23.90 \leq \Delta \text{TEC}\)

where \(\Delta \text{TEC}\) is the fluctuation in total electron content expressed in \(10^{15} \text{m}^{-2}\).

The scintillation index (SI), defined as \(\text{SI} = P_{\text{max}} - P_{\text{min}}\) (where \(P_{\text{max}}\) is the power amplitude of the third peak down from the maximum excursion in dB, and \(P_{\text{min}}\) is the power amplitude of the third level up from the minimum excursion in dB) at the time of these TEC fluctuations was also noted. A typical example of the temporal variation of TEC fluctuation and scintillation on a given night is shown in Fig. 1. Both scintillation and TEC fluctuations start around 2030 hrs local time and reach a
maximum around 2200 hrs. It is also clear from the figure that the peak value in both the cases continues for nearly 2 hr and then comes down by 2300 hrs. The correlation coefficient between the SI values and the corresponding TEC fluctuation amplitudes was calculated and found to be 0.72.

During the year 1979 a total of 1137 cases of TEC fluctuations of A, B, C, D and E types were identified of which 92.5 per cent cases were clearly associated with scintillations. The remaining 7.5 per cent cases, which were not associated with scintillations, were of extremely weak A type and hence were insignificant. It may be mentioned that there are instances when scintillations, generally of weak type, occur and they are not associated with TEC fluctuations.

3 Results

A number of occurrences of TEC fluctuations and scintillations in different months during 1979 are compared in Fig. 2. Fluctuations of B, C, D and E types and SI ≥ 5 dB are only taken into account because very weak scintillations are not usually related to TEC fluctuations. The number of occurrences of both are reckoned at intervals of 15 min.

Both scintillation and TEC fluctuation occurrences have exactly identical distributions, maximizing in summer months. It may be noted that there are more scintillation occurrences than TEC fluctuation occurrences in the months of March, April, August, September, October and November.

Fig. 3 shows the temporal variation of nighttime scintillation and TEC fluctuation in the year 1979. This representation again shows clearly the correlation between TEC fluctuations and scintillations. Fluctuations in TEC and scintillation are more frequent around midnight. The correlation coefficient between the two curves is 0.73.
To establish a quantitative relationship between the intensity of scintillations and amplitude of the TEC fluctuations the mean scintillation indices corresponding to TEC fluctuations of A, B, C, D and E types are calculated during the months of June, July and August when both activities are more frequent. A remarkable linear relationship has been found between these two parameters for all the three months and the mean graph is shown in Fig. 4.

4 Discussion and conclusions

Lee et al.\(^{12}\) proposed diffractive scattering by density irregularities with power law spectrum having an outer scale length of \(\approx 200 \text{ m}\) as responsible for intense and fast polarization fluctuation of 136 MHz signals at Ascension Island. Such irregularities also cause L band scintillations. The two location-dependent parameters favouring such scattering are (1) high ambient plasma density and (2) low angle \(\psi\) between the geomagnetic field and the propagation path. It was also shown that because these parameters are unfavourable for a propagation path to an equatorial station, unrealistically large density fluctuation and/or small irregularity sizes are required for the FPFs to be observed at an equatorial station at this frequency. It was shown by Sinno and Minakoshi\(^{16}\) that the scintillations at Tokyo were more severe than previously expected at such a midlatitude station due to the geometrical enhancement factor arising from the small value (5.3\(^{\circ}\)) of \(\psi\) for the ETS-II Tokyo path. Therefore we may conclude that such low value of \(\psi\) also favours the occurrence of FPFs at Tokyo. The other requirement of high ambient plasma density was qualitatively examined. It has been found that during the month of June 1979 when occurrence of FPFs was maximum, the nighttime F region peak electron density \(N_m\) is a factor of 4 higher than in the month of December when FPFs were absent. Even on a day to day basis, \(N_m\) is higher on nights with FPFs as compared to monthly mean value just prior to the occurrence of FPFs. Thus the ambient electron density is also favourable for the occurrence of FPFs. Therefore it may be concluded that diffractive scattering by small scale density irregularities with a power law spectrum may be responsible for FPFs and strong amplitude scintillations observed at Tokyo.

The FPFs and amplitude scintillations seen at Tokyo may not be related to the equatorial plume or bubble phenomenon which is due to the unstable growth of Rayleigh Taylor type instability in the fast rising F region with steep gradient in the post sunset hours forming plasma density depletions. These bubbles rise to the topside F layer through non-linear \(E \times B\) motion\(^{17}\). The steeping of the bubbles can form small scale structures and the resulting irregularities can have scale sizes from centimetre to tens of kilometre with a power law spectrum. However these bubbles are probably confined to the equatorial anomaly region and they have to rise up to an unrealistically large height to be mapped to latitudes of Tokyo. The present occurrence pattern of FPFs with maximum in June solstices also differs from that of the plume phenomenon which maximizes in equinoxes. Sporadic-E which mostly occurs in local summer, midlatitude-type irregularities and irregularities causing spread-F in the post midnight sector may be among the possible candidates causing the observed scintillations.

References

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