Daytime Radio Wave Scintillations in the Equatorial Electrojet Regions

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A study is made comparing the equatorial radio scintillations of ATS-6 signals during daytime hours at Huancayo (1974-75) and at Ootacamund (1975-76). The scintillations on VHF (137/140 MHz) band during the normal equatorial q-type of sporadic-E layer (eastward electrojet currents) are slow and weak, having 1-2 dB peak-to-peak amplitude fluctuations at Huancayo and about 5-6 dB peak-to-peak amplitude fluctuations at Ootacamund. Scintillations during the blanketing type of sporadic-E layer (westward electrojet currents) are slow but strong in amplitude exceeding 10-20 dB at either of the places. The local time variations of the daytime scintillations at Huancayo are consistently constant during any of the years within the period 1968-75. Average midday magnitude of scintillation index (SI) was 10-15% and the SI > 10% occurred more than 80% of the time in any of the years. There were no special peculiarities in VHF scintillations at Huancayo during the ATS-6 period anyway different from those during other years.

1 Introduction

The early observations of the radio star scintillations in the equatorial electrojet regions indicated the scintillation activity to be basically a nighttime phenomenon associated with the spread-F.1-4 The launching of the low orbiting satellites BE-B and BE-C with beacons on 20 and 40 MHz provided observations of equatorial radio scintillations along the East African longitudes by Sinclair and Kelleher,5 at Thumba by Chandra and Rastogi6 and at Huancayo by Chatterjee et al.7 These observations indicated a belt, 10-15° wide, of intense nighttime scintillations. Later observations of beacons from geostationary satellites made at Peru and Ghana confirmed these earlier observations.8-9 In his first review of ionospheric scintillations Aaron9 described the equatorial scintillations to be present within ± 15° from the geomagnetic equator and within 2100-0300 hrs LT. Daytime scintillations in the equatorial region (Huancayo) were reported by Mullen and Hawkins11 having peak-to-peak variations of 2 dB.

The launching of geostationary satellite ATS-6 with coherent beacons on 40, 140 and 360 MHz, stationed at 94°W during the first phase (1974-75) and at 35°E during the second phase (1975-76) provided the opportunities of equatorial ionospheric scintillations at Huancayo in Peru, and at Ootacamund and Thumba in India.

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whether type I or II of the electrojet irregularities were associated with the scintillations.

Rastogi and Muller\(^{16}\) have shown two cases of very intense scintillations activity recorded at Huancayo during the daytime on 257 MHz from MARISAT, on 254 MHz from LES-6 and on 137 MHz from ATS-3 satellite. Both these events were shown to be associated with an intense Es-layer over Huancayo.

Sengupta and Bandyopadhyay\(^{17}\) discussed some of these reported observations and felt that the observations of ATS-6 beacons at Huancayo were in conflict with earlier observations of the phenomenon. They suggested that observations of scintillations on 140 MHz during 1975 were unique for the period and were due to considerable change in the nature of the electrojet irregularities over the years 1967-75. They also felt that the observations at Ootacamund were in disagreement with those at Thumba and concluded that the Ootacamund observations should be more carefully examined. Thus they attempted to show a major inconsistency in the spatial as well as in the temporal variations of the daytime ionospheric scintillations near the magnetic equator. The present paper describes the equatorial radio wave scintillations at Ootacamund and at Huancayo, based on ATS-6 beacons, as well as the long-term observations of VHF scintillations at Huancayo based on ATS-6 observations and to examine this so called inconsistency.

2. Observations at Huancayo and Ootacamund

Scintillation observations were made at Huancayo, Peru (lat., 12°0'S; long., 75°3°W; dip lat., 0°6°N) receiving 41, 137, 140 and 360 MHz transmissions from ATS-6 satellite. The signals were amplified by low noise receiving system and the detected signals were recorded on strip chart recorders. The recordings were calibrated by a local signal generated at the beginning, at the end of the chart roll as well as during any adjustment of the equipment.

The Ootacamund experiment was jointly conducted by the Physical Research Laboratory, Ahmedabad, India, the NOAA Environmental Research Laboratory, Boulder, Colorado, USA and the SRI International, Stanford, USA. The equipment consisted of the receiving system developed at NOAA, described by Grubbs\(^{18}\) and Davies \textit{et al.}\(^{19}\). The antennae used were short backfire type having low side-lobes and wide bandwidth. The antennae were situated on the westward slopes of a hill thereby eliminating any chances of ground reflections. The recordings were done on multi-channel strip charts as well as, for the first few months, on digital magnetic tapes. The amplitude recordings were calibrated by local Hewlett-Packard frequency synthesized signal generator. Before discussing the daytime equatorial radio scintillation observations in the American and Indian sectors, it is necessary to summarize the characteristics of the E-region irregularities (sporadic-E) in the two sectors.

Although the first description of the equatorial Es phenomenon was for Huancayo and given by Berkner and Wells\(^{20}\), the first detailed study of equatorial Es phenomenon was described by Rangarajan\(^{21}\) for Kodaikanal. He classified the equatorial Es into two basic types, viz (i) patchy type with very well defined and marked diurnal variation now described as the q type of Es and (ii) the blanketing type which mostly occurs during afternoon, denoted as Es-b. New classifications of the Es were introduced during the IGY,\(^{22}\) namely, equatorial type (Es-q), slant type (Es-s), low type (Es-l), flat type (Es-f), cusp type (Es-c), high type (Es-h), retardation type (Es-r) and the auroral type (Es-a). As far as the low latitude regions are concerned the Es-q and Es-s occur over the belt of ± 5° magnetic dip\(^{28}\) analogous to the belt of equatorial electrojet currents. The blanketing Es (non-q type of Es) occur most frequently at the fringes of the electrojet belt.\(^{24}\) Bandyopadhyay and Montes\(^{25,26}\) have studied the occurrence of the different kinds of Es layers at Huancayo during IGY. They showed that between 1000 and 1300 hrs LT the Es-q occurred almost on all of the days of the year while the blanketing Es was almost rare at Huancayo; only two cases being observed during the whole IGY period. Rastogi\(^{27}\) studied the occurrence of Es at Huancayo during 1974, the year of minimum solar activity. There was a decrease in the occurrence of Es-q in the afternoon hours in 1974 as compared to what was in IGY period, due to more frequent counter-electrojet events, and thus, the non-q type of Es were more frequent during 1974 than during 1958. The cusp and high type of Es occurred at about 10% of time during the afternoon hours during 1958. Bhargava and Subrahmanyan\(^{28}\) showed that the occurrence of blanketing Es was much larger at Kodaikanal than that at similar latitudes in the West. Chandra and Rastogi\(^{29}\) have shown that the occurrence of blanketing Es is preceded by the occurrence of equatorial counter-electrojet event and they suggested that Es-b is due to the movement of ionization from neighbouring latitudes when the Hall polarization field is downward associated with the reversed equatorial electrojet. Chandra and
Rastogi showed that the blanketing Es is most common in the Indian zone, less frequent in the African and least common in American zone. Thus the longitudinal differences of the Es are the consequences of the longitudinal differences of the counter equatorial electrojet phenomenon.

Before discussing the results of daytime equatorial scintillation, let us examine the accuracies involved in strip chart records from which the basic data are derived. In Fig. 1 are shown the amplitude fluctuation records of ATS-6 (137 MHz) signal received at Huancayo on 10 Mar. 1975 at different times of the day from 0900 to 1400 hrs LT. The chart speed was 3 cm/min and the amplitude scale was roughly 4 dB/cm. Keeping in mind the thickness of the traces and other errors in chart reading 1 dB would be about the lowest limit of significant measurement of the scintillation amplitude on 140 MHz. It is seen that during the day hours, the fadings are fairly slow, 4-5 fades per minute, and the peak-to-peak fluctuations are about 1-2 dB or scintillation index of 10-20%.

Just to compare the daytime scintillations with the nighttime scintillations, in Fig. 2 are reproduced two sample scintillation records at ATS-6 (140 MHz) beacons received at Huancayo on 28 Feb. 1975. The magnetogram at Huancayo on the same day is also reproduced to indicate the geomagnetic activity conditions on the day. The trace of the H component is fairly smooth with a maximum shortly before noon indicating that there were no significant geomagnetic disturbances and the equatorial electrojet current was eastward from 0700 to 1500 hrs LT followed by a period of counter electrojet from 1500 to 1700 hrs LT. The scintillations during the daytime (1140-1155 hrs LT) were weak with peak-to-peak fluctuations of less than 2 dB. The scintillations during the nighttime (2200-2215 hrs LT) were very fast and strong (peak-to-peak fluctuations of about 20 dB).

Rastogi et al. have compared the average characteristics of the scintillations of ATS-6 beacons at Huancayo and Ootacamund. The magnitude of scintillations during the daytime hours were generally larger at Ootacamund than at Huancayo, whereas the nighttime scintillations were larger at Huancayo than at Ootacamund. In Fig. 3 are shown the mean diurnal variations of the scintillation index (%) and the scintillation depth (dB) of 40/41, 140 and 360 MHz beacons at Huancayo and Ootacamund. At Huancayo, the mean scintillations on 41 MHz were about 2 dB around

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Fig. 1—Sample amplitude fluctuation records of 137 MHz beacon from ATS-6 received at Huancayo on 10 Mar. 1975
sunrise and sunset hours and about 6 dB around midday hours. At Ootacamund, the range of scintillations on 40 MHz was much smaller being within 3-4 dB during any hour of the day. The yearly mean midday value of the scintillation index of 140 MHz was less than 1 dB at Huancayo and about 1.5 dB at Ootacamund. There were practically no scintillations on 360 MHz recorded at Huancayo whereas the mean midday scintillation index on 360 MHz at Ootacamund was about 0.3 dB. These values represent the mean of all observations and not necessarily the typical value observed at any particular time due to large day-to-day fluctuations in the scintillation level. Thus it is seen that the equatorial scintillations on 40/41 MHz band were almost a regular feature present at any time of the day or night, of course with decreased intensity around sunrise and sunset times. The equatorial scintillations on 140 MHz have similar characteristics with deeper minima of intensity during sunrise and sunset times. Further, while at Huancayo the mean amplitudes are larger during night than that during day, the scintillations at Ootacamund averaged for the whole year are stronger during day than during night. The equatorial scintillations on VHF band are observed only during the nighttime hours but at Ootacamund these events are observed during daytime too.

In order to establish any significant difference in the scintillation magnitudes at Huancayo and Ootacamund, in Fig. 4 are plotted the diurnal variations of the percentage occurrence of the scintillation index of 140 MHz beacon exceeding the levels of 10%, 20%, and 30%. The SI (140 MHz) at Huancayo exceeded 10% level which occurred for about 50% of occasions during the midday or midnight hours. The SI (140 MHz) 10% level at Ootacamund for the midday or midnight hours occurred only on 35% of occasions. The SI (140 MHz) at Huancayo never exceeded 20% level at any time during daytime. On the contrary SI (140 MHz) at Ootacamund during the daytime hours
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Fig. 3—Plots showing the diurnal variations of the average scintillation index and scintillation depth of 40/41, 140 and 360 MHz beacon signals from ATS-6 satellite received at Huancayo during 1974-75 and at Ootacamund during 1975-76.

Fig. 4—Plots showing the daily variation of the percentage occurrence of scintillation index of 140 MHz beacon from ATS-6 satellite at Huancayo and Ootacamund exceeding the levels of 10%, 20%, and 30%.

Exceeded 20% level on about 20% of occasions and 30% level on 15% of occasions. Thus, it is seen that the daytime scintillations at Huancayo and Ootacamund may have roughly the same mean levels but the values of SI at Huancayo were always less than 20% level whereas at Ootacamund very high levels of scintillations were recorded on some occasions during the daytime hours. This suggests that the comparatively weaker scintillations on VHF band are quite common at Huancayo but at Ootacamund the weak scintillations are less frequent and are often accompanied with stronger bursts of scintillations, letting the mean scintillation level be the same at the two places.

3. Equatorial Scintillations during Periods of Normal and Reversed Electrojet Currents

It is well known that the eastward flowing equatorial electrojet current reverses itself on certain occasions during the daytime hours indicated by the horizontal geomagnetic field intensity decreasing below the nighttime level. These events are associated with the disappearance of q type of sporadic-E irregularities and on certain occasions with the reappearance of blanketing type of Es layers. Therefore, we now examine the scintillations at Huancayo and Ootacamund during eastward and westward flowing electrojet currents.

In Fig. 5 are reproduced the H magnetograms, some ionograms and ATS-6 (137 MHz) amplitude records at Huancayo on 26 Apr. 1975. The recordings of H at Huancayo or $\Delta H$ (Huancayo—Fuquene) showed values above the mean night level for most of the daytime hours from 0700 to 1430 hrs LT suggesting eastward electrojet currents during this period. At about 1500 hrs LT, $\Delta H$ (Huana.—Fuq.) became negative indicating the beginning of counter-electrojet event. The negative value of $\Delta H$ remained up to about 1700 hrs LT.

The ionogram at 1445 hrs LT showed clearly the type of Es layer which was transparent to the upper F1 and F2 layers. At 1515 hrs LT the Es-q layer disappeared and normal E reflections were recorded. At 1600 hrs LT some non-q type reflections appeared and at 1615 and 1630 hrs LT strong blanketing type of Es with multiple reflections was recorded. At 1645 hrs LT the f$_E$ Es reduced and by 1700 hrs LT the blanketing Es had too disappeared.

The amplitude recordings of ATS-6 (137 MHz) signals showed very feeble fluctuations up to about 1614 hrs LT. Between 1615 and 1635 hrs LT strong
Fig. 5 - Reproduction of $H$ mag netograms, ionograms and the amplitude records of ATS-6 (137 MHz) beacon at Huancayo on 26 Apr. 1975
fluctuations often exceeding 5 dB were recorded. The signals were again steady after 1635 hrs LT. These intense scintillations were thus associated with the blanketing type of Es layer.

In Fig. 6 are reproduced the magnetogram, ionogram and ATS-6 beacon amplitude records for the Indian longitudes on 28 June 1976. The daily variation curve for $\Delta H$ (Trivandrum—Alibag) showed large positive values ($>65$ nT) near 1100 hrs LT indicating a strong eastward electrojet during the forenoon hours and a negative value of $\Delta H$ ($-35$ nT) around 1600 hrs LT indicating a counter-electrojet during the evening hours in the Indian longitudes on 28 June 1976. The ionograms showed strong q type of Es layer in the forenoon hours and strong blanketing Es layer with multiple reflections in the evening hours. The amplitude records of ATS-6 beacons showed small fluctuations in the forenoon hours while very strong scintillations were recorded in the afternoon hours even on 360 MHz band.

These observations indicate that the scintillations on 40 MHz bands are present during the daytime hours having fluctuations of the order of 4-5 dB during normal (Es-q) conditions and are increased to larger magnitude ($>8$-10 dB) during counter-electrojet periods accompanied by the occurrence of blanketing type of sporadic-E layer. The normal daytime scintillations on VHF band are of the order of 1-2 dB which are increased to 5-6 dB level during blanketing Es. The UHF scintillations are normally too weak to be recorded during the day under normal electrojet condition but the presence of blanketing Es may produce scintillations of a couple of dB magnitude. These conditions are true for both the Indian as well as the American longitude zones.

Thus there are basically two types of daytime equatorial ionospheric scintillation activity, one associated with the normal electrojet accompanied by the q type of Es activity and another comparatively stronger but rather temporary activity associated with the counter equatorial electrojet accompanied by the blanketing type of Es layer.

4. Solar Cycle Effects on VHF Scintillations

VHF scintillations at equatorial zone extending over a solar cycle or more have been recorded by Aarons of AFGL in Peru and by Koster in Ghana. The scintillation data for Ghana refer mainly to the nighttime observations. The VHF scintillation data at Huancayo over the long period, (from 1968 onwards) have been recorded on the 137 MHz beacons from ATS-3 satellite. In Fig. 7 is shown annual mean scintillation index of 137 MHz beacons from ATS-3 received at Huancayo for individual years till 1975. It is seen that during any of the years the main peak of scintillation activity occurs around 0300 hrs UT or 2200 hrs LT with average scintillation index of 40% or 4 dB. Further, there is another flat peak during the day with magnitude of about 15% or 1.4 dB during any of the years.

The scintillation level of 1 dB is fairly low to be recorded on strip charts and the mean value of scintillation index has to be examined more clearly in terms of the distributions of the individual readings. In Fig. 8 are shown the daily variations of the percentage of time for which the scintillation index of ATS-3 beacon on 137 MHz received at Huancayo exceeds the levels of 10%, 20% and 30% during the different years from 1968 to 1975. It is seen that the midday scintillation level of 10%
Fig. 8—Plots showing the annual average daily variations of the percentage occurrence of scintillation index of the 137 MHz beacon from ATS-3 received at Huancayo exceeding the levels of 10%, 20%, and 30%

Fig. 7—Plots showing the annual average daily variations of the scintillation index of 137 MHz beacon from ATS-6 satellite received at Huancayo during the years 1968-75

exceeds more than 80% of time during any of the years studied. The scintillation level of 20% during the midday hours occurred on more than 20% of time in 1975 and more than 40% of time in 1971. But in most of the SI, 20% level occurred for about 30% of time. The SI > 30% during the daytime occurred on some years like 1971 and 1972 but these events are rare in 1973 and 1975. Thus it can be concluded that the significant daytime VHF equatorial scintillations are present during any year of the solar epoch and were not the characteristics of the years 1974-76 when the multi-frequency beacons were available from ATS-6 satellite.

In Fig. 9 are shown the annual means of the daytime (1000-1400 hrs LT) values of 137 MHz scintillation index as well as the percentage of time for which the scintillation index exceeded the levels of 10%, 20% and 30%. It is seen that during any of the years the annual mean daytime scintillation index varied between the levels of 10 and 15%. The scintillation level exceeded 10% and level for about 85% of time during the years 1970-75 and about 60-70% of time during 1968 and 1975. The SI exceeding 20% occurred for about 40% of time in 1971 but during most of the years it varied from 10 to 30% of time. The SI exceeding 30% occurred during less than 10% of time during any of the years. Thus it can be concluded that the level of daytime VHF scintillation at Huancayo was fairly consistent during the entire period of 1968-75 presently studied, and were not characteristics of ATS-6 period only.
5. Daytime Scintillations at Equatorial Regions of Low Orbiting Satellite Beacons

The radio beacons on the BE-B and BE-C satellites had been recorded at Thumba in India, Huancayo in Peru and in the East African longitudes; but the daytime scintillations on these records have not been reported. This has led to the conclusion by Sengupta and Bandyopadhyay that during the period of BE-B and BE-C satellites there were no scintillations present at equatorial regions during daytime. We re-examined our records at Thumba and found that some of the observations indicated significant scintillations during the daytime passes of these satellites.

In Fig. 10 are shown the records of ATS-6 (140 MHz) amplitude at Huancayo on 9 Feb. 1975.
around 0800-0900 hrs LT, as well as the amplitude of 40 MHz beacons from the low orbiting satellite BE-C during the same period. It is seen that 140 MHz scintillations are of the order of 1 dB as normally expected. The BE-B signals do indicate scintillations during certain portions of the transit. As seen from the two records, the scintillations though smaller on VHF than HF bands are more easily identified from geostationary satellite records than from the low orbiting satellite.

In Fig. 11 are reproduced the Faraday fading records of two transits of BE-C satellite at Thumba on 30 Dec. 1965 and 16 Apr. 1966. The recordings of these satellites incorporate large variations of the received signal strength due to the Faraday fades and any scintillations present during these periods are superimposed on these Faraday fades. As the sensitivity of the receivers varies over the ranges of the signal amplitudes to record the Faraday fades, the scintillations are apparent only during the positive peaks of the signal except when the signals scintillate violently and the Faraday fades may also be obliterated. The magnitude of nighttime scintillations are stronger enough to obliterate the Faraday fades. The daytime scintillations being weaker produce only distortions in the smooth Faraday fades. The recordings of 40 as well as 41 MHz signals at Thumba do indicate large scintillations. Thus it is not correct to conclude that the daytime scintillations were not recorded at equatorial regions in Indian longitudes during BE-B and BE-C periods.

The scintillation of radio waves in the equatorial regions is known to be much larger during the nighttime than during the daytime hours both on individual as well as in the statistically average conditions. At Ootacamund the daytime scintillations had reached almost a saturated condition on certain occasions. These cases of saturated daytime scintillations occurred more often during local summer months. In Fig. 12 are shown the monthly mean daily variations of scintillation index of ATS-6 beacons on 40, 140 and 360 MHz received at Ootacamund. The maximum value of SI on 40 MHz was about 65% during the night and 75% during the day, indicating that even the mean scintillations were stronger during the day than during the nighttime. This is much more clearly seen in the case of 140 MHz scintillation index which reached maximum value of 15% during night and about 65% during the day. Similarly the scintillation index of 360 MHz was too small during the night but was more than 15% during the daytime.

6. Conclusion

There are basically two definitely different types of daytime equatorial VHF radio wave scintillations. The first associated with periods of eastward electrojet current indicates slow and weak fluctuations of about 1-2 dB at American longitudes and 4-5 dB in Indian longitudes. The other observed during periods of westward electrojet current indicates slow but strong fluctuations sometimes exceeding 10 dB and are associated with blanketing sporadic-E layer. There are no apparent contradictions in the phenomena in the different longitude zones. The higher average daytime scintillation index in Indian sector than that in the American sector is due to the more frequent occurrence of the blanketing sporadic-E layer in the Indian zone.

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