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Morphology of quiet time *F*2-layer disturbances: High to lower latitudes

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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 26 Northern Hemisphere high-to-lower latitude ionosonde stations. Both positive and negative Q disturbances were revealed, their amplitude being comparable to moderate $F2$-layer storm effects. The occurrence of Q disturbances exhibits a systematic dependence on solar activity, season, and local time. Spatial variation pattern is different for positive and negative Q disturbances with the amplitude of the former increasing with latitude while the amplitude of the latter being practically latitudinal-independent. Longitudinal variations of the amplitude for both types of disturbances look like a planetary wave with minimal deviations in the American sector and maximal deviations in the European sector. Large longitudinal gradients in N_mF2 can appear on the front of such waves. *INDEX TERMS:* 2435 Ionosphere: Ionospheric disturbances; 2423 Ionosphere: Ionization mechanisms; 2443 Ionosphere: Midlatitude ionosphere; *KEYWORDS:* Ionosphere; ionosphere-atmosphere interaction; ionospheric disturbances.

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1. Introduction

[2] Traditionally, ionospheric $F2$-layer disturbances are related to solar activity variations (geomagnetic activity being a part of it), but there exists a large class of disturbances which are not directly due to geomagnetic activity but have their origin in the atmosphere itself. Partly, such quiet time disturbances (Q disturbances) may be attributed to the impact from below. Presumably, the energy is transferred by internal gravity waves propagating from troposphere and stratosphere and producing perturbations in upper atmosphere not only at the heights of the lower ionosphere (D region), where the meteorological control is well known [e.g., *Danilov*, 1986; *Danilov et al.*, 1987], but also in the F region [*Forbes et al.*, 2000; *Kazimirovsky and Kokourov*, 1991; *Kazimirovsky et al.*, 2003; *Khachikjan,* 1987; *Rishbeth and Mendillo,* 2001]. One of the first attempts to analyze "pure" ionospheric disturbances in the $F2$ layer was undertaken by *Zevakina and Hill* [1978] using ionosonde observations at the low-latitude station, San Jose, for solar minimum (1964–1965) and solar maximum (1968) conditions. Quiet time N_mF2 deviations in the daytime $F2$ region observed around equinoxes were analyzed by *Mikhailov and Schlegel* [2001]. Another example of strong N_mF2 quiet time deviations presents the midlatitude nighttime $F2$ layer where strong up to a factor of 3–5 and even larger deviations in N_mF2 is a common feature of the night-to-night variability [*Farelo et al.*, 2002; *Mikhailov and Förster*, 1999; *Mikhailov et al.*, 2000a, 2000b]. Well-known quasi-2-day oscillation in the ionosphere [*Altadill and Apostolov*, 2001; *Apostolov et al.*, 1995; *Chen*, 1992; *Forbes and Zhang*, 1997; *Forbes et al.*, 2000; *Rishbeth and Mendillo*, 2001] also may be attributed to the meteorological effects in the $F2$ region as they are not related to geomagnetic activity. It should be noted that Q disturbances are not only rather frequent but their amplitude is comparable to the amplitude of moderate $F2$-layer storm effects. It seems that $F2$-layer Q disturbances have different origins depending on conditions, but no systematic analysis of this problem has been done yet. This paper is devoted to the morphological analysis of $F2$-layer Q disturbances using the worldwide ground-based ionosonde observations from high to lower latitudes in the Northern Hemisphere. Equatorial $F2$ layer exhibits different morphology, and it will be considered in a separate paper. Physical interpretation of the revealed morphological features will be given later elsewhere.

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Table 1. Stations and Periods of Observations Available, Geodetic Coordinates, and Invariant Latitudes of the Stations

Station	Latitude	Longitude	Invariant Latitude	Years
Kiruna	67.8	20.4	64.4	1957–1999
Sodankyla	67.4	26.6	63.6	1957–1989
Lycksele	64.7	18.8	61.5	1957–1999
Arkhangelsk	64.6	40.5	60.1	1969–1993
Uppsala	59.8	17.6	56.6	1957–1999
St. Petersburg	59.9	30.7	55.9	1957–1998
Magadan	60.1	151.0	52.8	1969–1999
Juliusruh	54.6	13.4	51.6	1957–1999
Gorky	56.1	44.3	51.4	1958–1989
Ekaterinburg	56.7	61.1	51.4	1957–1995
Kaliningrad	54.7	20.6	51.2	1964–1994
Tomsk	56.5	84.9	50.9	1957–1997
Moscow	55.5	37.3	50.8	1957–1997
Slough	51.5	−0.6	49.8	1949–1996
Dourbes	50.1	4.6	47.8	1957–1990
Kiev	50.7	30.3	46.5	1964–1992
Irkutsk	52.5	104.0	45.6	1957–1997
Poitiers	46.6	0.3	45.1	1957–1998
Khabarovsk	48.5	135.1	40.2	1959–1993
Sofia	42.6	23.4	38.5	1964–1999
Rome	41.9	12.5	37.2	1958–1998
Wakkanai	45.4	141.7	36.7	1957–1990
Alma-Ata	43.2	76.9	35.7	1957–1989
Ashkhabad	37.9	58.3	30.5	1957–1994

2. Data Analysis

[3] The main morphological analysis was made over 26 ionosonde stations located in the Eurasian sector using all observations available (Table 1). As the morphology of Q disturbances is expected to depend on latitude, all the stations in accordance with their invariant latitude were conventionally divided in high-latitude (six auroral and subauroral stations), midlatitude (12 stations), and lower-latitude (eight stations) ones. A 27-day f_oF2 running median centered for the day in question rather than usual monthly median was used for the Q disturbance analysis. On one hand, a 27-day running median looks more natural as this period equals to one solar rotation; on the other hand, this saves us from large and unreal disturbance effects in the beginning and in the end of a month as well as at the junction of 2 months especially during the equinoctial periods when changes in the thermosphere and ionosphere are very fast. The advantage of using running f_oF2 median for $F2$-layer disturbance analyses was stressed long ago [e.g., *Mednikova*, 1957]. Q disturbances were referred to hourly $(N_mF2/N_mF2_{\rm med} - 1)$ deviations more than 40% if all 3-hour Ap indices were ≤ 7 for 24 previous hours. This assumption is based on the empirical estimation of the ionosphere reaction to the forcing geomagnetic activity. Some estimates of this time constant for midlatitude $F2$ region are 0–6 hours for positive disturbances [*Zevakina and Kiseleva*, 1978], 12 hours [*Wrenn et al.*, 1987], 15 hours [*Wu and Wilkinson*, 1995], 6–12 hours [*Forbes et al.*, 2000]; 16–18 hours [*Kutiev and Muhtarov*, 2001], and 8–20 hours depending on season [*Pant and Sridharan*, 2001]. 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 $R_{12} > 100$. The total number of Q disturbances found depends on the latitude of a station and the period of observations available. For instance, at Slough with the longest period of observations the number of negative (257) and positive (1050) Q disturbances. At Arkhangelsk, located in the auroral zone but with a short period of observations, the corresponding numbers are 225 and 667 (see also section 3.1)

3. Morphological Results

[4] In the beginning, we present some examples of Q disturbances to get an idea of how they look in comparison with usual $F2$-layer storm effects. A strong daytime negative disturbance on 23 April 1980 is shown in Figure 1 (top). Note that only daytime period was subjected to the N_mF2 decrease, while N_mF2 values for the whole previous day and nighttime hours of 23/24 April are close to the median. Some residual effect takes place on the next day, 24 April, and again during daytime hours only. Another interesting feature of this type of disturbances is h_mF2 variations calculated using the expression by *Bradley and Dudeney* [1973]. Unlike usual negative $F2$-layer storm effect when h_mF2 al-

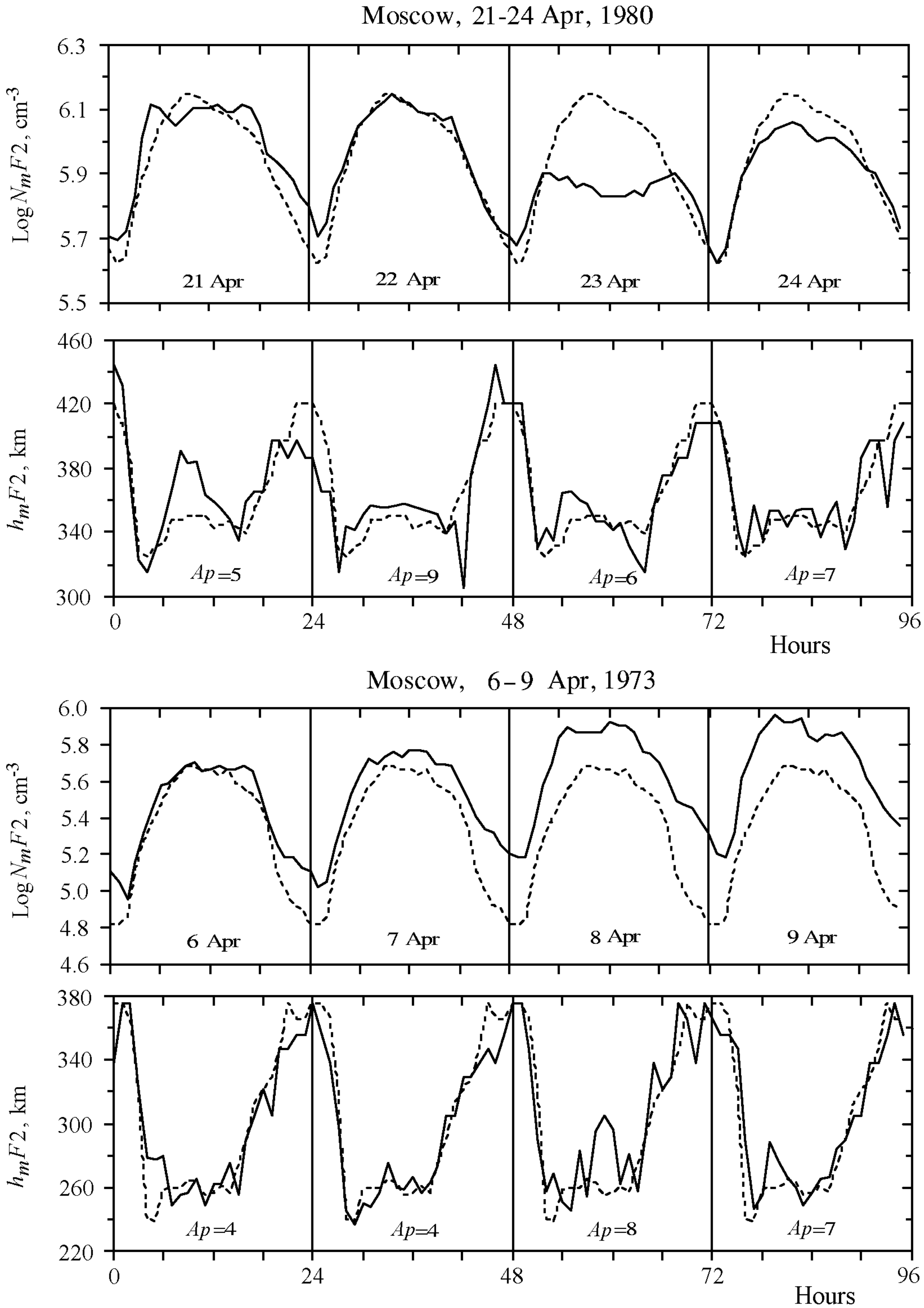

Figure 1. Examples of negative and positive daytime Q disturbances observed at Moscow (solid lines). A 27-day running median is given by dashed lines. Note that h_mF2 are close to median values during these events. Daily Ap indices are given.

ways increases, in this case, h_mF2 turns out to be close to the median values.

[5] A long-duration positive Q disturbance effect is shown in Figure 1 (bottom). A pronounced positive N_mF2 effect lasts for some days both during daytime and nighttime hours. Similar to the previous case, h_mF2 variations are very close to the median values, and this is not observed for a normal $F2$-layer positive storm effect.

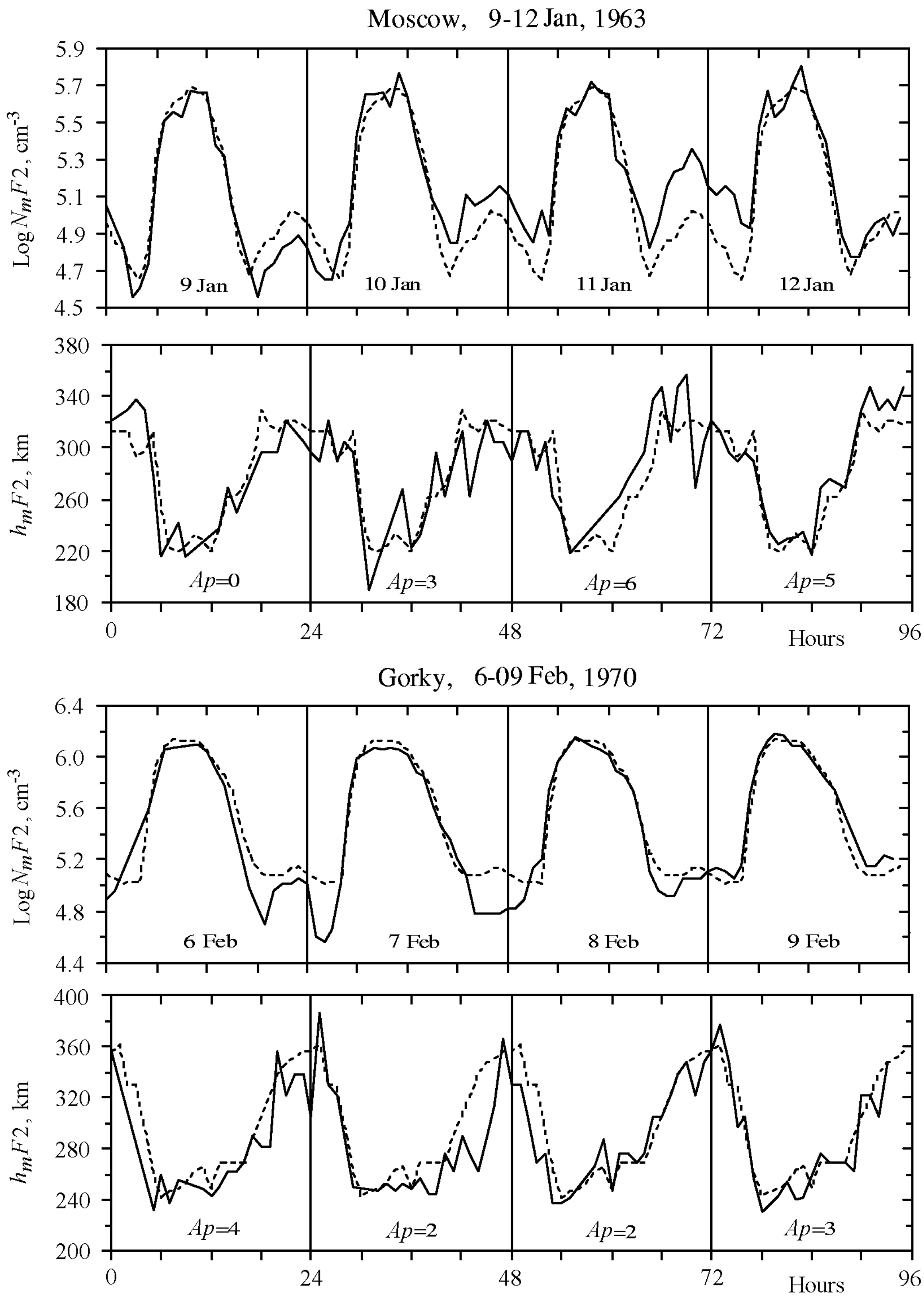

Figure 2. Same as Figure 1, but for positive and negative nighttime Q disturbances observed at Moscow and Gorky (solid lines). Note that the disturbance effect appears only during nighttime hours while daytime N_mF2 values coincide with the median, as earlier h_mF2 are close to median values.

[6] Positive (Figure 2, top) and negative (Figure 2, bottom) nighttime Q disturbances are shown in Figure 2. Note that the effect appears only during nighttime hours, while daytime N_mF2 values coincide with the median. An interesting feature of the positive effect (Figure 2, top) is a steady N_mF2 increase for three nights followed by a sharp N_mF2 decrease to the median value on 12 January, although the geomagnetic conditions conserved at a quiet level. Such be-

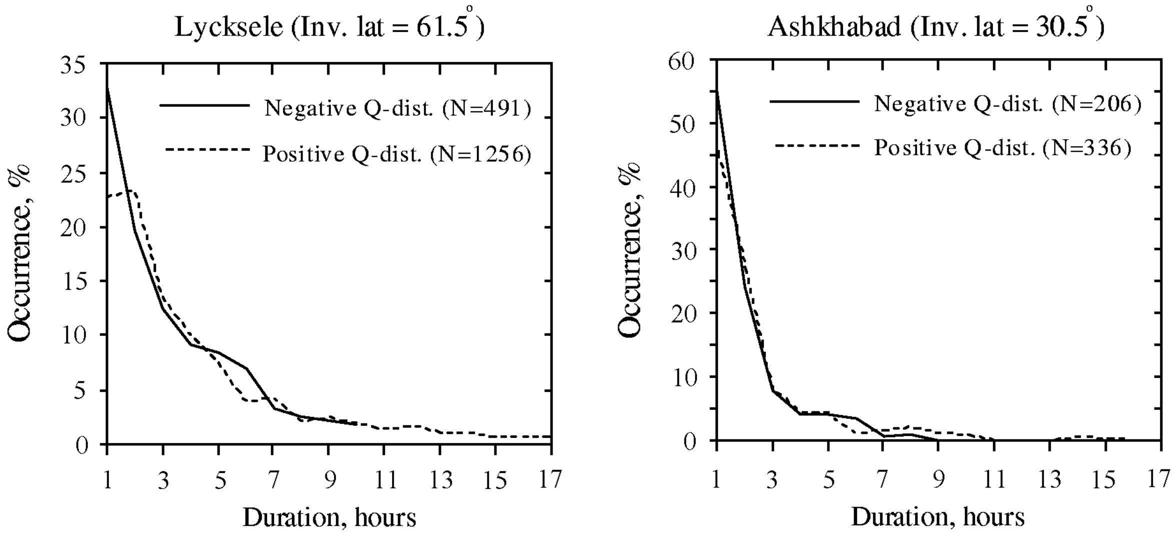

Figure 3. Distributions for the occurrence of positive and negative Q disturbances versus their duration. Total number of events is given in parentheses.

havior was revealed for some other cases. Similar tendency with a steady N_mF2 increase for three nights is seen for a negative Q disturbance case (Figure 2, bottom).

[7] Let us consider morphological results obtained over all stations and periods of observations available.

3.1. Duration and Total Number of Disturbances

[8] Distributions for the occurrence of positive and negative Q disturbances versus their duration are shown in Figure 3 for high-latitude Lycksele and low-latitude Ashkhabad stations. All levels of solar activity were put together. 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 thermospheric parameters. A 3-hour (4 hourly successive f_oF2 values) threshold was accepted for our analysis. The distributions are seen to be broader at high latitudes; that is, the percentage of long (both negative and positive) disturbances increases with latitude. This latitudinal dependence is shown in Table 2. Positive disturbances are seen to be more numerous than negative ones at all latitudes.

[9] The dependence on solar activity level was analyzed for Slough station by selecting 10 years of solar maximum and 10 years of solar minimum. The total number of cases (solar maximum/solar minimum) is (144/280) for positive disturbances and (38/92) for negative ones. It is seen that (1) positive Q disturbances are more numerous at any level of solar activity and (2) both types of disturbances are more numerous (by 2 times) at solar minimum.

Table 2. Percentage of Long ($\geq$ 3 hours) Q Disturbances at Lower-, Middle-, and High-Latitude Stations

Station	Ashkhabad	Slough	Lycksele
Positive	25	50	54
Negative	20	33	48

3.2. Occurrence Versus Local Time

[10] Distributions of the occurrence for negative and positive Q disturbances versus local time (LT) are given in Figure 4. The stations were grouped in accordance with their latitudes as mentioned earlier. Although there is some dependence on latitude, in general, both types of disturbances are the most frequent in the evening and night–early morning LT sectors, and they are rare during daytime. Similar results were obtained earlier for usual negative $F2$-layer storms [*Mednikova*, 1957; *Prölss and von Zahn*, 1978]. Partly, this is due to the method used as the deviations of $> 40\%$ are not frequent in daytime when N_mF2 are large. However, this effect also may have physical explanation as it takes place for usual negative $F2$-layer storms [*Prölss*, 1995]. Therefore three LT time intervals will be considered further in our analysis: daytime (0900–1500 LT), evening (1600–2200 LT), and nighttime-early morning (0100–0400 LT) sectors. A well-pronounced nighttime peak takes place for negative disturbances at high latitudes. The evening peak is forming earlier at lower and later at higher latitudes in case of negative disturbances. Midlatitude stations exhibit the maximal early morning peak for positive disturbances with the decreasing occurrence both to lower and higher latitudes. Contrary to the negative disturbance case, high-latitude stations exhibit the earliest evening peak for positive disturbances. All these morphological features imply different physical mechanisms of their formation.

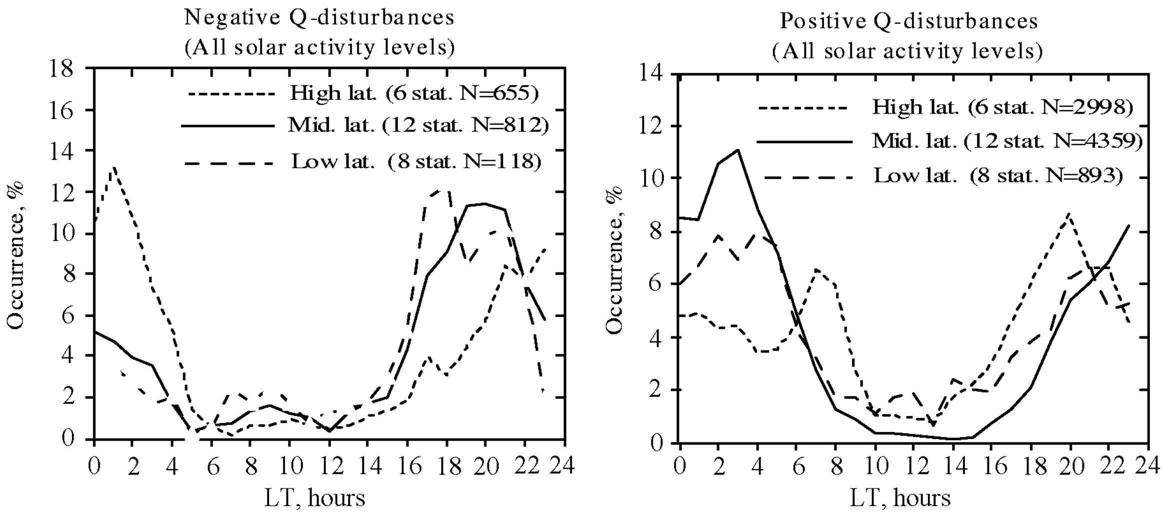

Figure 4. Occurrence for negative and positive Q disturbances versus local time for high-, middle-, and lower-latitude stations. Total number of stations and events are given in parentheses.

3.3. Seasonal Dependence

[11] Seasonal dependence for the occurrence of negative Q disturbances is shown in Figure 5 for daytime (0900–1500 LT) and evening (1600–2200 LT) sectors where the occurrence frequency is the minimal and the maximal, correspondingly. All solar activity levels were combined for daytime hours (Figure 5, left) as the total number of disturbances is small. However, it was possible to consider separately three solar activity levels for the evening hours (Figure 5, right). Negative disturbances are seen to cluster around winter months (November–January) at high and middle latitudes in both LT sectors for all solar activity levels. The pattern is somewhat different for lower-latitude stations. No seasonal dependence takes place for solar medium and minimum in the evening sector, the number of cases being sufficient. There also exists a summer increase of the occurrence in the daytime sector. However, in general, we may conclude that winter season is the most preferable for negative Q disturbances and the revealed stability of the seasonal pattern may help understand physical mechanism of the effect.

[12] Figure 6 gives seasonal dependence for the occurrence of positive Q disturbances for daytime (0900–1500 LT) and nighttime–early morning (0100–0400 LT) sectors. All solar activity levels were put together for daytime hours (Figure 6, left) as the total number of disturbances is small. However, it was possible to consider separately three solar activity levels for the other LT sector (Figure 6, right). Semiannual variations with peaks around equinoxes dominate at high and middle latitudes in the daytime sector, while a well-pronounced summer peak takes place at lower-latitude stations. Seasonal variations are different at different latitudes in the nighttime sector (Figure 6, right). All levels of solar activity demonstrate a pronounced summer peak in the occurrence at high-latitude stations. A very large May peak (106 points of 347) takes place at middle latitudes at high solar activity. On the other hand, no seasonal variations were found at medium and low solar activity at mid-latitude stations. No pronounced seasonal variations in the occurrence were revealed at low latitudes. Summarizing one may conclude that the seasonal variation pattern for positive Q disturbance is more complicated and less systematic compared to the negative Q disturbance case. This may tell us that some processes are responsible for the seasonal variation pattern and their contribution varies with geophysical conditions.

3.4. Spatial Variations

[13] The available set of stations allows us to consider spatial variations of some parameters. Figure 7 gives latitudinal variations of the percent of time occupied by disturbances in three LT sectors. This parameter is related to the number or occurrence frequency of the disturbances. Along with Q disturbances all observed $F2$-layer perturbations are considered for a comparison. Only disturbances with $\delta N_m F2 > 40\%$ and duration ≥ 3 hours are included. The $F2$-layer perturbations marked "All", in fact, present D disturbances related to geomagnetic activity as the share of Q disturbances is small in the total number of perturbations. Polynomial approximation of the variations is made for the sake of obviousness. The variations of D and Q negative disturbances are seen to be quiet different (Figure 7, left). D disturbances demonstrate large and well-pronounced latitudinal variations, but very small (especially during daytime) latitudinal changes take place for Q disturbances. Obviously, this tells about different mechanisms of their formation. The picture is different for positive Q disturbances (Figure 7, right). The character of their latitudinal variation is similar to the D disturbance ones especially in the evening and early morning LT sectors. This tells us that mechanisms of their formation may be similar.

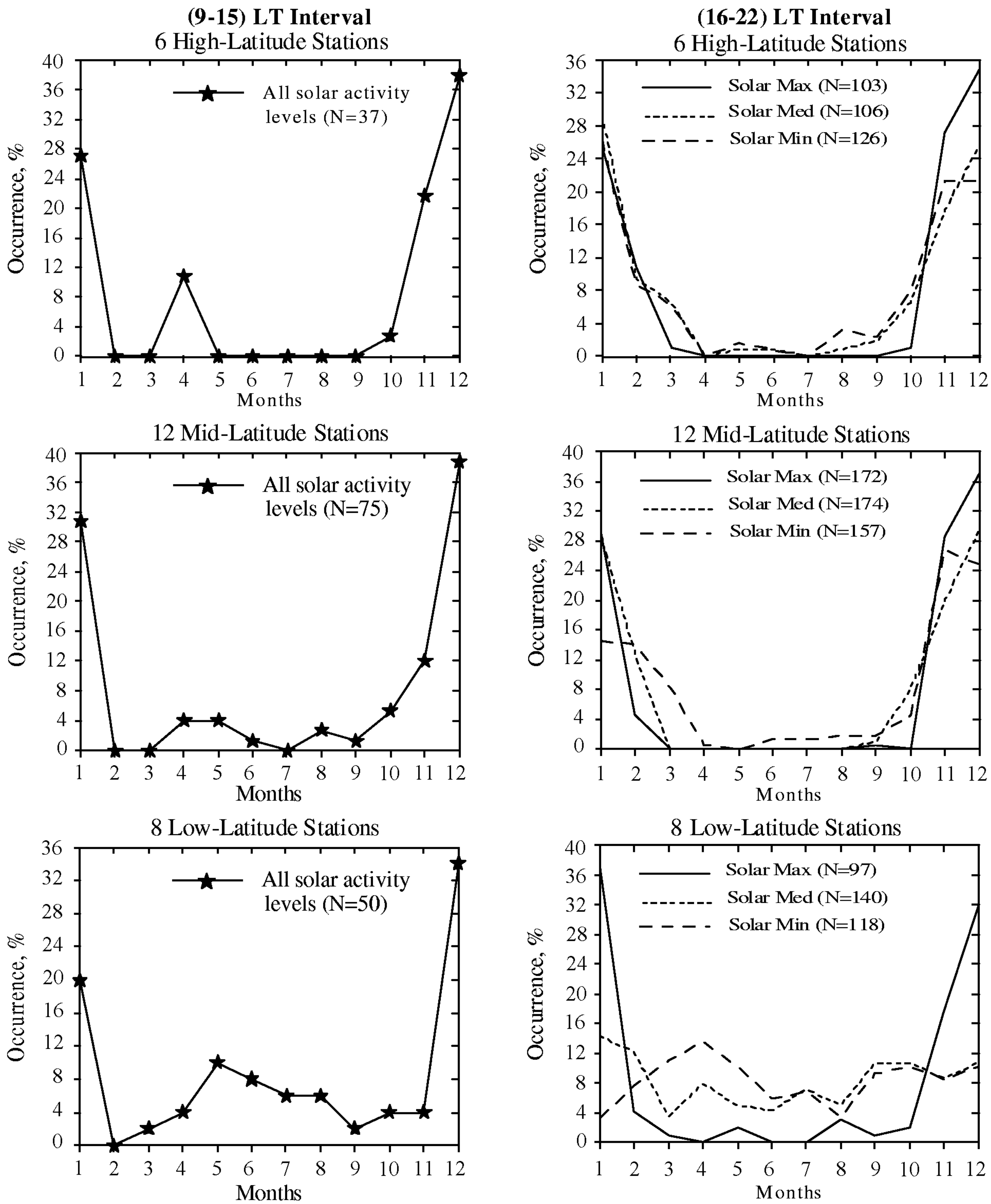

Figure 5. Seasonal variations of the occurrence for negative Q disturbances at high, middle, and lower-latitude stations in the daytime and evening LT sectors. Because of insufficient number of daytime disturbances all solar activity levels are put together (left), but three solar activities are given separately for the evening sector; total number of events is given in parentheses.

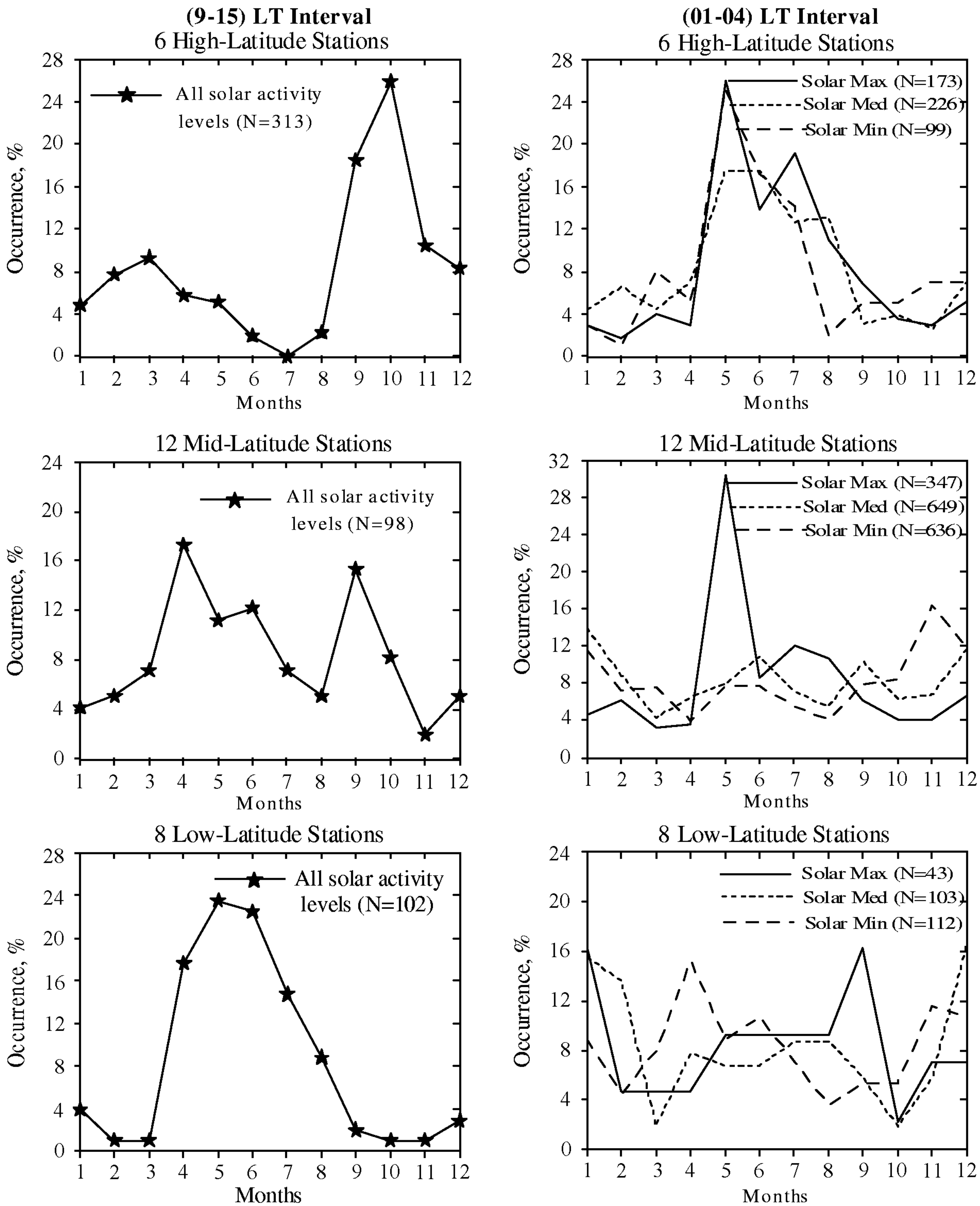

Figure 6. Same as Figure 5 but for positive Q disturbances.

[14] Figures 8 and 9 give 2-D plots for the amplitude ($N_mF2/N_mF2_{\rm med}$ averaged over 1100–1400 LT time interval) of strong positive (6–9 April 1973) and negative (6–8 January 1970) Q disturbances. All available over the Northern Hemisphere, middle- and high-latitude ionosonde observations were included. Invariant latitudes were used in Figures 8 and 9, but similar results are obtained with geodetic latitudes as well. An obvious difference is seen between the two cases, in particular in the Eurasian longitudinal sector where the number of stations is sufficient. The positive dis-

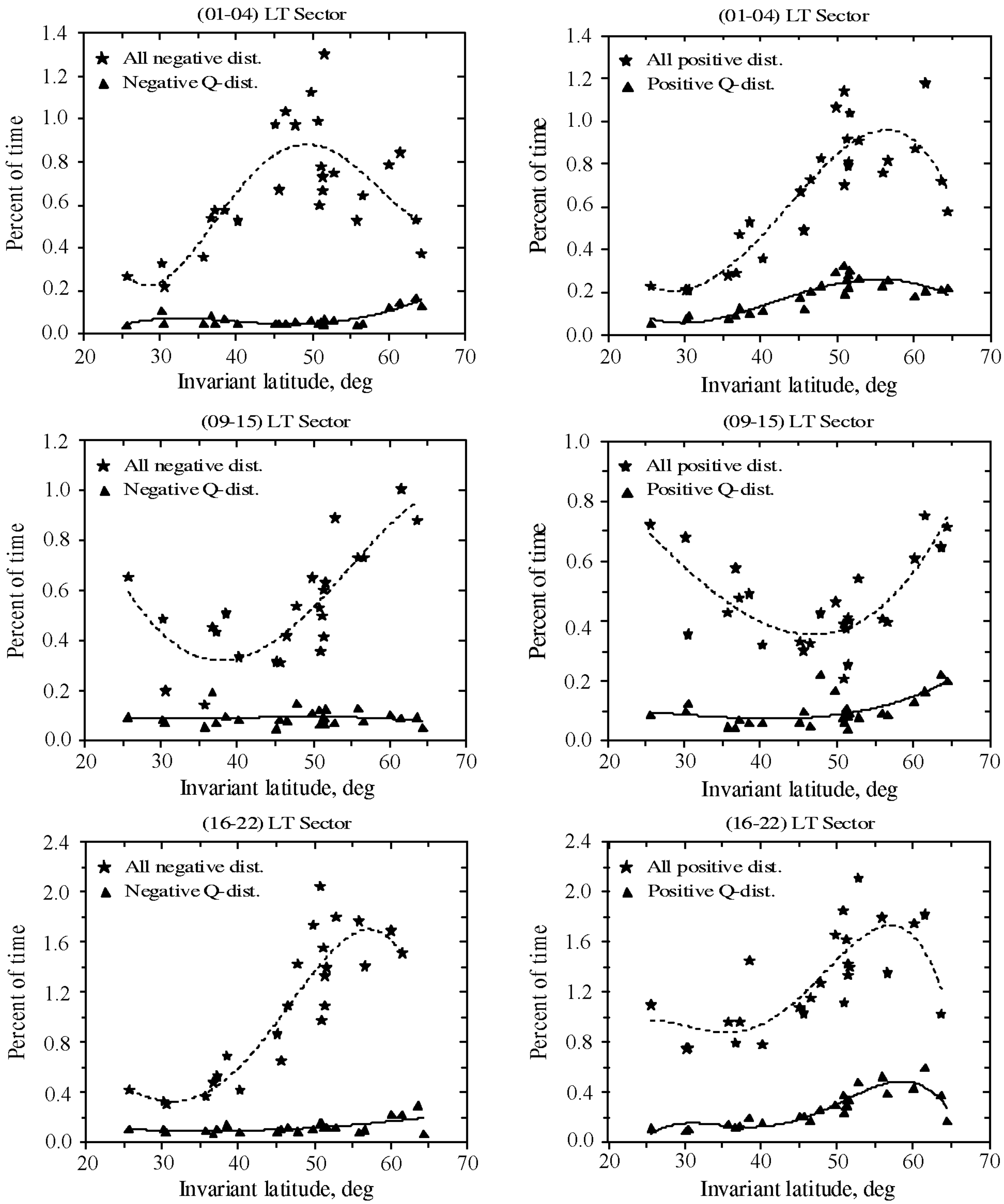

Figure 7. Latitudinal variations of the percent of time occupied by negative and positive Q disturbances in three LT sectors (triangles). Polynomial approximation of the variations is given for the sake of obviousness. Along with Q disturbances all observed $F2$-layer perturbations (stars) are given for a comparison. Note a principle difference between the two variations for negative disturbances and some similarity in variations in case of positive disturbances.

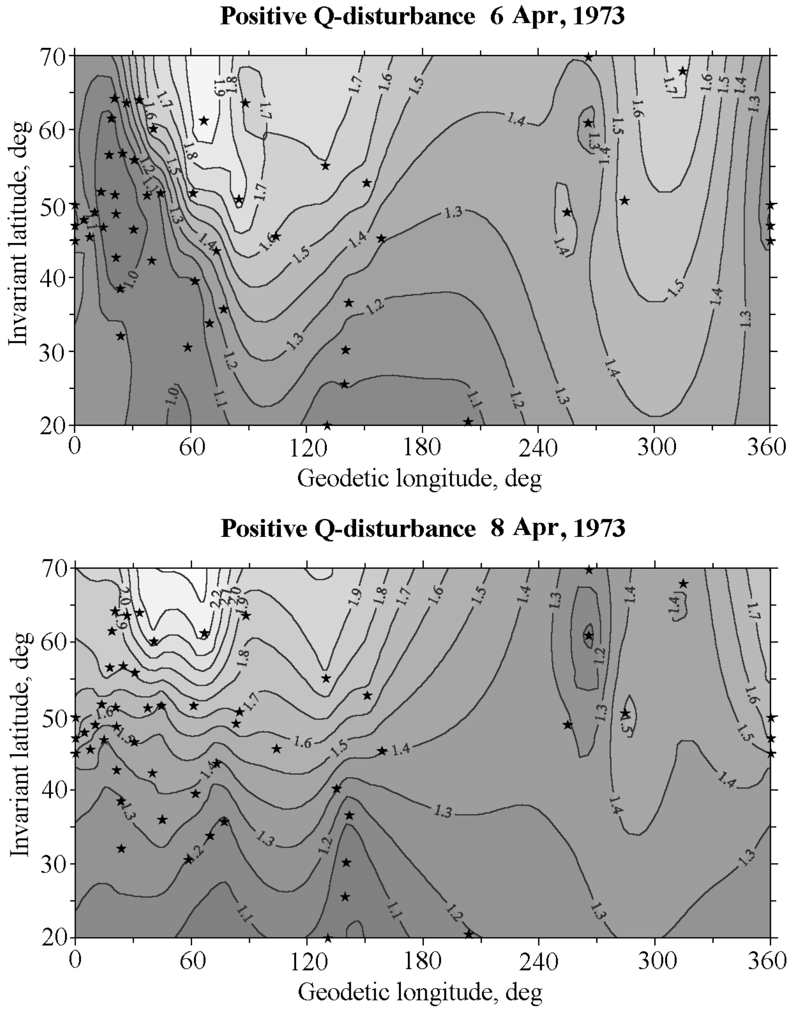

Figure 8. Two-dimensional distributions for the amplitude ($N_mF2/N_mF2_{\mathrm{med}}$ ratio averaged over 1100–1400 LT time interval) of a strong positive Q disturbance on 6–9 April 1973. Note a latitudinal type of variations for the amplitude in this case as well as a relatively stable minimum in the American sector and large variability of the amplitude in the European one. A steep longitudinal gradient is seen in the eastern Europe on 6 April, but the whole Europe is covered by the disturbance wave on 8 April.

turbance exhibits mostly latitudinal variations for the amplitude, the latter increasing with latitude. On the contrary, the negative disturbance demonstrates mainly longitudinal variations with the amplitude slightly varying with latitude (compare Figure 7). This difference in the amplitude variations was stressed earlier by *Mikhailov and Schlegel* [2001] for other cases of positive and negative Q disturbances.

[15] The 2-D plots were used to analyze longitudinal variations of the amplitude along the $\Phi_{\mathrm{inv}} = 60°$ latitude. The points were read from the 2-D plots with a step of contour lines and then approximated by a polynomial (Figure 10). In case of the positive disturbance, besides latitudinal variation of the amplitude clearly seen in the Eurasian sector (Figure 8), pronounced longitudinal variations take place especially at high latitudes. The disturbance looks like a wave with the latitudinal increasing amplitude. A relatively stable minimum of the amplitude takes place in the American sector, while the maximum is observed in the Eurasian sector. The peak is seen to move back and forth in its day-to-day variations (Figure 10, top). The front of this wave may be very steep as on 6 April or gently sloping as on 7 April. In the western European sector (where the number of stations is sufficient) the disturbance is seen to be absent on 6 April as it is located a little to the east. In 2 days (8 April) the disturbance covers Europe, and its amplitude reaches the maximum and then starts to decrease on 9 April (Figure 10, top). So this wave demonstrates a complex spatial structure.

[16] In case of negative disturbance on 6–8 January 1970 (Figure 9), there is practically no latitudinal dependence for the amplitude in any longitudinal sector. Again the dis-

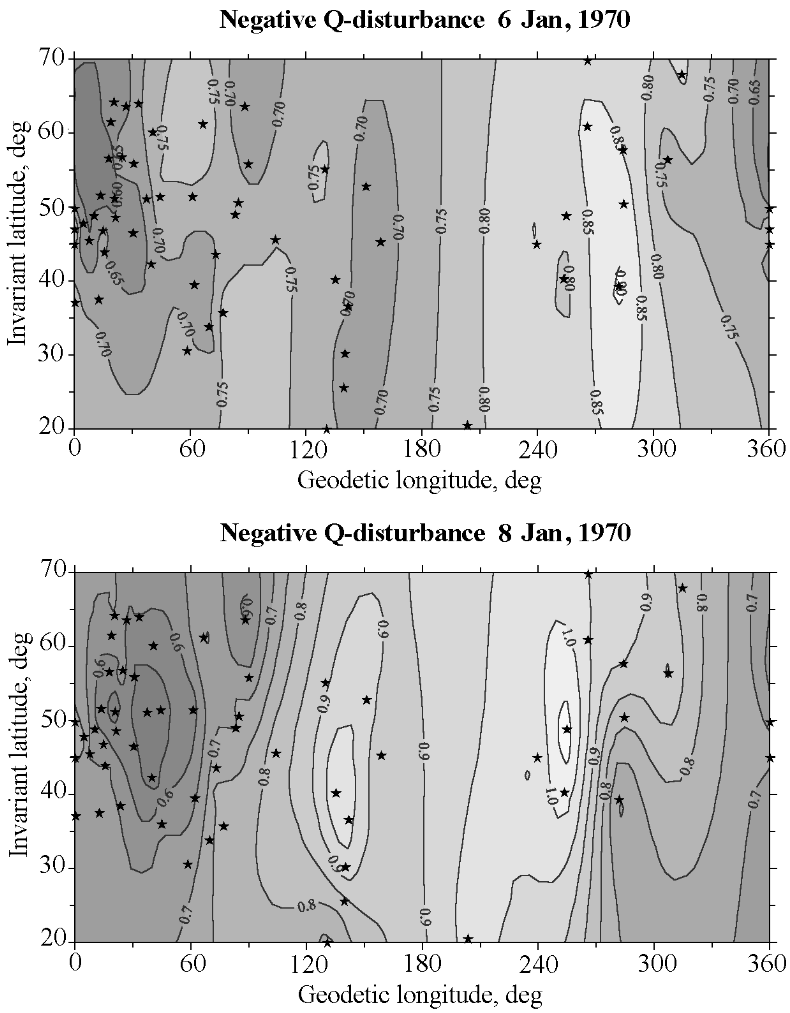

Figure 9. Same as Figure 8, but for a strong negative Q disturbance on 6–8 January 1970. Note the absence of latitudinal variations for the amplitude contrary to a positive disturbance case. Again a pronounced longitudinal difference between the American and European sectors takes place; the former is less disturbed.

turbance looks like a planetary wave with the minimal deviations located in the American sector and the maximal amplitudes in the European sector. In this case unlike the previous one, the ionosphere seems to shift as a whole simultaneously at all latitudes in a given longitudinal sector, and this is a principle differences between the two types of disturbances. In both cases a pronounced longitudinal difference between the two sectors takes place: the American sector is less disturbed compared to the European one. An additional analysis is needed to check whether this is a propagating wave with a period of one day or a standing one with varying day-to-day positions of its extremes. Although the number of stations available is small in the Western Hemisphere, the difference between the European and American sectors is obvious, and it should be stressed: the disturbance effect is less pronounced in the Western Hemisphere.

4. Discussion

[17] Lots of interesting morphological features have been revealed in our analysis. We suppose that most of them can be explained in frames of the present-day $F2$-layer formation mechanism, that is, via variations of solar EUV radiation, neutral composition, winds, and plasmaspheric fluxes. For instance, daytime long-duration Q disturbances seem can be related with the atomic oxygen abundance variations in the thermosphere [*Mikhailov and Schlegel*, 2001]. A steady increase of N_mF2 values for some successive nights (Figure 2) may be due to the increasing plasmaspheric flux to the nighttime $F2$ region as similar effect was observed at Millstone Hill and explained in this way [*Mikhailov and Förster,* 1999]. The effect of low-occurrence probability for daytime Q dis-

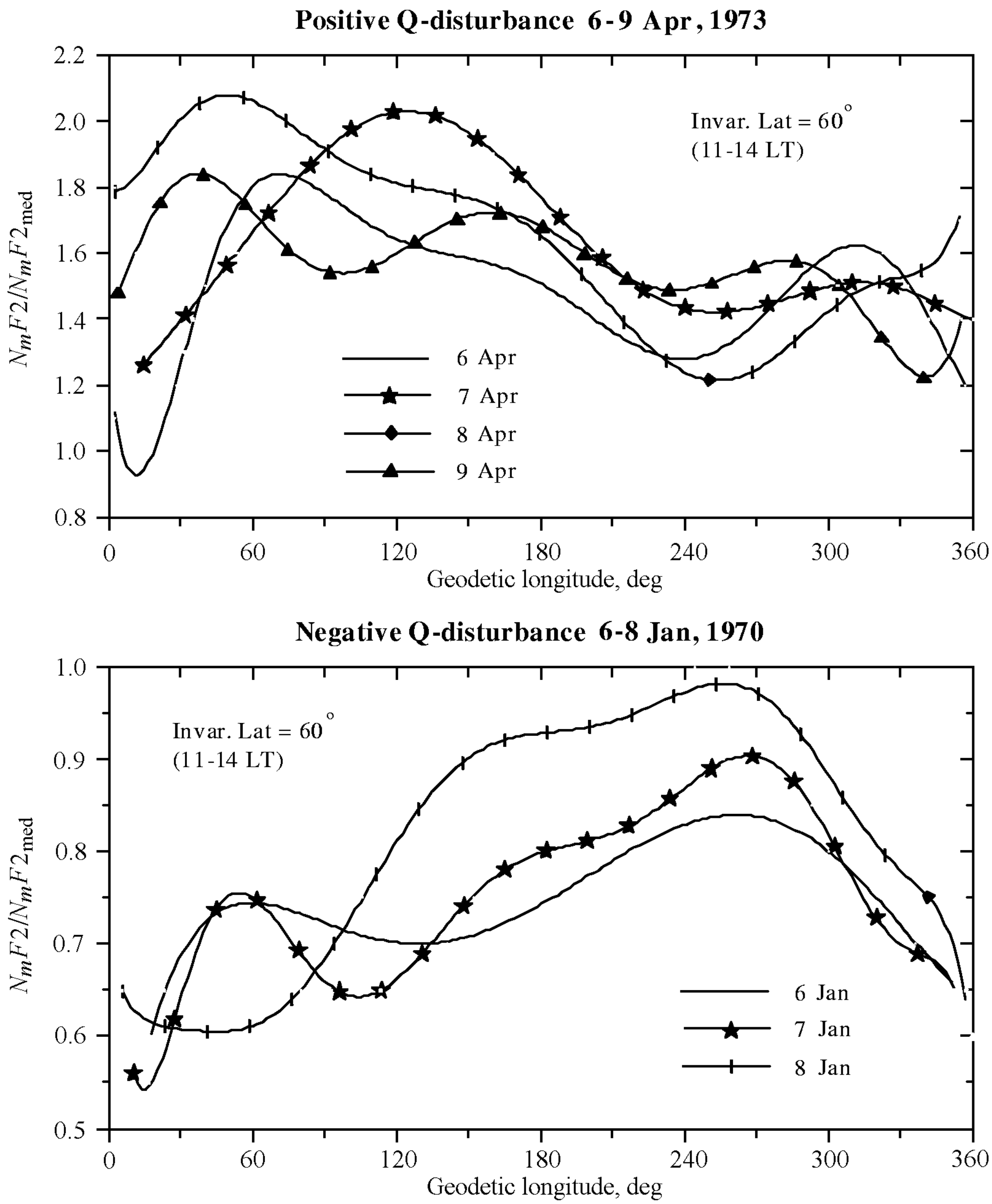

Figure 10. Longitudinal variations of the $N_mF2/N_mF2_{\mathrm{med}}$ ratio at 60° invariant latitude for some successive days during a positive (6–9 April 1973) and negative (6–8 January 1970) disturbances. Note that the peak amplitude of the wave moves back and forth in its day-to-day variations (top) and the front of this wave may be very steep as on 6 April or gently sloping as on 7 April. In both cases the American sector is less disturbed than the European one.

turbances (Figure 4) is very similar to the well-known "forbidden time" effect for $F2$-layer negative storm commencements [*Mednikova,* 1957; *Prölss and von Zahn*, 1978]. The effect is related to diurnal variations of the meridional thermospheric wind, so its role may turn out to be important in case of Q disturbances as well. Model calculations will be made in future to check possible mechanisms.

[18] On the other hand, some morphological results may be due to the method of Q disturbances extraction. For instance, it was found that positive Q disturbances were more numerous compared to negative ones. A 27-day running median used in our analysis bears the effects of negative $F2$-layer disturbances as their amplitude usually is larger and they are more often compared to positive $F2$-layer storms especially at high latitudes. Therefore any normal quiet day is perceived as a positive Q disturbance, while $F2$ layer should be strongly modified to mark a given day as a negative 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. However, morphological differences between positive and negative Q disturbances really exist. It appears in seasonal variations of their occurrence (Figures 5 and 6). Negative disturbances distinctly cluster around winter months, while the picture is not that clear and depends on conditions for positive disturbances.

[19] In our previous analysis [*Mikhailov and Schlegel*, 2001] we found that both types of daytime Q disturbances had a tendency to cluster around equinoxes. The reason for this difference may be due to the method of the Q disturbances extraction. A rough criterion with daily $Ap \leq 12$ was applied earlier to select Q disturbances. This allowed some negative D disturbances to appear in the list, but these usual negative $F2$-layer perturbations exhibit the largest occurrence in the equinoctial periods due to enhanced geomagnetic activity during equinoxes. A more severe criterion to select Q disturbances was used in the present analysis. This does not abolish the conclusion made by *Mikhailov and Schlegel* [2001] that daytime negative Q disturbances were due to a decrease in atomic oxygen concentration. Usual negative $F2$-layer disturbances are also resulted from O/N_2 ratio decrease [e.g., *Prölss*, 1995]. Changes of the O/N_2 ratio in this case is due to the [O] decrease and [N_2] increase (the latter dominates), while in case of Q disturbances we have solely [O] changes. This difference in mechanisms is clearly seen in Figure 7 (left middle) where the percent of time (proportional to the number of disturbances) sharply increases with latitude for usual negative disturbances while it is practically unchanged for Q perturbations. The former are directly related to the auroral activity while the latter are due to other reasons for [O] changes.

[20] Daytime positive Q disturbances clustering around equinoxes (Figure 6) can be related to the equinoctial transition in atomic oxygen abundance [*Mikhailov and Schlegel*, 2001; *Shepherd et al.*, 1999]. The most probable reason for such variations is a change in the global circulation pattern accompanied by vertical motions inferred from observations at E region heights [e.g., *Ward et al.*, 1997].

[21] Daytime negative Q disturbances demonstrate quite different pattern of spatial variations with the amplitude being practically independent on latitude (Figure 9). Again, a well-pronounced longitudinal difference takes place between European and American sectors (Figure 10, bottom), the latter being less disturbed. It should be noted small longitudinal differences between the two sectors for monthly median N_mF2 values according to the empirical IRI 90 model. So, such perturbations (both positive and negative) should be considered as planetary waves disturbing the N_mF2 longitudinal pattern. It would be interesting to check if these waves are propagating or standing. Unfortunately, it is not easy to do as the mechanism of the $F2$-layer formation is different in different LT sectors when different processes play the leading role.

[22] An analysis of the negative Q disturbance case (Figures 9 and 10) shows that the worldwide pattern is characterized by a general N_mF2 decrease on 6 January, although a 30% longitudinal (America/Europe) difference conserves. Such global N_mF2 decrease could be attributed to a decrease in solar EUV ionizing radiation keeping in mind possible day-to-day variations [*Hinteregger et al.*, 1981]. However, in 2 days, N_mF2 restores to median values in the American sector (Figure 10, bottom) but not in the Eurasian one. Therefore such worldwide variations should be attributed to planetary waves in the upper atmosphere accompanied by changes in neutral winds and composition presumably in atomic oxygen abundance [*Mikhailov and Schlegel*, 2001]. The effect may be also related to quasi-2-day oscillations in the ionosphere [*Altadill and Apostolov*, 2001; *Apostolov et al.*, 1995; *Chen*, 1992; *Forbes and Zhang*, 1997; *Forbes et al.*, 2000; *Rishbeth and Mendillo*, 2001], which are connected with quasi-2-day oscillation in mesosphere/lower thermosphere winds.

[23] Analyzing the $F2$-layer variability, *Rishbeth and Mendillo* [2001] ascribe 15% of the variability to meteorological sources. They as well as *Forbes et al.* [2000] suggest that meteorological sources of the F-layer variability are comparable to the geomagnetic source (each 15–20% of N_mF2) being much larger than the solar component. This is close to the estimations by *Mendillo and Schatten* [1983], who reported a 13–18% variability of daytime TEC values for magnetic QQ (the 5 quietest days of a month) days.

[24] Obviously, the meteorological component (impact from below) of the $F2$-layer day-to-day variability is a very interesting and challenging problem. As the first step, model calculations are required to specify the quantitative contribution of neutral temperature, composition, thermospheric winds, and electric field variations to the observed Q disturbances and to explain the revealed morphology at the agronomic level at least.

5. Conclusions

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

[26] 1. An analysis of all available N_mF2 observations over 26 Northern Hemisphere high-to-lower latitude ionosonde stations during geomagnetically quiet periods has revealed both positive and negative Q disturbances, their amplitude being comparable to moderate $F2$-layer storm effects resulted from increased geomagnetic activity.

[27] 2. Positive disturbances are more numerous than negative ones at all latitudes and at any level of solar activity. Both types of Q disturbances are more numerous (by 2 times) during solar minimum. The percentage of long-duration (both negative and positive) Q disturbances increases with latitude.

[28] 3. Both types of disturbances are the most frequent in the evening and night–early morning LT sectors and they are rare during daytime.

[29] 4. Winter season (November–January) is the most preferable for negative Q disturbances. The occurrence probability is small for other seasons. The seasonal variation pattern for positive Q disturbance is more complicated and less systematic, telling us that some processes contribute to

their formation and their efficiency varies with geophysical conditions.

[30] 5. Spatial variation pattern is different for positive and negative Q disturbances. The amplitude of positive disturbance increases with latitude, while it is practically latitudinal-independent for negative perturbations. Longitudinal variations of the amplitude for both types of disturbances look like a planetary wave with the minimal deviations in the American and the maximal deviations in the European sectors. The position of the extremes varies from day-to-day keeping linked to the two longitudinal sectors. In general, the American sector looks less disturbed. Large longitudinal gradients in N_mF2 are related with the front of such waves.

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