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Quiet time *F*2-layer disturbances at geomagnetic equator

A. Kh. Depueva, A. V. Mikhailov, and V. Kh. Depuev

Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation, Troitsk, Moscow Region, Russia

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[1] Ionospheric $F2$-layer disturbances not related to geomagnetic activity (Q disturbances) were analyzed using all available N_mF2 observations over Huancayo (American sector) and Kodaikanal (Indian sector) stations located at the proximity of geomagnetic equator. Both positive and negative Q disturbances were revealed, their amplitude being comparable to usual $F2$ layer storm effects. The occurrence of Q disturbances exhibit a systematic dependence on solar activity, season, and local time. The revealed morphology of Q disturbances at Huancayo can be explained by the observed at Jicamarca $\mathbf{E}\times\mathbf{B}$ vertical drifts. There are some differences between Huancayo and Kodaikanal Q disturbance morphological patterns that cannot be attributed to small differences in $\mathbf{E}\times\mathbf{B}$ vertical drifts in the two longitudinal sectors. *INDEX TERMS:* 2415 Ionosphere: Equatorial ionosphere; 2435; Ionosphere: Ionospheric disturbances; 2431 Ionosphere: Ionosphere/magnetosphere interactions; *KEYWORDS:* Ionosphere-atmosphere interaction; ionospheric disturbances; equatorial ionosphere.

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1. Introduction

[2] The morphology of quiet time $F2$-layer disturbances (Q disturbances) at middle latitudes along with general discussion of the problem has been described by *Mikhailov et al.* [2004] (hereinafter referred to as MDL). The revealed morphological picture turned out to be pretty complicated indicating that various processes (depending on geophysical conditions) contribute to those variations. The formation mechanism of the equatorial $F2$ layer is different from the midlatitude one; therefore different morphological pattern of quiet time disturbances is expected. The $F2$ layer at geomagnetic equator is mainly controlled by vertical $\mathbf{E}\times\mathbf{B}$ plasma drift due to zonal electric field. The latter is known to be very variable [*Fejer et al.*, 1991; *Hari and Krishna Murthy,* 1995; *Namboothiri et al.*, 1989; *Ramesh and Sastri*, 1995; *Scherliess and Fejer*, 1999; *Woodman*, 1970], even under quiet conditions; therefore one may expect strong quiet time perturbations in the equatorial $F2$ region. Vertical plasma drifts demonstrate longitudinal variations; therefore the morphology will be considered for two equatorial stations, Huancayo (American sector) and Kodaikanal (Indian sector) separated practically by half a globe and located in the southern and northern hemispheres, respectively. This lucky situation allows one to analyze longitudinal and hemispheric differences. This paper is devoted to a morphological study of the equatorial Q disturbances along with a qualitative discussion of their possible mechanisms.

2. Data Analysis

[3] The morphological analysis was made for Huancayo (φ = 12.0°S; λ = 284.7°E; I = 1.3) and Kodaikanal (φ = 10.2°N; λ = 77.5°W; I = 2.6) over all available years of observations, (1957–1989) and (1957–1987) for the two stations, respectively. Following to the method by MDL a 27-day N_mF2 running median centered to the day in question rather than usual monthly median was used for the Q disturbances analysis. The advantages of using the 27-day median were discussed by MDL. In our analysis, Q disturbances were referred to hourly $(N_mF2/N_mF2_{\mathrm{med}} - 1)$ deviations more than 40% if all 3-hour ap indices were ≤ 7 for 24 previous hours. Normally, this provides a selection of quiet time periods (MDL). Three levels of solar activity were considered using 12-month running mean sunspot number: solar minimum $R_{12} < 50$, medium $R_{12} = 50 - 100$, and maximum $R_{12} > 100$.

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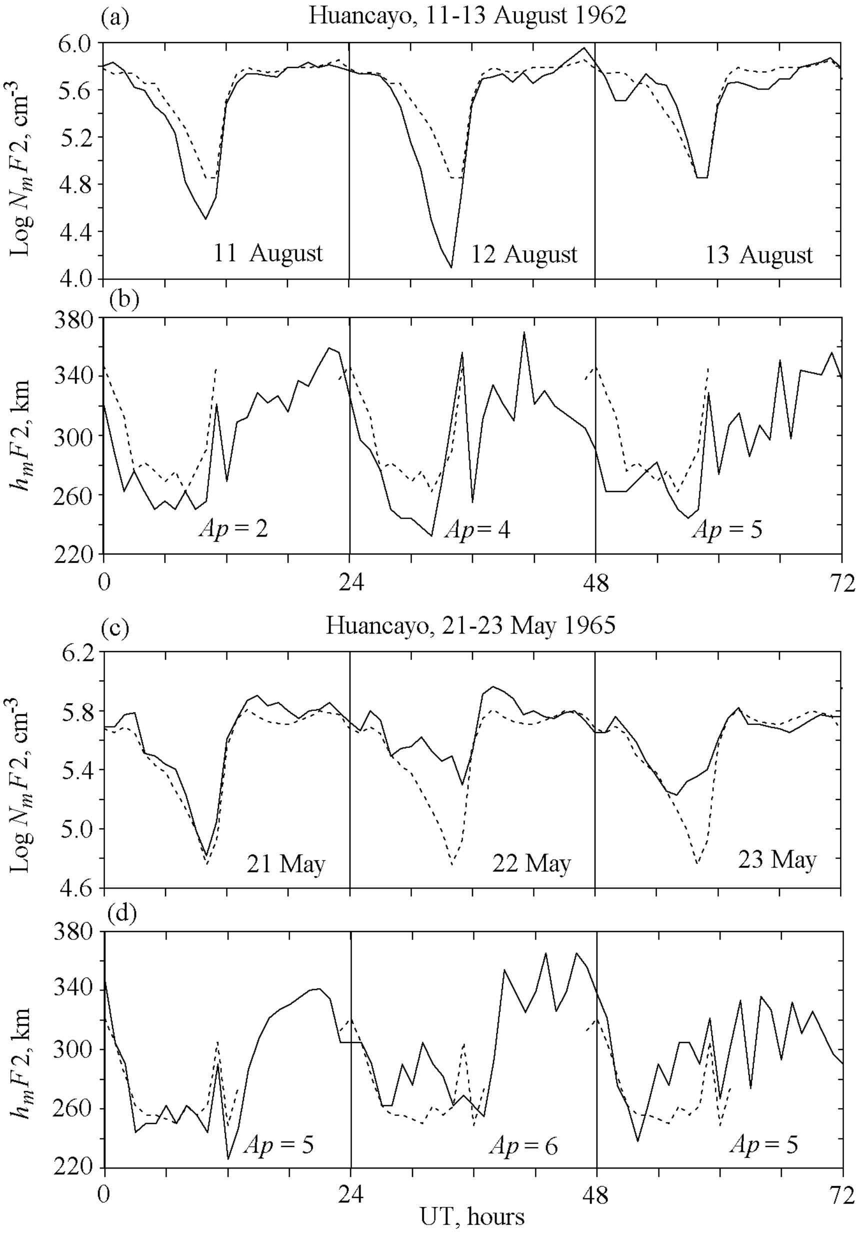

Figure 1. Examples of negative and positive nighttime (LT is UT minus 5 hours) Q disturbances observed at Huancayo (solid lines). A 27-day running median is given by dashes. Daily Ap indices are given in Figures 1b and 1d.

3. Morphological Results

[4] In the beginning we present some examples of Q disturbances to get an idea of how they look in the equatorial $F2$ layer. According to our analysis (see later) both negative and positive Q disturbances are the most frequent in the dark LT sector and in the daytime sector (only positive disturbances). Therefore three examples of Q disturbances observed at Huancayo are given in Figures 1 and 2. A strong nighttime negative disturbance on 12 August 1962 is shown in Figures 1a and 1b. Note that only nighttime period was subjected to the N_mF2 decrease, while N_mF2 values for the whole previous daytime hours of 11/12 August coincide with the median. Similar effect with less amplitude took place on the previous night of 11 April. In both cases a preceding decrease is seen in the h_mF2 variations calculated using the expression by *Bradley and Dudeney* [1973]. That was a strong disturbance with N_mF2 decrease by a factor of 6 and h_mF2 decrease by 30–40 km. The period was characterized by very low geomagnetic activity.

[5] The 22/23 May 1965 period presents a case of strong positive nighttime Q disturbance (Figure 1d). Again the disturbance has developed under very quiet geomagnetic condi-

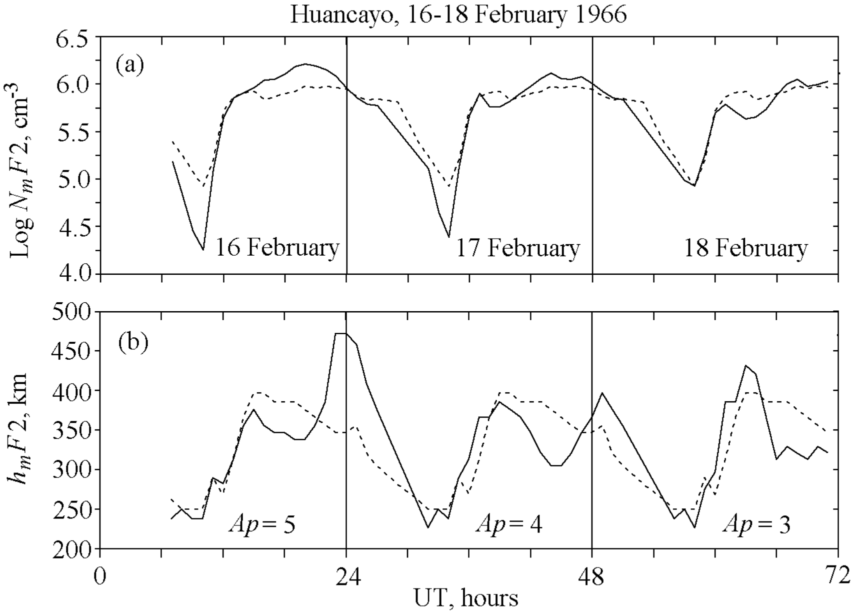

Figure 2. Example of positive daytime (LT) Q disturbance on 16 February at Huancayo (solid lines). A 27-day running median is given by dashes. Daily Ap indices are given in Figure 2b.

tions and took place for two adjacent nights, while daytime N_mF2 values were close to the median. By analogy with the previous case the positive N_mF2 disturbance was preceded by positive deviations in h_mF2. The positive N_mF2 effect in this case was a factor of 4 and about 40 km in h_mF2. Therefore nighttime equatorial $F2$-layer Q disturbances demonstrate synchronous (of one sign) N_mF2 and h_mF2 deviations and this is different from midlatitude Q disturbances (MDL). These examples show that equatorial quiet time disturbances may be very large with the amplitude comparable to normal $F2$-layer disturbances related to geomagnetic activity.

[6] Figure 2 gives an example of daytime positive Q disturbance observed on 16 February 1966. The daytime positive effect is not so impressive (only a factor of 1.7 in N_mF2) compared to the nighttime ones, but this implies pretty large changes in aeronomic parameters. The daytime $F2$ region is mainly controlled by local processes, while in case of nighttime disturbances we have a cumulative effect resulting in large N_mF2 deviations by the end of night (Figure 1). Contrary to the nighttime case, here we have antiphase N_mF2 and h_mF2 variations. This is also different from the midlatitude daytime Q disturbance case (MDL). It should be also stressed that this differs from the usual midlatitude daytime positive storm effect when N_mF2 and h_mF2 vary synchronously. All these peculiarities are due to the equatorial $F2$-layer formation mechanism, but this will be discussed in this paper only at a qualitative level. Model calculations along with a quantitative analysis of various aeronomic parameters contribution will be given later elsewhere. Let us consider morphological results obtained over the periods of observations available at the two stations.

3.1. Duration and Total Number of Disturbances

[7] Distributions for the occurrence of positive and negative Q disturbances versus their duration are shown in Figure 3 for both stations. Three levels of solar activity are shown separately although the total number of events is small for solar maximum conditions. Similar to middle latitudes (MDL) short-term (< 3 hours) deviations are seen to be the most numerous and they may be attributed to short-term ionosphere fluctuations which lie beyond our scope. We are interested in longer disturbances which can be related to background changes in the controlling aeronomic parameters. A 3-hour (4 hourly successive N_mF2 values) threshold was accepted for our analysis. Contrary to middle latitudes, negative Q disturbances are seen to be more numerous than positive ones at both stations and all levels of solar activity. The distributions are seen to be broader at Huancayo, that is the percentage of long (both negative and positive) disturbances is larger in the American sector. In general, long-duration disturbances are more numerous at solar minimum compared to solar maximum. The occurrence of long deviations is low during solar maximum especially at Kodaikanal. Therefore, in some cases we had to put together all solar activities to present the results.

3.2. Occurrence Versus Local Time

[8] Distributions of the occurrence for negative and positive Q disturbances (duration ≥ 3 hours) versus local time (LT) are given in Figure 4. It was possible to show separately

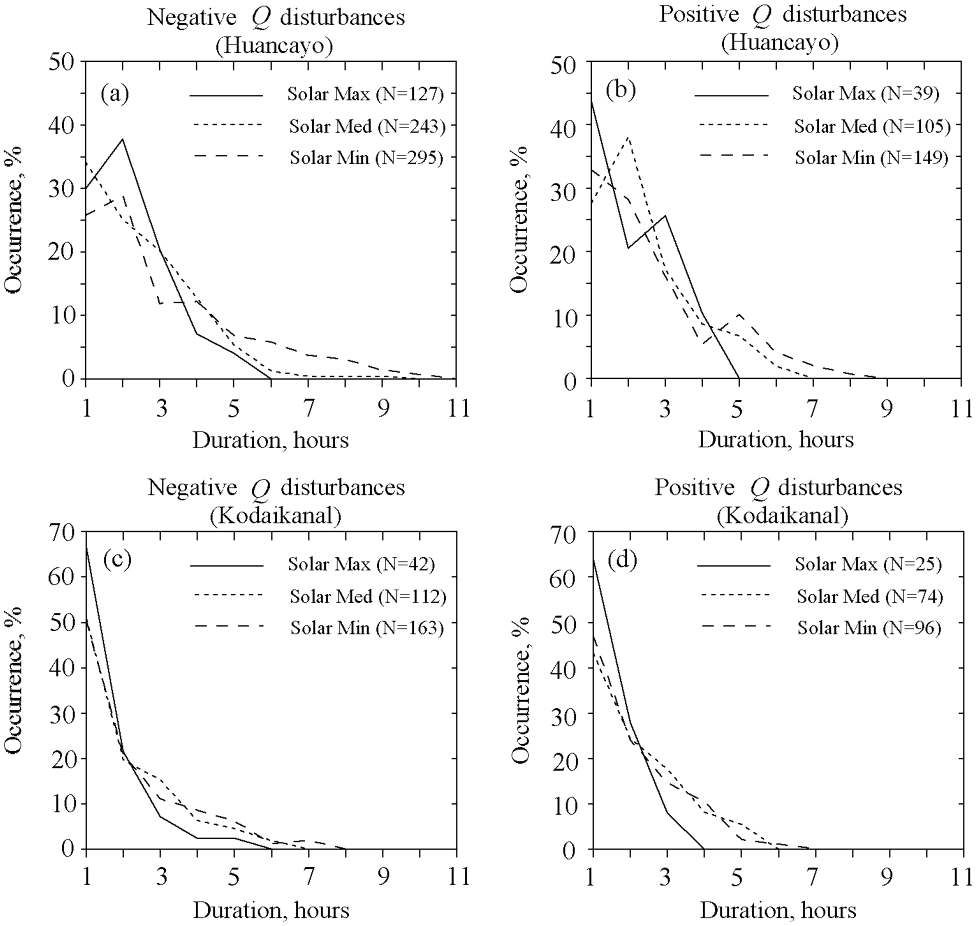

Figure 3. Distributions for the occurrence of negative and positive Q disturbances versus their duration for Huancayo and Kodaikanal. Total number of events is given in parentheses. Note a small number of long disturbances at Kodaikanal.

three solar activities for negative disturbances at Huancayo and this is important for further discussion of the mechanism. In general, both stations demonstrate similar occurrence distributions, but some differences are also obvious. There is a well-pronounced night-early morning peak in the occurrence frequency for negative disturbances, while they are practically absent during daytime hours. This nighttime peak is broad at Kodaikanal overlapping the whole dark period with the maximal occurrence in the premidnight LT sector. At Huancayo the nighttime peak is large and narrow maximizing in the early morning LT sector. There is a pronounced dependence on solar activity level (Figure 4a) with the majority of negative disturbances clustering in the early morning LT sector at solar maximum, while the disturbances are spread over the whole dark LT sector under solar minimum. The disturbances start to occur early in the evening at solar minimum, but they are practically absent in the evening sector at solar maximum.

[9] Positive Q disturbances exhibit two maxima, the nighttime–early morning and the daytime ones. Similar to the negative disturbance case the variation at Kodaikanal is shifted to earlier LT hours compared to Huancayo. The nighttime peak is broad at Kodaikanal and covers the whole dusk-dawn LT sector. At Huancayo the peak localizes in the postmidnight LT sector similar to the negative disturbance case. In general, the equatorial Q disturbance pattern looks simpler compared to the midlatitude one (MDL) and this may help understand the revealed morphology.

3.3. Annual Variations

[10] The season/solar activity distribution of the number of cases for negative and positive Q disturbances at the two stations is given in Tables 1–3. The summer and winter seasons include the months selected in accordance with the different hemisphere location of the two stations (November, December, January, February, winter/summer; May, June, July, August, summer/winter; and March, April, September, October, equinoxes). For the presentation obviousness the annual distribution of occurrences (all solar activities put together) are given in Figure 5. The daytime LT sector for positive disturbances is shown only for Huancayo due to in-

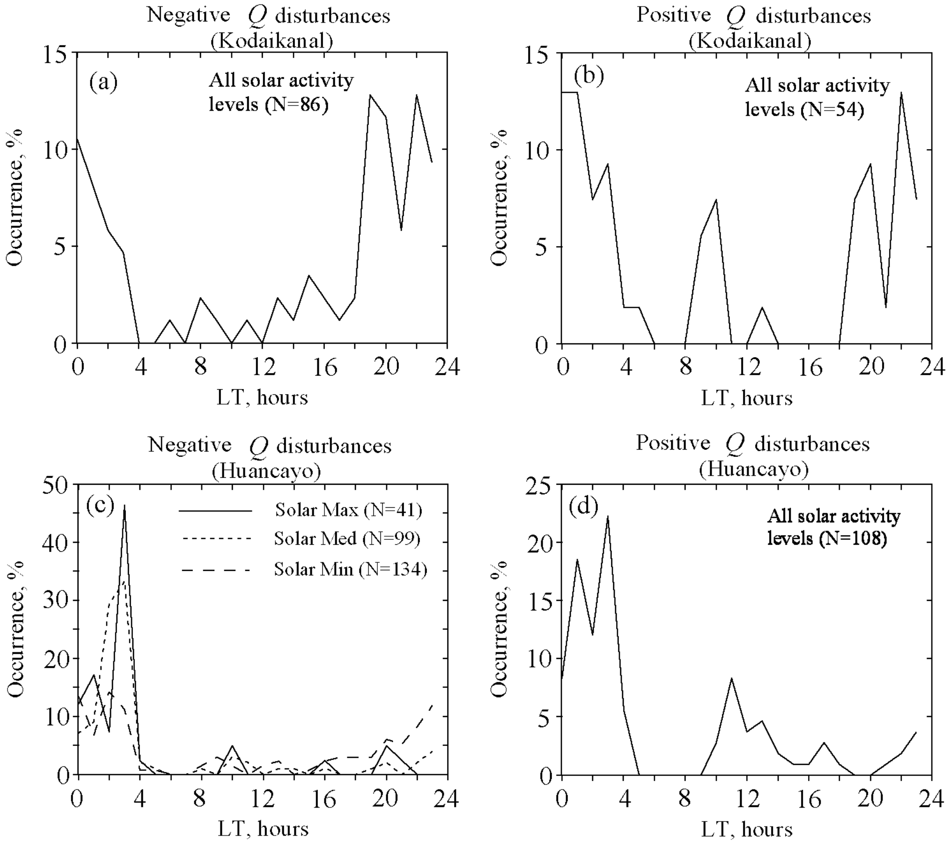

Figure 4. Occurrence for negative and positive Q disturbances with duration $\geq$ 3 hours versus local time at Huancayo and Kodaikanal. Total number of events is given in parentheses. Because of insufficient total number of disturbances all solar activities are put together in three cases.

sufficient number of events at Kodaikanal (Table 3). In general, seasonal variations are more distinct and pronounced at Huancayo. The occurrence of negative disturbances at Huancayo exhibits a broad and well-pronounced distribution with the peak maximizing in winter (Figure 5a). This is valid for all solar activities (Table 1). The morphology of positive nighttime Q disturbances at Huancayo is similar to the negative one. They also show a well-pronounced seasonal variation of the occurrence maximizing in winter (Figure 5c) under all solar activities (Table 2). The disturbances are also clustering in the early morning LT sector (Figure 4). An interesting seasonal distribution exhibit daytime positive Q disturbances at Huancayo (Figure 5e), which is inverse to the distribution of nighttime disturbances. Although the total number of events is small (Table 2), the seasonal variation is well pronounced with the maximal occurrence in summer while these disturbances are completely absent in winter (May–August).

[11] At Kodaikanal the morphological pattern is quite different. Figures 5b and 5d and Tables 1 and 3 show that seasonal variations are not distinct, although there is a tendency for a distribution with winter and summer maxima. As the equatorial $F2$ region is strongly controlled by vertical $\mathbf{E} \times \mathbf{B}$ drifts, the revealed morphological differences tell about longitudinal and perhaps hemispheric differences in vertical drifts at the two stations.

Table 1. Number of Negative Nighttime Q Disturbances at Huancayo and Kodaikanal for Different Seasons and Levels of Solar Activity

	Huancayo 1800–0500 LT			Kodaikanal 1700–0500 LT		
Solar Activity	Summer	Winter	Equinox	Summer	Winter	Equinox
Minimum	14	65	34	17	16	8
Medium	15	40	35	14	9	4
Maximum	4	25	9	4	–	1

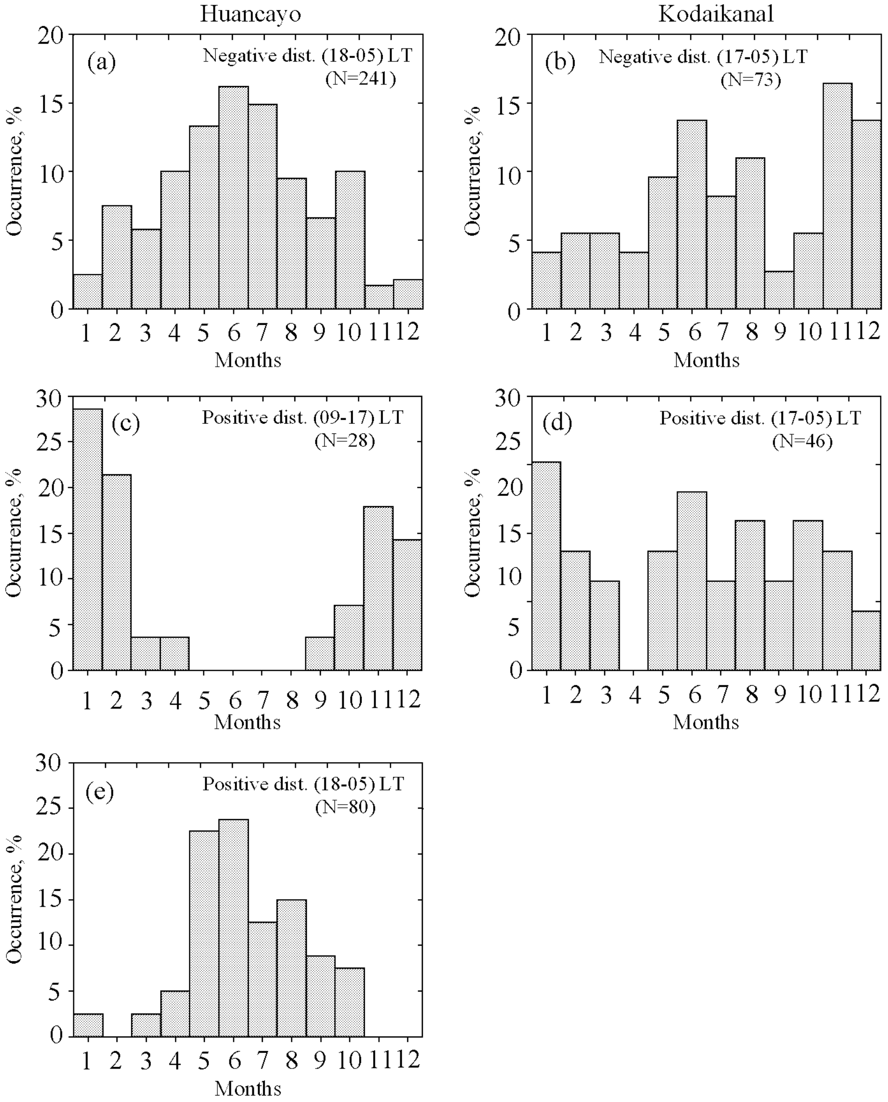

Figure 5. Seasonal variations of the occurrence for negative and positive Q disturbances with duration of ≥ 3 hours at Huancayo and Kodaikanal. The daytime LT sector is presented only for Huancayo because of the very small number of events at Kodaikanal. All solar activity levels are put together because of insufficient total number of events (given in parentheses).

3.4. Amplitude of Disturbances

[12] The $N_mF2_{\mathrm{obs}}/N_mF2_{\mathrm{med}}$ ratios for negative and positive Q disturbances versus local time are given in Figure 6 for Huancayo. Similar results were obtained for Kodaikanal, but they being less representative are not given here. Here all disturbances with the duration ≥ 1 h were taken into account and the maximal ratio observed within each particular disturbance along with the corresponding LT moment were used to draw the plots. All durations were considered

Table 2. Number of Nighttime and Daytime Positive Q disturbances at Huancayo for Different Seasons and Levels of Solar Activity

	1800–0500 LT			0900–1700 LT		
Solar Activity	Summer	Winter	Equinox	Summer	Winter	Equinox
Minimum	–	37	11	10	–	–
Medium	2	20	5	8	–	1
Maximum	–	2	3	6	–	3

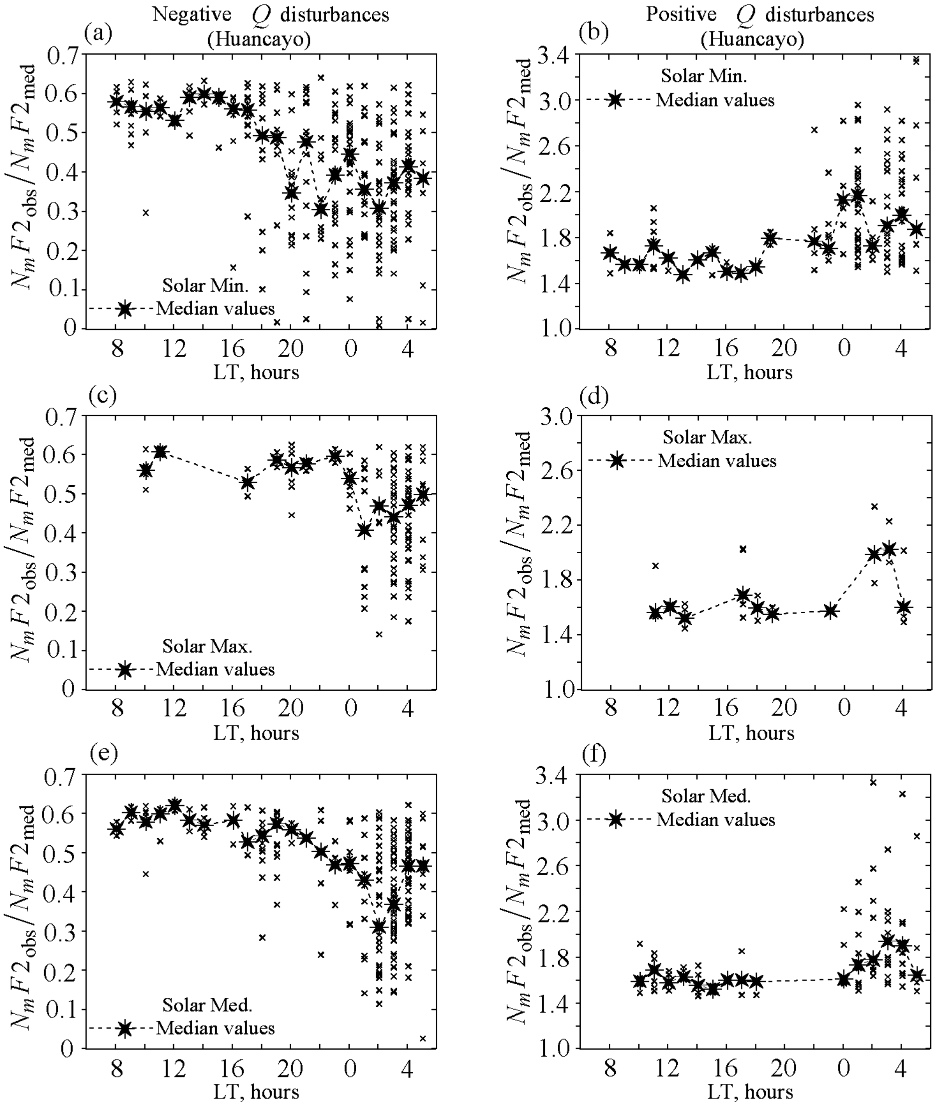

Figure 6. Diurnal variations of the maximal amplitude of negative and positive Q disturbances observed at Huancayo for three levels of solar activity. All disturbances with the duration $\geq$ 1 hour were considered to include the presunrise hours.

for the following reason. The disturbances practically do not commence during the sunrise and for a couple of hours after (Figure 4a and 4b); therefore, considering only long-duration disturbances, we are loosing many of them which commence within 1–2 hours before the dawn and then being terminated by the sunrise. Therefore we have included all disturbances to have a picture more complete. Median values over the observed ratios were found for each LT to demonstrate average diurnal variations.

[13] Negative Q disturbances exhibit a pronounced dependence on LT and solar activity level. The disturbance effect strongly increases from daytime hours ($N_mF2_{\mathrm{obs}}/N_mF2_{\mathrm{med}}$ ratio $\approx$0.6 under all solar activity levels) to nighttime hours, the effect being stronger at solar minimum when the N_mF2 decrease may reach an order of the magnitude and even larger. The disturbances are more moderate under high solar activity (Figure 6e). This dependence is seen not only in the individual disturbances but in the median values as well. The maximal negative effect is reached by the early morning hours (at 2000–0400 LT).

[14] In case of positive Q disturbances both dependencies look more moderate. Similar to the previous case the maximal disturbance amplitudes are observed in the early morning LT sector. However, the amplitude of the majority of disturbances is less than a factor of 3 even at solar minimum (Figure 6b). The dependence on solar activity is not distinct for median values, although the tendency for median ratios to increase by the nighttime hours is seen.

Table 3. Number of Nighttime and Daytime Positive Q Disturbances at Kodaikanal for Different Seasons and Levels of Solar Activity

	1700–0500 LT			0800–1600 LT		
Solar Activity	Summer	Winter	Equinox	Summer	Winter	Equinox
Minimum	9	11	5	1	1	1
Medium	8	6	6	1	3	–
Maximum	1	–	–	–	–	1

4. Discussion

[15] Let us consider the revealed morphological features from the point of view of their possible origin. Unlike middle latitudes where Q disturbances seem to be due to different processes depending on conditions (MDL), the $F2$-layer variations at the geomagnetic equator can be mainly related to vertical $\mathbf{E}\times\mathbf{B}$ plasma drifts [*Leschinskaya and Mikhailov*, 1984; *Mikhailov et al.*, 1996], and this strongly simplifies the analysis. It should be noted, however, that some morphological results may be due to the method of the Q disturbances extraction used. For instance, contrary to the midlatitude case it was found that negative Q disturbances were more numerous compared to positive ones (Figure 3). A 27-day running median used in our analysis bears the effects of positive $F2$-layer disturbances which dominate in the equatorial $F2$ region [*Adeniyi,* 1986]. Therefore any normal quiet day is perceived as a negative Q disturbance, while the $F2$ layer should be strongly modified to mark a given day as a positive Q disturbance event. Thus the situation is not symmetric with respect to the two types of disturbances. We have tried to avoid this effect dealing only with large ($\delta N_mF2 > 40\%$) deviations, but such asymmetry however takes place in our results and it can be at least partly attributed to the method used. On the other hand, morphological differences between positive and negative Q disturbances really exist. It appears in diurnal and seasonal variations of their occurrence (Figures 4 and 5) as well as in their amplitudes (Figure 6) and this may be related to a great extent to $\mathbf{E}\times\mathbf{B}$ vertical drift variations.

[16] During nighttime hours when vertical drift V_z is downward [*Fejer et al.*, 1991; *Scherliess and Fejer*, 1999; *Woodman*, 1970], Q disturbances are due to recombination of O^+ ions presenting the main ion in the $F2$ region. The stronger downward V_z the lower h_mF2, and so the higher recombination rate which increases exponentially being proportional to linear loss coefficient $\beta = \gamma_1[N_2] + \gamma_2[O_2]$. This effect is clearly seen in Figure 1 where large h_mF2 deviations from the median result in large negative and positive N_mF2 deviations. It should be stressed that the effect is totally due to the vertical $\mathbf{E}\times\mathbf{B}$ plasma drift rather than thermospheric winds as the magnetic inclination $I = 0$ at the geomagnetic equator. In principle, any noticable variations of neutral composition are not expected in the equatorial thermosphere under quiet conditions, but this question needs a special analysis for the periods of Q disturbances. Therefore here all nighttime morphological results will be considered in the framework of the vertical $\mathbf{E}\times\mathbf{B}$ drift/recombination mechanism.

[17] Figures 4 and 6 show that negative Q disturbances at solar minimum are observed for the whole night, while they cover only the postmidnight period at solar maximum. The maximal disturbance amplitudes are also larger at solar minimum. These differences can be related to the peculiarities of the observed vertical drifts. According to *Fejer et al.* [1991, Figure 1], vertical drifts during the dusk (1600–2000 LT) period at solar minimum are systematically lower compared to those at solar maximum being around zero or even negative. Another peculiarity of the drifts under solar minimum compared to solar maximum is their large day-to-day variability [*Woodman et al.*, 1977] especially during nighttime hours [*Fejer et al.*, 1979]. Therefore large negative drifts are very probable in the night at solar minimum, and this can contribute to the observed occurrence and amplitude distributions for negative disturbances under solar minimum (Figures 4a and 6a). Negative disturbances at solar maximum are seen to cluster in the postmidnight LT sector only and they are less in number compared to solar minimum. This may be related to the following reasons. The earlier discussed recombination effect depends on the linear loss coefficient β variations when $F2$ layer is shifted by vertical drifts. The thermospheric temperature is much higher at solar maximum compared to solar minimum. For instance, according to the thermospheric model MSIS 86 [*Hedin,* 1987] at the location of Huancayo and 0000 LT $T_{\mathrm{ex}} = 1060$ K under solar maximum ($F_{10.7} = 200$) and $T_{\mathrm{ex}} = 676$ K at solar minimum ($F_{10.7} = 70$). This temperature difference results in corresponding neutral scale height ($H = kT/mg$) difference for $[N_2]$ and $[O_2]$ height distributions. Therefore the same $F2$-layer shift in altitude due to vertical drift gives larger changes in β (and in N_mF2) at solar minimum when neutral scale height is less. Similarly, according to MSIS 86 at high solar activity T_{ex} decreases from 1264 K (1900 LT) to 985 K (0600 LT). Therefore the early morning hours are more preferable for negative disturbances to appear. Moreover, average negative drifts are large in the postmidnight LT sector at solar maximum [*Fejer et al.*, 1991], and this implies that individual (for a particular day) V_z values may be even larger, thus increasing the probability for a negative disturbance to occur.

[18] Another peculiarity of the vertical drift variations, the evening prereversal upsurge of V_z, which is large at solar maximum and is practically absent at solar minimum [e.g.,

Fejer et al., 1991], may also contribute to the discussed solar activity differences in the disturbance occurrence. Because of strong upward V_z at solar maximum more plasma is uplifted and stored in the topside ionosphere (in the magnetic tubes of force). Any nighttime increase of the downward V_z (after the time of V_z reversal) is accompanied by plasma influx to the equatorial $F2$ region from above, which compensates to some extent the recombination losses. The low-latitude plasma tube content is not large [*Carpenter and Park*, 1973], and this process may be efficient only for some evening hours after the V_z reversal. When by the second part of the night the electron content of the magnetic tubes is depleted, the loss process begins to dominate in nighttime $F2$ region. This is another reason for negative disturbances to appear only in the early morning LT sector during solar maximum (Figures 4 and 6). At solar minimum, on one hand, the background magnetic tube electron content is relatively small, on the other hand, the prereversal plasma uplift is practically absent [*Fejer et al.*, 1991]. Therefore the plasma influx to the evening $F2$ region due to downward V_z is not sufficient to cover the recombination losses and large negative disturbances are seen to occur starting from the evening hours (Figures 4 and 6).

[19] Positive nighttime Q disturbances correspond to low downward V_z and are due to low recombination losses as $F2$ layer is located high enough in this case (see Figure 1d). Being determined with respect to the running N_mF2 median, the maximal positive deviations are read in the early morning (presunrise) hours when the median N_mF2 values are the lowest (see Figure 1). This explains the occurrence of positive disturbances in the postmidnight LT sector (Figure 6). Also, in the end, relatively small total number of negative and positive disturbances revealed at solar maximum may be also related to higher stability of vertical drift variations observed under solar maximum conditions [*Woodman et al.*, 1977].

[20] Daytime negative and positive Q disturbances are not numerous (Figures 4 and 6 and Tables 2 and 3), however, the daytime peak in the occurrence of positive disturbances is well pronounced both at Huancayo and Kodaikanal (Figure 4), the amplitude of both type of disturbances being practically independent of solar activity level (Figure 6). The formation of the equatorial daytime $F2$ region is also strongly controlled by vertical $\mathbf{E}\times\mathbf{B}$ plasma drifts which normally are upward with a velocity of about 20 m s^{-1} [*Fejer et al.*, 1991; *Scherliess and Fejer,* 1999]. The main mechanism of N_mF2 changes is the plasma uplift from the $F2$-region heights with its subsequent transfer along magnetic lines apart from the geomagnetic equator, so-called fountain effect [*Hanson and Moffett*, 1966]. Therefore an increase of V_z (eastward electric field) results in an N_mF2 decrease, while a decrease of V_z helps plasma to store at the $F2$-region heights thus increasing N_mF2. Because of this upward plasma drift the $F2$ layer is lifted from the region of strong recombination and its effects are not that crucial as in the nighttime $F2$ region. However, in case of strong westward electric field (strong downward plasma drift) the daytime $F2$ layer may be moved downward to the strong recombination area with a subsequent N_mF2 negative disturbance effect [*Mikhailov and Leschinskaya*, 1991]. However, normally daytime $\mathbf{E}\times\mathbf{B}$ drifts vary staying positive and N_mF2 changes are controlled by the efficiency of plasma removal from the $F2$ region due to this upward drift.

[21] Therefore daytime positive Q disturbances (Figure 4) result from V_z decrease followed by h_mF2 lowering clearly seen in Figure 2 on 16 February 1966. The effect may be related to a well-known equatorial phenomenon, counter electrojet [*Mayaud*, 1977; *Rastogi et al.*, 1992; *Vyas et al.*, 1979] when normal zonal E_y electric field is decreased or even reversed. An example of strong counter electrojet observed in the Indian sector on a quiet ($Ap = 3$) day 21 July 1976 is given by *Rastogi et al.* [1992]. A decrease in E_y is clearly manifested in ΔH diurnal variations as well as in the $F2$-layer parameter changes. As a result of V_z decrease, f_oF2 at Kodaikanal is elevated with respect to a control (also quiet with $Ap = 4$) day 22 July 1976, $h'F$ is decreased, and TEC in the crest zone (Ahmedabad) is also decreased, the latter is due to a weakening of the fountain effect. Some cases of V_z direct observations at Jicamarca for the days of counter electrojet are given by *Woodman et al.* [1977]. In four presented cases the observed daytime V_z becomes negative for some hours.

[22] The other morphological feature of daytime Q disturbances: the independence of the amplitude on solar activity (Figure 6) may be also related with the daytime vertical drifts which are essentially independent of solar activity [*Fejer et al.,* 1991, 1995; *Scherliess and Fejer,* 1999]. A comparison of Q disturbance occurrences in the American and Indian sectors (Figure 4) shows general similarity in diurnal variations, but the variations are shifted to earlier hours at Kodaikanal. Besides, the nighttime peaks in the occurrence are broader at Kodaikanal than at Huancayo, practically covering all dark hours. In accordance with the earlier discussed mechanisms these differences should reflect the longitudinal differences in the vertical drift variations. Although the global equatorial F region vertical drift model by *Scherliess and Fejer* [1999] demonstrates longitudinal variations in the vertical drifts, the differences between Indian and American sectors are not that large to explain the revealed differences in the Q disturbances occurrence. Relatively large differences between vertical drift variations at Trivandrum and Jicamarca are reported by *Hari and Krishna Murthy* [1995] but for high solar activity only when Q disturbances are rarely observed. Therefore the problem of longitudinal differences in the Q disturbance occurrence needs a special analysis.

[23] Annual variations of the nighttime negative and positive Q disturbance occurrence at Huancayo exhibit well-pronounced winter peaks (Figure 5). This annual variation pattern may be also explained by vertical drift seasonal variations. Jicamarca observations [*Fejer et al.,* 1991, Figure 1] show that winter prereversal upward vertical drifts are the smallest in the year and the prereversal upsurge V_z is completely absent at solar minimum. In accordance with the earlier discussed mechanism one may expect a very modest plasma influx from above to the nighttime $F2$ region after the V_z reversal. This plasma influx seems to be insufficient to cover the recombination losses when $F2$ layer is shifted to lower heights by an increased negative V_z. Large number of negative disturbances at solar minimum (Figure 6) seems

to confirm this explanation. The other factor discussed earlier (winter/summer neutral temperature difference) is small (≤ 20 K) and cannot much contribute to the seasonal difference in the disturbance occurrence.

[24] The seasonal peculiarities in the vertical drift variations should reflect in the N_mF2 median values as well. Indeed, the *International Telecommunications Union* [1997] global empirical monthly median model gives the lowest N_mF2 early morning values in winter (June–July). This model prediction was checked using real monthly medians observed at Huancayo for some selected years when R_{12} index was relatively stable during the whole year. The model annual N_mF2 variations were confirmed with one exception; there is an additional minimum in January taking place for some years. This allows us to explain annual variations for the nighttime positive Q disturbance occurrence (Figure 5c). As it was mentioned earlier positive deviations are read with respect to the running median N_mF2 values which are the lowest in winter. The results of our analysis also give some percent of events in January (Figure 5), which obviously are related to the additional January minimum in median N_mF2 values.

[25] The situation with the annual variations of Q disturbances in the Indian sector is less obvious (Figure 5a, 5c, and 5e) and seasonal variations are not pronounced. It looks as if there are seasonal and nonseasonal components and their contributions vary with the station location. *Mayaud* [1977] has drawn to such a conclusion analyzing the effect of counter electrojet at Huancayo and Kodaikanal. As it was mentioned earlier daytime positive Q disturbances may be related to counter electrojet when zonal electric field is decreased or even reversed. The daytime (afternoon) counter electrojet occurrence exhibits a well-pronounced summer peak at Huancayo, while at Kodaikanal the occurrence distribution is broad covering all seasons [*Mayaud*, 1977, Figure 8]. However, *Vyas et al.* [1979] give the maximal daytime counter electrojet occurrence in summer for the Indian sector as well. Mayaud suggests that there exists two sources for the counter electrojet events. A source centered on the month of January at any longitude and strongly modulated by the Moon and a source centered on the solstice in each hemisphere. The two sources overlap at Huancayo and we have a well-pronounced summer peak for the daytime positive Q disturbance occurrence (Figure 5e).

5. Conclusions

[26] The main results of our analysis can be summarized as follows:

[27] 1. An analysis of all available N_mF2 observations over Huancayo (American sector) and Kodaikanal (Indian sector) during geomagnetically quiet periods has revealed both positive and negative Q disturbances, their amplitude being comparable to $F2$-layer storm effects resulted from increased geomagnetic activity.

[28] 2. Contrary to middle latitudes, negative Q disturbances are more numerous compared to positive ones at both stations and all levels of solar activity. The percentage of long (both negative and positive) disturbances is larger in the American sector. Long-duration (≥ 3 hours) disturbances are more numerous at solar minimum compared to solar maximum.

[29] 3. The majority of negative long-duration disturbances occur in the dark LT sector, and they are practically absent during daytime hours. At Huancayo, negative disturbances are clustering only in the postmidnight LT sector under solar maximum, but they cover the whole dark LT sector at solar minimum; the latter takes place at Kodaikanal for all solar activity levels.

[30] 4. Positive long-duration Q disturbances exhibit two occurrence maxima, the nighttime–early morning and the daytime ones. The nighttime peak is broad at Kodaikanal and covers the whole dark LT sector, while at Huancayo the peak localizes in the early morning LT sector similar to the negative disturbances occurrence.

[31] 5. Annual variations for the occurrence of both negative and positive Q disturbances at Huancayo exhibit a well-pronounced pattern with the occurrence maximizing in winter for all solar activity levels. On the contrary, daytime positive Q disturbances at Huancayo are observed only in summer. At Kodaikanal, annual variations for the occurrence are not distinct, although there is a tendency for a distribution with winter and summer maxima.

[32] 6. The revealed morphology of Q disturbances can be explained (at least qualitatively) by the observed $\mathbf{E} \times \mathbf{B}$ vertical drifts, whose diurnal, seasonal, and solar activity variations are well documented especially in the American sector using Jicamarca observations. The situation at Kodaikanal is not that clear. Keeping in mind that variations of the $F2$ region at the geomagnetic equator is mostly controlled by $\mathbf{E} \times \mathbf{B}$ vertical drifts, the morphological differences between Huancayo and Kodaikanal in Q disturbance occurrences should be attributed to corresponding differences in the vertical drift variations. However, the observed and modeled [e.g., *Scherliess and Fejer,* 1999] longitudinal (American/Indian) differences are not large enough to explain the revealed morphological differences. Further analyses using model calculations are required to clear up this problem as well as to answer the question if the observed $\mathbf{E} \times \mathbf{B}$ drift variations are sufficient at a quantitative level to explain the revealed morphology of equatorial Q disturbances.

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V. Kh. Depuev, A. Kh. Depueva, and A. V. Mikhailov, Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation (IZMIRAN), 142190 Troitsk, Moscow Region, Russia. (avm71@orc.ru)