Intense night-time equatorial radio scintillations by sporadic *E* layers

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Abstract. Almost saturated scintillations of radio beacons from geostationary satellites received at an equatorial station during night-time have been shown to occur even during complete absence of spread *F* on the vertical incidence ionograms at the same location. These scintillation events were observed when the ionograms showed blanketing type of sporadic *E* layers simultaneously at different heights. It is suggested that strong equatorial radio wave scintillations during night-time are caused by multiple scattering between different levels of large plasma density gradients in the *F* or sometimes in the *E* regions of the ionosphere.

Keywords. Radio scintillations; sporadic *E* layers.

1. Introduction

Equatorial radio scintillations have been considered to be basically a night-time phenomenon associated with spread *F* irregularities (Wright *et al* 1956; Koster 1972; Bandyopadhyay and Aarons 1970; Bhargava 1964). A detailed comparison of the equatorial scintillations with the corresponding ionograms at a close-by station was undertaken by Rastogi (1982a) using the amplitude scintillation records of 41, 140 and 360 MHz radio beacons from the geostationary satellite at 94° W longitude received at Huancayo during the period October 1974 to May 1975. It was shown that it was only that type of range spread where different layers of strong reflections were recorded on the ionograms which produced scintillations exceeding the amplitude fluctuations of 20 dB or the scintillation index of 100%. The range spread showing uniform amorphous spreading of echoes caused only moderate scintillations on the VHF waves having fluctuations of less than 5 dB. The frequency spread with no range spreading either causes no scintillations or some times produce scintillations of only about 1-2 dB. The blanketing type of sporadic *E* layer during the night-time was found to cause scintillations of about 1-2 dB on VHF and of about 5 dB on HF bands. It was concluded that strong equatorial scintillations during the night-time hours are the result of multiple scattering between different layers of large plasma density gradient produced at fully developed stage of range spread.

Wild and Roberts (1956) were the first to find that the occurrence of day-time scintillations were correlated with sporadic *E*. Chivers and Greenhow (1959) suggested the presence of a significant contribution from the *E_s* region irregularities in radio star scintillations in the auroral regions. At a tropical latitude station, Ahmedabad, Rastogi and Iyer (1976) found an excellent correlation between the occurrence of strong blanketing multiple type of *E_s* and of scintillations from the region of ionosphere over Ahmedabad, defining very localized effect of *E* layer on scintillations. Regarding the equatorial region, the records at Huancayo indicated day-time scintilla-

tions, with S.I. 20% to be strongest during local winter months in the years of sunspot minimum (Mullen and Hawkins 1975).

Early results of ATS-6 beacons recordings at Ootacamund indicated day-time scintillations occurring in about 25% of time (Rastogi *et al* 1977a). Basu *et al* (1977) suggested the day-time equatorial scintillations to be due to type 2 irregularities, identified by the radar as well as Esq echoes on ionograms. Rastogi *et al* (1977b) showed that intense day-time scintillations were due to non- q type, *i.e.* either high or flat type of E_s which blankets the higher reflections. The scintillations in detail by Rastogi (1980) for day-time of different epochs of solar cycle.

Chandra *et al* (1979) found that some of the events of scintillations of ATS-6 beacons received at Ootacamund were associated with night-time E_s . Rastogi (1982b) found that during phase I of ATS-6 project (1974–75), when the satellite was in the western hemisphere, the blanketing type of sporadic E layer which occurred during night-time caused scintillations of about 1–2 dB on VHF and of about 5 dB of HF bands. During day-time, of course, VHF scintillations of index 100% have been detected associated with blanketing sporadic E at Huancayo (Rastogi and Mullen 1981). This paper describes two events of intense night-time VHF scintillations exceeding the amplitude of 18 dB or 100% index during the complete absence of F region irregularities (spread F). The necessary conditions and mechanism of VHF radio wave scintillations are discussed.

2. Observations

The first set of observations is based on recordings of the amplitude of radio beacons on 41, 140 and 360 MHz from ATS-6 satellite received at Huancayo (elevation 64° , azimuth 58° West of North) on 14 February 1975, a sample of which is reproduced in figure 1. The E region irregularities causing any scintillations would have been within 100 km distance from Huancayo and thus a comparison of scintillation records with the ionogram records at Huancayo is quite justified. The amplitude of 41 MHz wave was fluctuating at a very slow period until 2016 LT which then became very rapid and deep in intensity. Similarly the fluctuations of 140 and 360 MHz radio waves were very feeble till 2016 LT and then became very clear and strong. These extra scintillations occurred in all the three frequencies almost simultaneously.

In figure 2(a) are shown the temporal variations of the scintillation index of 41 and 140 MHz beacons from ATS-6 on 14 February 1975. Complete recordings of the

Figure 1. Sample records of the scintillations of ATS-6 radio beacons received at Huancayo on 14 February 1975 showing the sudden start of scintillations on 41, 140 and 360 MHz at 2016 LT.

Figure 2. (a) The temporal variation of the scintillation index of 41 and 140 MHz radio beacons from ATS-6 to Huancayo (b) Some of the ionograms at Huancayo on 14 February 1975 during the scintillations of the ATS-6 beacons.

amplitude of 360 MHz were not available due to the malfunctioning of the equipment. The ionograms at Huancayo on the night of 14 February 1975 are also reproduced for comparison in figure 2(b). One can clearly notice that the scintillation of ATS-6 beacons (41 and 140 MHz) started increasing at about 2000 LT and reached saturation (scintillation index 100%) at about 2015 to 2115 LT after which it decreased slowly to normal conditions by 2330 LT. This is a very rapid and strong but fairly short duration scintillation event not characteristic of the scintillations caused by the spread *F*. It is noteworthy that there was no spread *F* activity observed on the ionograms, the critical frequency was roughly identifiable on all the ionograms. There were some scattering of the radio waves at 2045–2215 LT but such characteristics have been shown to be not sufficient for producing scintillation of radio waves traversing the ionosphere. At 1915 LT only, weak *E_s* were recorded but at 1945 LT at least four different levels of *E_s* were seen on the ionogram. These periods correspond to the starting of the scintillation activity. At 2000 LT the maximum frequency reflected from *E_s* at 100 km exceeded 7 MHz and five multiple reflections were recorded on the ionograms. Strong multiple *E_s* layers were recorded at 2015 LT and *E_s* at different levels were again visible on the ionograms at 2030 LT. The ionogram at 2045 LT shows multiple layer of *E_s* at 100 km, another strongly reflecting layer at 130 km, and some spread *F* at the base of the *F* layer. At 2125 LT the *E_s* at two distinctly different altitudes were clearly recorded on the ionograms. At 2215 LT again both multiple reflections were recorded from *E_s* at different altitudes. By 2245 LT both the different heights of the layer of *E_s* as well as the number of multiple reflections from one particular height of *E_s* had

greatly decreased and the ionograms showed normal condition without spread F activity.

Another set of observations is based on the amplitude of VHF (137 MHz) signals from the satellite Geos-1 (at 74.9° W longitude) and the ionosphere sounding records at Huancayo (75.3° W longitude) on the night of 7–8 March 1977. In this case, the geostationary satellite was situated in the most favourable position providing the highest possible elevation (76°) of the satellite from the ground ionospheric observatory at Huancayo. Therefore, the ionospheric sounder had been recording E region irregularities from almost the same region of the ionosphere which had caused scintillations of satellite radio beacons during this event.

In figure 3(a), the temporal variation of the scintillation depth of Geos-1 (137 MHz) signal received at Huancayo on 7–8 March 1977 is compared with the same average for the whole month. The temporal variation of the monthly mean scintillation index showed a rather rapid increase from 1.3 dB at 1900 LT to 14 dB by 2100 LT. This conforms to the general character of VHF scintillations at Huancayo for both low or high sunspot year (Rastogi 1982b). On the night of 7–8 March 1977, there were no scintillations up to 2000 LT, but later scintillations with a maximum of 2 dB at 2015 LT and another of 4.5 dB at 2130 LT were recorded. After 2215 LT scintillation index started increasing, reaching 18.5 dB at 2330 LT. It decreased to about 1.0 dB at 0015 LT after which it increased to 7 dB at 0045 LT. No observations were available after 0045 LT. The peak value of scintillation at 2330 LT was very sharp, especially the

Figure 3. (a) The scintillations of 137 MHz signals from Geos-1 satellite to Huancayo on 7–8 March 1977 compared with the same averaged for the whole month. (b) Temporal variations of the number of multiple reflections for the E_s layer, maximum frequency reflected by E_s , fE_s , and frequency blanketed by E_s , $f_b E_s$, at Huancayo on the night of 7–8 March 1977.

decrease of the activity was too rapid to be that due to spread F . The ionograms at Huancayo was examined to determine the cause of such a large and sharp increase of scintillation during the night.

The ionograms at Huancayo on the night of 7–8 March 1977 reproduced in figure 4 showed that there was absolutely no spread F activity at Huancayo at any time during the night of 7–8 March 1977. In the evening of 7 March 1977 there was a weak E_s layer at 100 km and a E_2 layer at 140 km with no multiple reflections. At 1845 LT there were E_s and E_2 layers recorded but a large number of multiple layers below the second order trace indicating $(2F - E_s)$ type of M reflections. This suggested a weaker overhead but stronger off-vertical sporadic E layer ionization patches around the station at that time. The ionogram at 2030 LT showed strong multitude of layers of sporadic ionization below first order F reflection trace. A trace parallel and only 30 km below the second order F trace indicates the presence of scattering between these different patches of ionization or between sporadic ionization and the main F layer. This spurt of sporadic E activity caused an increase of scintillations at 2015 LT to 2 dB. The ionogram at 2100 LT shows four multiple reflections from the sporadic E layer and blanketing of F reflections up to about 6 MHz. The scintillations increased to 5 dB at 2130 LT. At 2200 LT the ionograms recorded clearly 6 multiple reflections from E_s at 95 km level. At 2215 LT another sporadic E layer at 120 km appeared and later grew stronger in terms of both maximum frequency reflected from it as well as in the number of multiple reflections. The ionograms at 2345 LT shows E_s at 100 km with $fE_s = 4.2$ MHz simultaneously with E_s at 120 km with $fE_s = 8$ MHz. At 0030 LT simultaneously five multiples from E_s at 100 km and three multiples from E_s at 120 km were recorded. The fE_s for the layer at 120 km exceeded 10 MHz which was even greater than $f2F2$. The important point to be noted is that the first order F layer reflection at 0030 LT was completely blanketed by 120 km E_s , but the second order F layer reflection was blanketed only up to 3 MHz. This suggests an extremely large

Figure 4. Ionograms at Huancayo on 7–8 March 1977 showing simultaneous occurrence of sporadic layer at 95 km and 115 km heights.

spatial variation in the electron concentration in the E region. The ionogram at 0045 LT shows $f \min F$ to be much greater for the first than for the second order F trace suggesting a much stronger and uniform sheet of ionization overhead the station than at off-vertical areas. Very strong activity of E_s layer is seen in the ionogram for 0100 LT.

The temporal variations of the number of multiple reflections from the sporadic E layer, the maximum frequency reflected from the E_s layer (fE_s) and the maximum frequency blanketed by E_s layer ($f_b E_s$) are shown in figure 3(b) for comparison with the variation of the scintillation index, SI at Huancayo on the night of 7-8 March 1977. The sporadic E layer activity was abnormally high on that night whether one considers the maximum ionization in the E layer in terms of fE_s or in terms of the patches of the E_s cloud by its reflectivity or transmissivity. It may be noted that for a q type of E_s layer, fE_s is not the index of ionization in E_s layer but in a blanketing sporadic E layer $f_b E_s$ is close to the maximum ionization density in the E_s layer (Reddy and Rao 1968). Thus the increased scintillation activity in general is in conformity with the increased E_s activity, but when examined in detail the peak scintillation does not coincide with the highest frequency reflected from the E_s or on the number of multiple reflections from the E_s . The examination of ionograms does indicate some speciality during the period of maximum scintillation. This is the simultaneous occurrence of strong E_s layer at different altitudes; and it seems that it is the multiple scattering between these different E_s layers which produces strongest scintillations rather than the increase of fE_s or $f_b E_s$.

Rastogi and Mullen (1981) have reported two events of intense scintillations at Huancayo during day-time associated with the occurrence of strong E_s activity. From a closer examination of the ionograms reproduced by them it is seen that the event was marked by multiple layers of sporadic ionization below F region of the ionosphere. Thus it appears that a single sporadic E layer is not effective in producing intense scintillations. It is the multiple scattering between the layers that produces strong scintillations. Earlier, Rastogi (1982a) has shown that even in the case of F region irregularities, the strong scintillations are the result of multiple scattering between the regions of large plasma density gradient produced at fully developed stage of range spread. Even a thick F region irregularity indicated by uniform range spread is not very efficient in generating scintillations of satellite radio signals.

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