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Relation between parameters of the stratosphere and ionospheric $F2$ layer

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Abstract. The relation between the stratospheric parameter $h(100)$ (the height of the 100 hPa isobaric level) and f_oF2 critical frequency is considered. The data of four stations (Moscow, Kaliningrad, Gorky, and Tomsk) are analyzed for the entire solar cycle 1979–1989. A significant correlation between $h(100)$ and f_oF2 is obtained with the correlation coefficient $r(h, f_o)$ of about 0.6–0.8. It is found that the significant correlation is manifested not over the entire year but only over the period of the end of spring and beginning of summer. The diurnal behavior of $r(h, f_o)$ is characterized by two regions with high positive values at night and high negative values in the daytime. Characteristics of $r(h, f_o)$ behavior (including the relation to solar activity) are considered in detail. A negative correlation between the daytime and nighttime values of f_oF2 for the same day is also found, the correlation depending on solar activity. Possible relation of the found experimental facts to physical processes is briefly discussed.

1. Introduction

The problem of the relation between various atmospheric layers is of a great scientific interest. It is related directly to two fundamental problems of the geophysics: influence of solar activity on the weaver and climate and meteorological influence on the state of the ionosphere. Currently, there are no doubts that the behavior of various atmospheric layers from the troposphere up to the thermosphere (the ionospheric behavior is an indicator of the latter) is interrelated. Principally, some of the mechanisms realizing this interrelation are known. These mechanisms are wave-like processes of various time and spatial scales (from internal gravity waves to planetary waves and tide oscillations).

Unfortunately, our knowledge is still limited by the above very general statement. The cause of this is that the relations in question are masked by a strong impact of the external factors such as variations of the solar short-wave and corpuscular radiation (in the upper and middle atmosphere), changes in the greenhouse effect (in the lower atmosphere), and also long-term variations in various aeronomical parameters (in all atmospheric layers). Because of the above indicated reasons, a revealing of the relation between different layers present serious difficulties.

A review of the entire huge problem of the interrelation between atmospheric layers is in no way a goal of this paper. We refer the reader to (the only known to us) monograph on this problem by *Danilov et al.* [1987] and the vast references therein.

The aim of this paper is some generalization of the results of many year work of the authors dedicated to the relation between the parameters of the stratosphere and ionospheric $F2$ layer. The results have never been published before in the western journals so the paper may present some interest to the international community. Because of the fact that obtaining aerological sounding data (that is, of the stratospheric parameters needed for this work) meets some difficulties, the study has been developing gradually, starting from the analysis of the data for 1 year and one station and ending with the analysis of four stations for the entire solar cycle (1979–1989). Thus the results of the study have been published by pieces: as soon as more and more aerological data became available, there appeared new opportunities to compare the stratospheric and ionospheric data and to obtain new information on their interrelation. In this paper we attempt to collect together all the most significant points that

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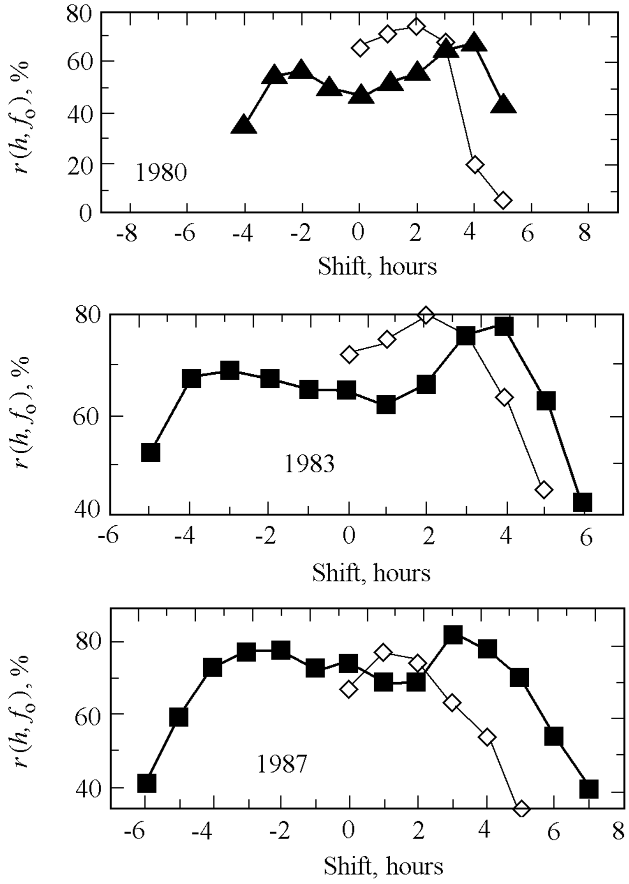

Figure 1. Variations of $r(h, f_o)$ versus the shift Δt for various years according to *Vanina and Danilov* [2003a]. Solid and open symbols are for Kaliningrad and Gorky, respectively.

have been spread out in several publications in Russian journals and summarize the facts what currently seem doubtless. Since the studies performed gave some unexpected results, it is useful to look at them from the point of view of the possibility of further development of studies in this direction (not obligatory only by the authors of this paper).

Below we will frequently use the term statistical significance of the values obtained. To avoid coming to this question each time, we note here that in all cases the statistical significance is determined by the Fisher criterion. In the majority of cases the significance level according to this criterion (99, 95, and 90%) is indicated in the text. In the cases when exact values are not important and simply statistically significant values are mentioned, a statistical significance not below 90% is meant. Values with a statistical significance below 90% are considered insignificant.

2. Procedure of the $h(100)$ and f_oF2 Comparison

The aerological (balloon) sounding is carried out strictly at 0000 UT. In all the comparisons the values of $h(100)$ for 0000 UT of each day were used. The routine vertical sounding of the ionosphere is carried out hourly at integer hours of universal time: 0100 UT, 0200 UT, etc. Initially, analyzing the data of Moscow station for 1996–1999 to compare with the value of $h(100)$ (we emphasize measured at 0000 UT), *Vanina and Danilov* [1999, 2000] and *Mikhailov et al.* [1998] used the critical frequency f_oF2 measured also at 0000 UT. So all the conclusions of the above indicated papers described in section 3 are true for the comparison of the values of $h(100)$ and f_oF2 measured simultaneously.

Analyzing the data of Gorky station [*Vanina and Danilov*, 2002], there appeared a possibility of comparing the same values $h(100)$ for 0000 UT with the values of f_oF2, measured in other but close moments of time. It was found that the maximum correlation between $h(100)$ and f_oF2 is observed not for the simultaneously measured values but at the shift of the f_oF2 measurements by 2 hours relative the $h(100)$ measurements.

Using the data of Gorky and Kaliningrad stations to the analysis, *Vanina and Danilov* [2003a] showed that the maxima in the behavior of $r(h, f_o)$ at the two stations do not coincide but are separated by about 2 hours. One can see this in Figure 1 (taken from *Vanina and Danilov* [2003a]). Thus, in further analysis of the $r(h, f_o)$ behavior the maximum value of the correlation coefficient for each year was taken and designated $r(h, f_o)$max. For example, in Figure 1 (top), $r(h, f_o)$max for 1980 is $r(h, f_o)$ for the shift of 2 and 4 hours for Gorky and Kaliningrad, respectively.

Later on, the aerological sounding data became available for the same solar cycle (1979–1988) at 4 stations where the vertical sounding of the ionosphere is carried out: Kaliningrad, Moscow, Gorky, and Tomsk. This database made it possible not only to check the conclusions obtained in the earlier publications but to consider in more detail the "UT effect," that is, the variation of $r(h, f_o)$ with universal time at various stations [*Vanina and Danilov*, 2003b]. Below, in all considerations of the diurnal behavior of $r(h, f_o)$ the values of $h(100)$ measured at 0000 UT are compared to the values of f_oF2 measured at even UT hours of the same day.

Since the choice of the maximum in $r(h, f_o)$ has a random effect, *Vanina and Danilov* [2004] considered a third way of choosing $r(h, f_o)$ to characterize the particular period (season or year). For the nighttime "plateau" of each year a period not shorter that 5 hours was chosen during which $r(h, f_o)$ did not change more than by 10%. For this period an average value of $h(h, f_o)$ was calculated and denoted $r(h, f_o)$night. The comparison of $r(h, f_o)$night and $r(h, f_o)$max is described in section 7.

To analyze the behavior in $r(h, f_o)$ in the daytime when $r(h, f_o)$ is negative (see below), we took the minimum (maximum by the magnitude) value and called it $r(h, f_o)$min. Its behavior is considered in sections 8 and 10. Just for the sake of a control, we performed the same procedure as at night: we calculated averaged over several (not less than 5)

Table 1. Correlation Coefficients Between f_oF2 and Isobaric Surface Heights for Various Levels for Moscow Station[†]

	L, hPa										
	400	300	250	200	150	100	70	50	30	20	10
N	65	65	65	65	65	65	59	54	48	34	18
$r(h, f_o)$, %	44	51	55	58	70	72	75	75	80	72	79

[†] L is isobaric level; N is the number of measurements; $r(h, f_o)$ is the correlation coefficient. From *Mikhailov et al.* [1998].

hours values of $r(h, f_o)$ and denoted them $r(h, f_o)$day (see section 8).

3. Choice of the Approach and the First Results

Mikhailov et al. [1998] considered the approach to the problem of looking for the relation between parameters of the stratosphere and ionosphere $F2$ region. First, the critical frequency f_oF2 of the $F2$ layer was chosen as an ionosphere parameter because it is determined much more reliably than the second parameter (the maximum height h_mF2). During a few decades the critical frequency has been on a regular basis measured (mainly once per hour) on the global network of ionosphere vertical sounding. The data of these measurements can be found in Internet sites of various world data centers and also on special CD disks.

For the comparison to the above indicated ionosphere data it was decided to use the data of aerological (balloon) sounding carried out by some organizations. Unfortunately, the results of aerological sounding are significantly less available than the ionosphere sounding data, and the receiving of the aerological data is related to both financial and organizational difficulties. That is why the first publications of the authors on the problem in question were based on relatively small database.

Initially, it seemed obvious [*Mikhailov et al.*, 1998] that the relatively weak influence of the meteorological processes can be easily noted in the ionosphere $F2$ region if one takes the nighttime hours when the influence of variable shortwave solar radiation is minimum. *Mikhailov et al.* [1998] chose the period of very low solar activity from the end of the spring to the beginning of the autumn 1996. Only magnetically quiet days ($Ap < 10$) were considered. Within the entire period from 20 April to 30 September 1996, 65 quiet days were chosen for the analysis.

The above mentioned analysis showed that a statistically significant positive correlation is observed between the height of the 100 hPa isobaric surface (about 17 km) in the stratosphere and the critical frequency f_oF2. The level of 100 hPa was chosen because of the fact that all the launched balloons ascended up to this level. One can see from Table 1 that some of the balloons ascended up to higher altitudes but the number of such cases considerably decreased with height. For example, out of 65 considered launchings only 54 and 34 balloons reached the level of 50 hPa and 20 hPa, respectively. Naturally, a decrease of number of launchings reduces the statistical significance of the obtained results. Nevertheless, for these levels, statistically significant correlation coefficients were obtained of the same order as for the 100 hPa level.

If one moves down from the 100 hPa level, then (see Table 1) the correlation coefficient $r(h, f_o)$ between the corresponding height level h and f_oF2 decreases (the number of the launchings (65) naturally being conserved). However, down to the 250–300 hPa level, this coefficient is still rather high and therefore is significant. Thus *Mikhailov et al.* [1998] assumed that by analyzing the correlation between $h(100)$ and f_oF2 we analyze the relation between the $F2$ layer critical frequency and entire lower stratosphere. On the basis of the above considerations, all the further analysis described below has been carried out primarily for the $h(100)$ value.

First results of the comparison of $h(100)$ and f_oF2 showed [*Mikhailov et al.*, 1998] that one obtains a statistically significant value $r(h, f_o) = 72\%$ for Moscow station in April–June (the choice of particular months is in detail discussed in the next paragraph). *Vanina and Danilov* [1999, 2000] continued the data analysis for Moscow station for 1997–1999.

In order to increase the statistical validity of the results (that is, the number of compared points), *Vanina and Danilov* [1999, 2000] considered jointly the data on f_oF2 and $h(100)$ for the April–June periods of 1996–1999. Since the value of f_oF2 directly depends on solar activity, a corresponding normalization of the f_oF2 values to the same solar activity (April–June 1997) was performed (for details, see *Vanina and Danilov* [2000]). The total number of points was now 227 and that significantly increased the statistical provision of the conclusions (for each particular April–June period, there were less then 80 points due to the presence in some days of gaps both in f_oF2 and $h(100)$ data).

The results of the comparison of the f_oF2 and $h(100)$ values are shown in Figure 2. One can see that in spite of the presence of some scatter of the points (the standard deviation $\sigma = 0.2$) a positive correlation between these values is observed. In this case the value of $r(h, f_o)$ is equal to 63% and is significant at the 99% level by the Fisher criterion.

4. Seasonal Effect

Mikhailov et al. [1998] were the first to note that the largest value of the correlation coefficient between $h(100)$ and f_oF2 is obtained if one takes not the entire interval for

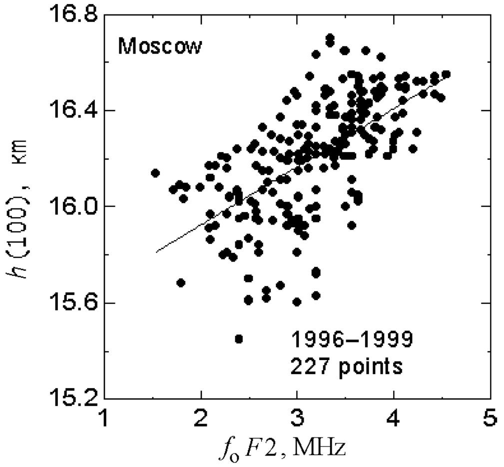

Figure 2. Values of f_oF2 versus $h(100)$ according to the observations in April–June 1996–1999 [from *Vanina and Danilov*, 2000].

which the data on $h(100)$ were available but only the April–June period. *Vanina and Danilov* [1999] specially studied the seasonal effect. They had aerological data for 3 years with some gaps (the data for July, August, and October 1996 and March 1998 were absent) and so the relation between $h(100)$ and f_oF2 was analyzed on much larger database.

The results of the analysis are shown in Table 2 (taken from *Vanina and Danilov* [1999]). One can see in Table 2 that for all three April–June periods (1996, 1997, and 1998) the value of the correlation coefficient is positive, statistically significant (65–75%) and exceeds considerably the $r(h, f_o)$ values for other seasons considered.

The problem of the season when the correlation in question is best pronounces was later considered by *Vanina and Danilov* [2002] on the basis of Gorky station data for the 1979–1989 period. Table 3 from *Vanina and Danilov* [2002] shows that actually the largest values of $r(h, f_o)$max are obtained for the April–June (considered in the earlier publications) and March–June, the values for the latter period being even slightly higher than for the former. This difference, being considerable in some years (for example, in 1981 and 1988), is not of a principal character and does not change significantly the conclusions obtained by *Vanina and Danilov* [1999, 2000] and *Mikhailov et al.* [1998] for Moscow station. It is important that an addition to the analyzed database of July and next months sharply decreases the correlation in question for the majority of the years considered (see Table 3).

Table 2. Correlation Coefficient $r(h, f_o)$ and the Number of Days for Various Periods at Moscow Station†

Period	$r(h, f_o)$, %	N
April, May, and June 1996	64	46
September, November, and December 1996	−15	45
January, February, and March 1997	−27	39
April, May, and June 1997	66	46
July, August, and September 1997	30	66
October, November, and December 1997	−31	46
January and February 1998	20	37
April, May, and June 1998	67	56

† According to *Vanina and Danilov* [1999].

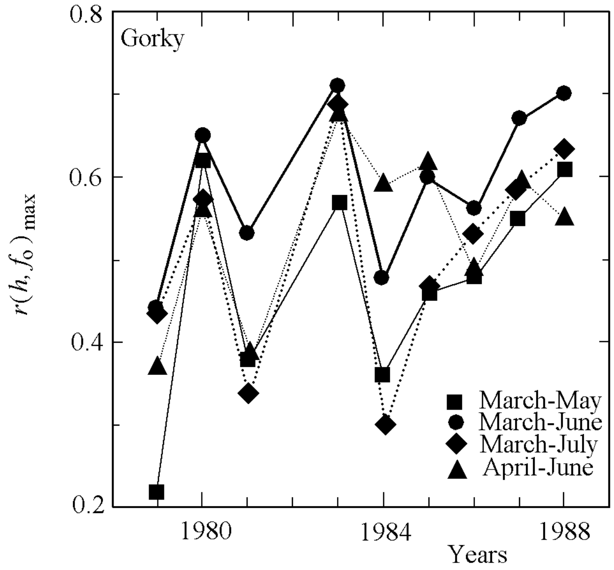

Figure 3. Correlation coefficients between $h(100)$ and f_oF2 for various months according to *Vanina and Danilov* [2002].

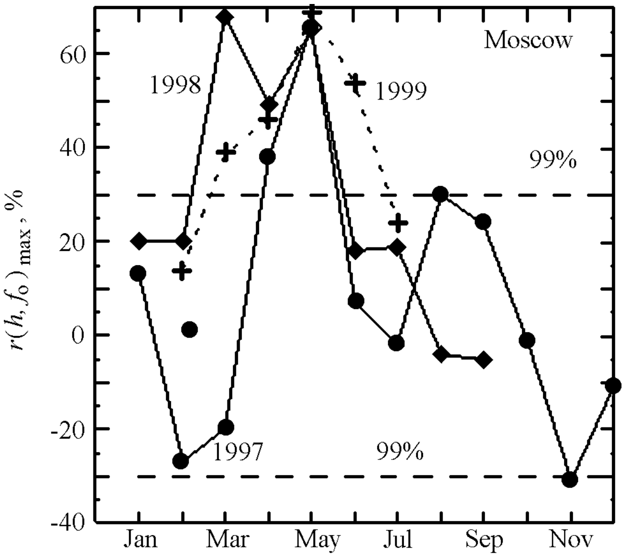

Figure 4. Values of $r(h, f_o)$max for Moscow for different months of 1997–1999.

Table 3. Correlation Coefficients $r(h, f_o)$max for Gorky Station[†]

	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988
					April–June					
r, %	37	57	41	13	69	59	62	49	58	55
N	68	72	66	52	51	53	59	62	77	76
$A(\Phi)$, %	99	99	99	90	99	99	99	99	99	99
					March–June					
r, %	44	65	53	10	71	47	60	56	67	70
N	89	93	92	74	74	71	83	86	96	99
$A(\Phi)$, %	99	99	99	< 90	99	99	99	99	99	99
					March–July					
r, %	41	57	33	06	69	30	46	53	59	63
N	115	109	118	97	100	84	100	94	121	119
$A(\Phi)$, %	99	99	99	< 90	99	99	99	99	99	99

[†] Here r is the correlation coefficient $r(h, f_o)$max; N is the number of days of comparison; and $A(\Phi)$ is the significance level according to the Fisher criterion. From *Vanina and Danilov* [2002].

Figure 3 shows variation of $r(h, f_o)$max with years for four intervals according to *Danilov and Vanina* [2002]. One can see that almost for all years the data for the March–June period are located higher than the data for other intervals, the difference in some years being significant and equal to 0.2 in the $r(h, f_o)$max value.

Averaging for each set of months the value of $r(h, f_o)$max for all years for Gorky station, *Vanina and Danilov* [2002] obtained the following values: 0.46 (March–July), 0.54 (March–June), 0.5 (April–June), and 0.44 (March–May). The averaged values thus confirm quantitatively the qualitative effect well seen in Figure 3: the correlation coefficient between f_oF2 and $h(100)$ is maximum if the March–June period is taken.

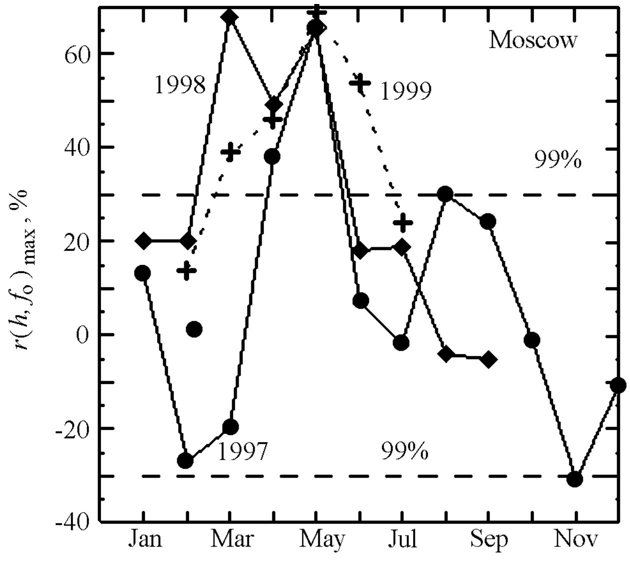

Figure 5. Variation of $r(h, f_o)$ with UT for 1983 according to *Vanina and Danilov* [2003b] for Kaliningrad, Moscow, Gorky, and Tomsk.

To study the seasonal variation in $r(h, f_o)$max the following procedure was additionally performed. For the given year a 3-month running mean window was taken (January–March, February–April, etc.), and the value of $r(h, f_o)$max was calculated within each window and was put on the graph for the average month (for example, the value shown for April corresponds to the $r(h, f_o)$max value calculated for the March–May period). Figure 4 shows the results for Moscow for 1997–1999. One can see that the values of $r(h, f_o)$max statistically significant above the 99% level are for all 3 years only in the March–June interval.

Thus the values of $r(h, f_o)$max for various periods analyzed by different ways show that the time behavior of this value is the same for all time intervals considered, but the absolute value of $r(h, f_o)$max varies, staying the highest for the March–June period. According to the above described results, the March–June period was taken below for the analysis of the correlation coefficient behavior for all stations and all years considered.

5. Diurnal Behavior of $r(h, f_o)$

Vanina and Danilov [2003b] noted that a significant correlation between $h(100)$ and f_oF2 is detected not only if the values of f_oF2 are taken exactly for the moment of $h(100)$ measurements, but for the adjacent moment as well. So it was reasonable to draw a complete picture of the correlation coefficient $r(h, f_o)$ of $h(100)$ (measured at 0000 UT) with f_oF2 measured at other UT moments for all the stations and years available.

This picture was found slightly different for various years of the considered interval (1979–1988); however, the most important characteristic features of the $r(h, f_o)$ behavior are the same for all studied years. An example of the $r(h, f_o)$ variation with UT for 1983 (the most typical picture with characteristic features which will be discussed below) is presented in Figure 5.

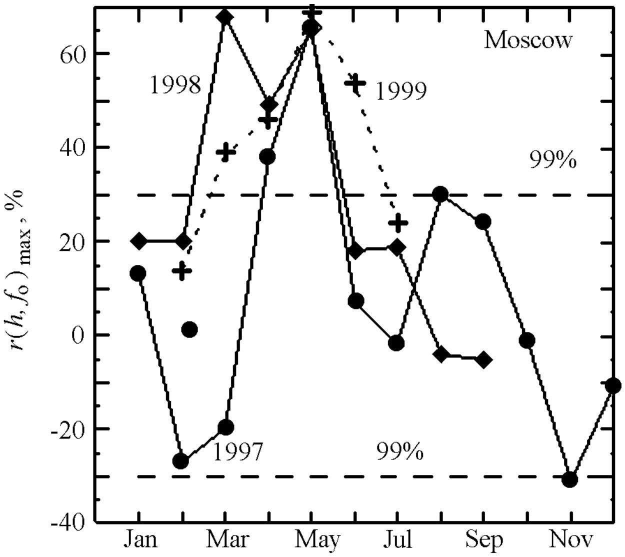

Figure 6. Variation of $r(h, f_o)$ with UT for 1985 according to *Vanina and Danilov* [2003b] for Kaliningrad, Moscow, Gorky, and Tomsk.

The main feature of Figure 5 which draws attention first is that there are two regions with opposite signs and high magnitudes of the $r(h, f_o)$ values. Around midnight (we emphasize that we are operating by the time of day in UT), there is a region of high enough (60–80%) positive values of $r(h, f_o)$, covering the time interval from about 1600 UT to 0500 UT. From about 0600 UT to 1400 UT, there is a region where the values of $r(h, f_o)$ are also high enough by the magnitude (40–60%) but negative in sign. Between these regions there are two intermediate regions where the value of $r(h, f_o)$ varies strongly from one hour to another going from one region to the other.

The second feature visually seen in Figure 5 is that the r(UT) curves for different stations have a similar shape but are shifted relative each other (see also Figure 1). For example, the deviation from the "positive plateau" and sharp depletion of $r(h, f_o)$ begins for Tomsk, Moscow, and Kaliningrad at approximately 2300 UT, 0300 UT, and 0400 UT. Similarly, the positive plateau begins approximately at 1700 UT, 1900 UT, and 2000 UT for Tomsk, Kaliningrad, and Moscow. We will come back to a detailed analysis of this shift in section 6.

The third feature of the $r(h, f_o)$ behavior in Figure 5 is the following. At the end of the positive plateau for all stations, there is observed a maximum in $r(h, f_o)$ before the beginning of a sharp depletion of its value. The presence of this maximum was noted by *Vanina and Danilov* [2003a]. As has been noted in section 2, to analyze seasonal and year-to-year variations, the maximum values $r(h, f_o)$max in this peak (or just the maximum value of $r(h, f_o)$ in the diurnal curve) are taken.

The detailed analysis of the r(UT) behavior for various stations and various years performed by *Vanina and Danilov* [2003b] shows that the shape of the r(UT) behavior on the whole and the positive plateau itself vary from one year to another. Nevertheless, the maximum in $r(h, f_o)$ at the very end of the plateau stays though in some cases the plateau itself may be nonsmooth.

Thus the r(UT) behavior differs for different years though it contains all the main features described above for the example of the behavior for 1983. Another example of $r(h, f_o)$ behavior versus UT is shown in Figure 6 for 1985.

Figure 6 shows that in 1985 the situation in the nighttime part of the r(UT) variations does not differ significantly from the picture considered above for 1983. From about 1600 UT to 0400 UT the values of $r(h, f_o)$ were positive and high enough (40–80%). At the same time, if in Figure 5 the negative values of $r(h, f_o)$ in the daytime for all stations went down to about 50%, in Figure 6 these values for Moscow, Gorky, and Kaliningrad stations hardly reach 20% and only for 1–2 hours. Such values of $r(h, f_o)$ with the amount of points of about 100 available for each year (we consider only the March–June period and only the days when the aerological data were available) have a statistical significance below or about 90%. This means that for the particular year, there was no stable statistically significant negative correlation between $h(100)$ and daytime values of f_oF2 for all the stations considered except for Tomsk where (as one can see in Figure 6) the value of $r(h, f_o)$ went down to -60% and was statistically significant at the 99% level, respectively.

If the f_oF2 values measured around midday and midnight provide a correlation of opposite sign with the same value $h(100)$, these f_oF2 values should have a negative correlation between themselves. We will consider this problem in detail below.

Following *Vanina and Danilov* [1999, 2000, 2002], we first consider in detail the behavior of $r(h, f_o)$ in the upper part of the figures similar to Figures 5–6. The daytime values of $r(h, f_o)$ will be considered later.

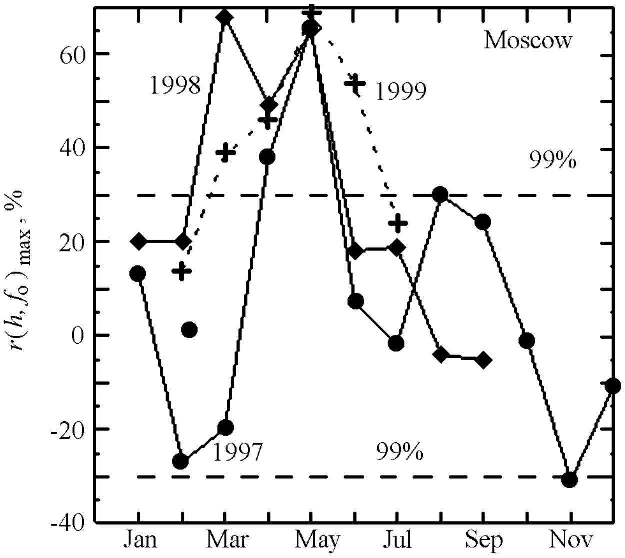

Figure 7. Variations of $r(h, f_o)$ with UT for 3 years for Moscow station according to *Vanina and Danilov* [2003b].

6. Behavior of $r(h, f_o)$ at Night

For the sake of visuality, Figure 7 shows variations of $r(h, f_o)$ at the nighttime hours only for Moscow and only for 3 years, providing examples of three typical $r(\mathrm{UT})$ profiles. Figure 7 shows that there are three types of $r(\mathrm{UT})$ variations: The variation with a well-pronounced "nighttime plateau" and a small maximum at 0300 UT (1984), and the variation with two sharp maxima, the maximum at 0200 UT having considerably higher amplitude than the earlier maximum (1989). The variation with two maxima is of nearly the same amplitude (1986), with one of the maxima again falling on 0200 UT. Distributions of $r(\mathrm{UT})$ for the rest of the years of the interval studied (1979–1989) is close to one of the distributions shown in Figure 7. It is worth emphasizing that the presence of the maximum at 0200–0300 UT is a typical feature of the $r(\mathrm{UT})$ profile for Moscow.

The $r(\mathrm{UT})$ profiles for other stations every year repeat in a significant degree the profile for Moscow: however, for each station the profile is shifted relative to the Moscow profile by some time interval. To illustrate this statement, Figure 8 shows the profiles for 1989 for only two stations (Moscow and Kaliningrad). One can easily see the similarity of the $r(\mathrm{UT})$ profiles for two stations and the shift of the profile for Kaliningrad by 1 hour to the right as compared to the Moscow profile.

The $r(\mathrm{UT})$ profiles for all four stations for 1987 are shown in Figure 9. One can easily see that the right maxima fall at 0300 UT, 0200 UT, 0100 UT, and 2300 UT for Kaliningrad, Moscow, Gorky, and Tomsk, respectively. The profiles are shifted as follows: the Kaliningrad profile is the most right and the Tomsk profile is strongly shifted to the left. Before coming to the discussion of the above described shift, we provide one explanation. Out of 11 years considered for Moscow, the maximum falls 7 and 4 times to 0200 UT and 0300 UT, respectively. The step in the f_oF2 data available is 1 hour. So the fact that the maximum in question for Moscow may fall in our figures to 0200 UT or to 0300 UT means only that this maximum is located somewhere between 0200 UT and 0300 UT and small deviations to this or that side lead to its appearance (because the ionosphere data are limited by integer hours) at this or that moment. Evidently, the same is true for all other stations.

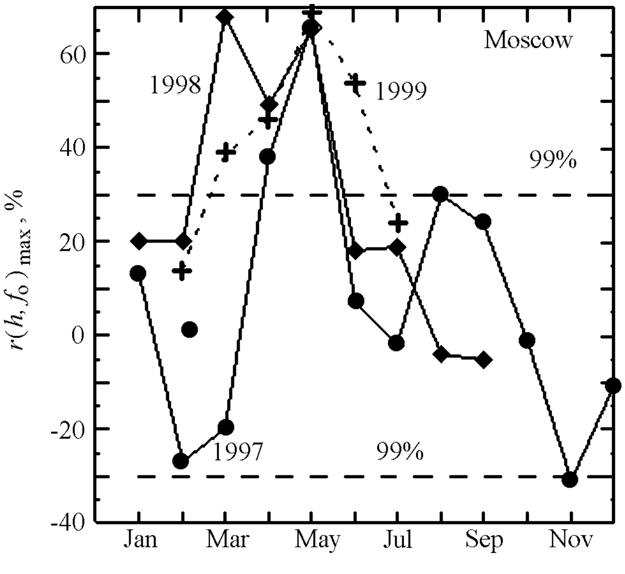

Figure 8. Variation of $r(h, f_o)$ with UT for 1989 and two stations according to *Vanina and Danilov* [2003b].

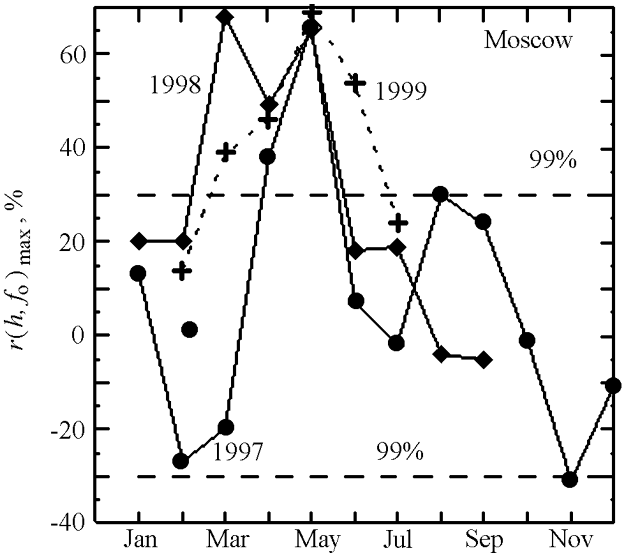

Figure 9. Variations of $r(h, f_o)$ with UT at night for four stations (Kaliningrad, Moscow, Gorky, and Tomsk) and 1987 according to *Vanina and Danilov* [2003b].

According to the above, there is no sense in a formal averaging of the moments of the maxima for each station over all years. For our purposes it is enough to note that most often the maxima are observed at 0300 UT, 0200 UT, 0100 UT, and 2200 UT for Kaliningrad, Moscow, Gorky, and Tomsk, respectively. Table 4 shows the geographical longitudes of these stations and the corresponding difference in the local time ΔLT relative to Moscow. Table 4 shows that roughly speaking, Moscow is located by about 1 hour eastward from Kaliningrad, Gorky is located about 1 hour eastward from Moscow, and Tomsk is located about 3 hour eastward from Moscow. In other words, the considered shifts of $r(\mathrm{UT})$ between the stations correspond to the difference in the local time between these stations. Actually, if one overlaps the profiles for the same year but different stations in local time, the profiles would be very similar. To illustrate the latter statement, Figure 10 shows the $r(\mathrm{UT})$ profiles for the Tomsk and Alma-Ata stations for 1983. Both stations have

Table 4. Station Longitudes

Station	Kaliningrad	Moscow	Gorky	Tomsk
Longitude	20.6°E	37.2°E	44.2°E	84.9°E
ΔLT, hours	−1.1	0	0.5	3.1

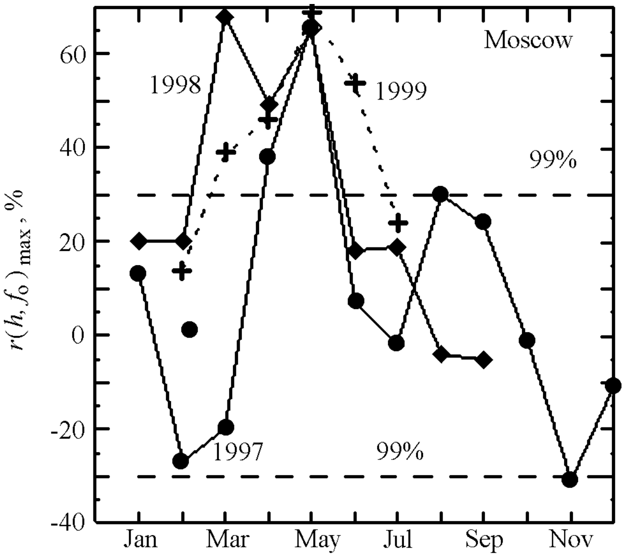

Figure 10. Variations of $r(h, f_o)$ with UT for two stations for 1983.

close longitudes but different latitudes. The coincidence of the profiles is impressive.

Thus, for the March–June period used in the study the following picture is observed at all four stations. Approximately from 2100 LT to 0400 LT (we emphasize once more that deviations by 1 hour in both directions are possible due to the discreteness of ionospheric observations) in all the years considered, a region of high enough (50–80%) values of the correlation coefficient $r(h, f_o)$ is observed. For this period a significant (99%) positive correlation between the stratospheric parameter $h(100)$ and the critical frequency f_oF2 is detected.

Since the $r(\mathrm{UT})$ profile for 2100–0400 LT is far from being smooth (see Figure 10), one can consider the nighttime plateau only conventionally (meaning that to the right and to the left the value of $r(h, f_o)$ falls down sharply to the region of zero or even negative values) in the sense that within the plateau the value of $r(h, f_o)$ does not go below +50%. We have already mentioned above that 1982 presents an exception. It demonstrates the same characteristic features in the $r(\mathrm{UT})$ behavior at night as all other years but gives much lower absolute values of $r(h, f_o)$ at all four stations.

7. Mutual Correlation Between Stations

We have already mentioned that the picture of $r(h, f_o)$ variations with UT changes slightly from one year to another. First, it is true for the maximal value $r(h, f_o)$max reached at the given station in the given year (we remind that we discuss only the nighttime part of the $r(\mathrm{UT})$ curve and so consider positive values of $r(h, f_o)$. *Vanina and Danilov* [2003c] compared values of $r(h, f_o)$ in the nighttime maximum $r(h, f_o)$max for all four stations and all years considered.

The results of the comparison are shown in Table 5. One can see from Table 5 that very high positive correlation is observed between the variations of $r(h, f_o)$max from year to year. All the numbers presented in Table 5 are statistically significant at the level above 99%. This means that on the whole $r(h, f_o)$max changes from one year to another almost similarly at stations fairly strongly separated in space (by longitude).

At the same time the detailed analysis shows that there are two considerably different time intervals. In the first interval (1979–1984) the variation of $r(h, f_o)$max with years occurs almost similarly at all four stations (the deep minimum in $r(h, f_o)$max in 1982 and a peak in $r(h, f_o)$max in 1983 are typical examples). In the second interval of years (beginning from 1985) the picture looks different. Some differences are seen between changes of $r(h, f_o)$max from year to year for different stations. Certainly, for the analysis we have only 11 years, and so splitting into two intervals sharply decreases the statistical significance of the results. Nevertheless, it is useful for the sake of visuality to present some numbers. For the 1979–1984 period (6 points) the correlation coefficient between the $r(\max)$ variations reaches 96%, 94%, and 98% for Moscow and Kaliningrad, Moscow and Gorky, and Kaliningrad and Tomsk, respectively. The statistical significance of these values even with the indicated small number of points is 99%.

The picture becomes less systematic for the 1985–1989 period. The correlation coefficient between Moscow and Kaliningrad (5 points) stays high and positive (74%), whereas it falls down to −23% between Gorky and Kaliningrad (4 points) and to −65% between Moscow and Tomsk (3 points). Though because of a small number of years these values are statistically insignificant, the general effect apparently indicates that considerable changes occur in the processes determining the relation between the stratosphere and ionospheric F region while switching from the first to the second period.

All the above said indicate a solar activity control of the positive correlation coefficient between $h(100)$ and nighttime values of f_oF2. The value $r(h, f_o)$max decreases with an increase of $F_{10.7}$. The correlation coefficient $R(r, F)$night between $r(h, f_o)$max and $F_{10.7}$ for Kaliningrad is −0.67 and with 11 points available provides the statistical significance at the 95% level. For three other stations, $R(r, F)$night

Table 5. Correlation Coefficients Between the Values of $r(h, f_o)$max for Various Stations (1979–1989)[†]

Station	Kaliningrad	Moscow	Gorky	Tomsk
Kaliningrad	–	92	85	95
Moscow	92	–	96	88
Gorky	85	96	–	83
Tomsk	95	88	83	–

[†] In percent.

varies from 0.5 to 0.67, confirming the inverse dependence of $r(h, f_o)$max on $F_{10.7}$.

Since the $r(h, f_o)$max value may bear some random element, *Vanina and Danilov* [2004] performed additionally the following procedure. For the nighttime plateau of each year a period not shorter that 5 hours was chosen during which $r(h, f_o)$ did not change more than by 10%. For this period an average value of $h(h, fo)$ was calculated and denoted $r(h, f_o)$night. Figure 11 shows the $r(h, f_o)$night behavior with time. The comparison with other figures shows that the absolute values of $r(h, f_o)$night differ slightly for each year from $r(h, f_o)$max, the principal picture of the time behavior staying the same.

8. Correlation of $h(100)$ With the Daytime Values of f_oF2

The comparison of $h(100)$ with daytime values of f_oF2 was considered by *Vanina and Danilov* [2003c]. The diurnal variations of $r(h, f_o)$ for all stations presented in Figures 5, 6, and 10 show that in the 0800–1600 UT period the values of $r(h, f_o)$ are negative and their magnitude lies within the 0.6–0.85 interval.

To characterize the $r(h, f_o)$ seasonal and year-to-year variations in the daytime *Vanina and Danilov* [2003c] took the smallest (i.e. the highest by the magnitude) value of $-r(h, f_o)$ (see section 2). Figure 12 shows variations of $r(h, f_o)$min for all four stations.

For 4 months (March–June) of each year, there were (taking into account gaps in observations of both $h(100)$ and f_oF2) about 100 points. The correlation coefficient corresponding to the statistical significance of 99% according to the Fisher criterion for 100 points is 0.26. This value is shown by the horizontal dashed line in the bottom part of Figure 12. It is evident that the vast majority of the points in Figure 12 are statistically significant with the probability exceeding 99%.

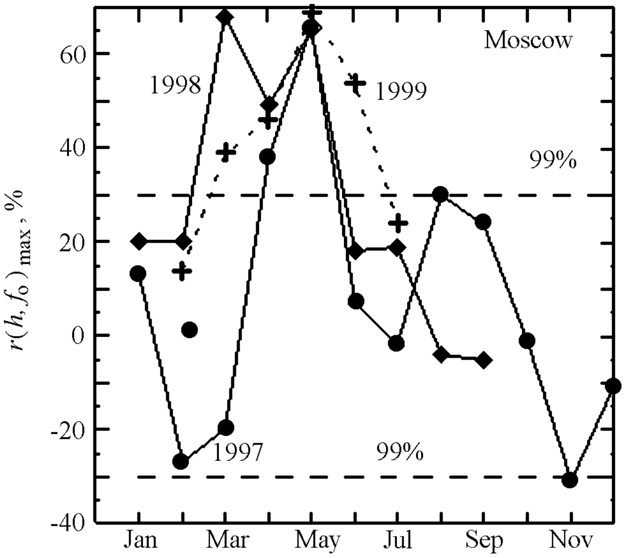

Figure 11. Variations with time of the $r(h, f_o)$night values according to *Vanina and Danilov* [2004].

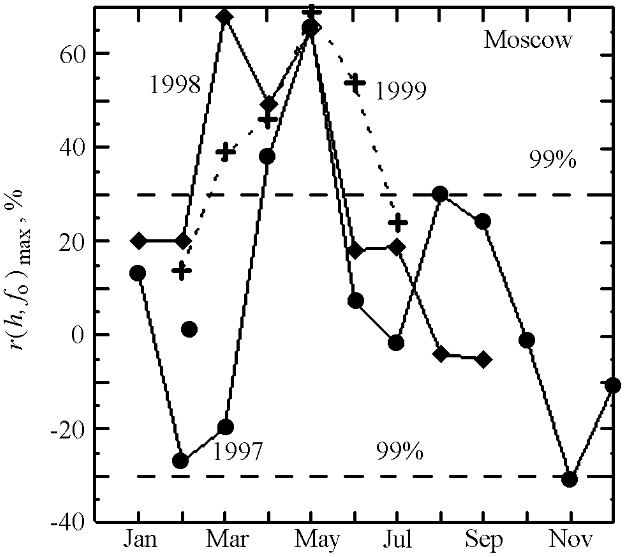

Figure 12. Variations with time of the $-r(h, f_o)$min values for four stations according to *Vanina and Danilov* [2003c].

Two facts draw attention in Figure 12. The first is that the data of all stations indicate some systematic behavior of $r(h, f_o)$min with time within the considered solar cycle (1979–1989). We will return to this fact below. The second is that the behavior of the $r(h, f_o)$min value with time is similar for different stations. Quantitatively, it may be illustrated by the following numbers. The correlation coefficients $R(1)$ between the values of $r(h, f_o)$min obtained in the same years at different stations are 0.93 (Kaliningrad–Moscow); 0.92 (Kaliningrad–Gorky); 0.98 (Kaliningrad–Tomsk); 0.98 (Moscow–Gorky); 0.93 (Moscow–Tomsk); and 0.92 (Gorky–Tomsk). Though the number of points is not large and changes from 11 to 9 (for some stations, there are no data for some years), the statistical significance of the $R(1)$ values obtained exceeds 99%.

The obtained result seems astonishing if we recognize that behind each point in Figure 12 there is a comparison of two sets of values ($h(100)$ and f_oF2) obtained by different equipment, different methods and different people. Also in spite of all that, the correlation coefficient between the two indicated parameters varies from year to year almost similarly in four locations separated by thousand kilometers! With values of $r(h, f_o)$min and $R(1)$ the presented above, the probability of a random coincidence is negligibly small and a conclusion is inevitable that we deal with some large-scale (the distance from Kaliningrad to Tomsk is longer than 4000 km) process determining the relation between the state of the stratosphere and daytime ionospheric F region.

In the same way as for the nighttime conditions, the daytime values $r(h, f_o)$ depend on solar activity. The absolute values of the negative correlation coefficient between

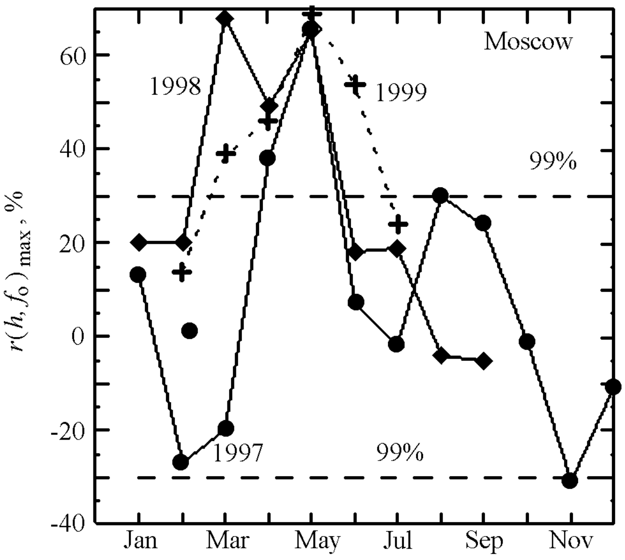

Figure 13. Variations with time of $R(f_oF2)$ for two stations according to *Danilov and Vanina* [2003c].

$h(100)$ and the daytime values of f_oF2 increase with an increase of $F_{10.7}$. The correlation coefficient $R(r, F)$day between $-r(h, f_o)$min and $F_{10.7}$ for Kaliningrad is 0.74 and with 11 points available provides the statistical significance at the 99% level. The value of $R(r, F)$day for three other station lies within 0.69–0.81 confirming the positive correlation between the magnitude of $r(h, f_o)$min and $F_{10.7}$.

We performed for the daytime values of $r(h, f_o)$ the same procedure as for the nighttime values. We averaged for each year the daytime values of $r(h, f_o)$ over several (not less that 5) hours during which $r(h, f_o)$ varied less than by 10%. The obtained values of $r(h, f_o)$day behave with years quite similarly to $r(h, f_o)$min though the absolute values of $r(h, f_o)$min and $r(h, f_o)$day are slightly different because of obvious reasons. Below in the further analysis the values of $r(h, f_o)$min are used.

9. The Relation Between the Nighttime and Daytime Values of f_oF2

It follows from the previous sections that the correlation of the daytime and nighttime values of f_oF2 with $h(100)$ has opposite signs. This leads to an inevitable suggestion that a negative correlation should be observed between the daytime and nighttime values of f_oF2. To analyze the relation between the daytime and nighttime values of the critical frequency, *Vanina and Danilov* [2003c] took the values of f_oF2 for 0200 LT and 1400 LT of the same days. To reduce the influence of ionospheric disturbances (ionospheric storms) accompanying magnetic storms, not all the days of the given interval were taken but only quiet days with $Ap < 8$. As a result, the number of points (days) in each interval decreased; however, the "purity" of the comparison (from the point of view of the final aim of the work, that is, revealing of the "meteorological" input into variations of f_oF2) increased.

To analyze the relation between the nighttime and daytime values of f_oF2, *Vanina and Danilov* [2003c] used the correlation coefficient $R(f_oF2)$ which manifests the correlation between the f_oF2 values at 0200 LT and 1400 LT of the same day over the chosen data set. At first, *Vanina and Danilov* [2003c] analyzed all the data for each year (but fulfilling the condition $Ap < 8$). The amount of points varied from year to year because of the different number of geomagnetically quiet days, but on the average, it oscillated around 100 points. The corresponding boundary value of the correlation coefficient for the 99% statistical significance according to the Fisher criterion was 0.26.

Figure 13 shows the variations with time of $R(f_oF2)$ for two stations: Moscow and Kaliningrad. Two facts draw attention. The first is a strong variability of the $R(f_oF2)$ values with time from about -0.55 at the edges of the time interval to 0.10–0.15 in 1984–1985. Figure 13 shows that only the negative values of $R(f_oF2)$ before 1984 and after 1987 are significant at the 99% level. The second is very close values of $R(f_oF2)$ obtained for each year at two different stations. The correlation coefficient $R(2)$ between the $R(f_oF2)$ values for two stations is 0.94, and (though the number of points (years) is only 11) the probability of an occasional coincidence is negligible small.

To study the seasonal variation in $R(f_oF2)$, *Danilov and Vanina* [2003c] performed the same procedure of 3-month running mean window as for $r(h, f_o)$ (see section 4 and Figure 4). The variations of $R(f_oF2)$ during 1980 for three stations are shown in Figure 14. Also shown in Figure 14 are the values of $R(f_oF2)$ corresponding to the statistical

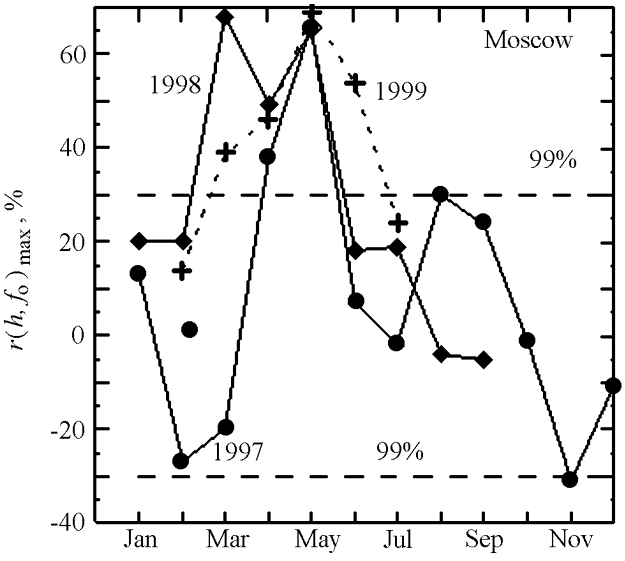

Figure 14. Seasonal behavior of $R(f_oF2)$ for three stations for 1980 (circles for Kaliningrad; squares for Moscow; and crosses for Gorky). The horizontal dashed lines correspond to the statistical significance for 45 points.

significance of 95% and 99% for the mean number of points (quiet days) equal to 45.

Two conclusions are evident in Figure 14. First, the value of $R(f_oF2)$ varies strongly during the year and reaches negative values at the significance level above 99% at the end of spring to the beginning of summer. In the rest of the months the statistical significance of $R(f_oF2)$ is below 95%. Actually, this means that there is only one interval during the year (approximately March–June) when the negative relation between daytime and nighttime values of f_oF2 does really exist. It is the very time interval for which the highest correlation between the state of the stratosphere and values of f_oF2 has been revealed (see above). That is why below for the comparison with values of $r(h, f_o)$ we will use values of $R(f_oF2)$ for the March–June period. The value of $R(f_oF2)$ for the March–June period for 1980 and Moscow is −0.79.

Such a strong correlation in the March–June period is not, however, seen in all years. The year (1980) shown in Figure 14 falls on the period of high solar activity (the mean value of $F_{10.7}$ for the March–June period was 201). However, in 1986 (low solar activity, $F_{10.7} = 74$) the picture is different. The character of the $R(f_oF2)$ variations in 1986 is close to that in 1980: in both cases, there is a decrease of $R(f_oF2)$ in March–May. However, in 1980 the $R(f_oF2)$ values in this period go below −0.75 and are statistically significant at the 99% level, whereas in 1986 the lowest values of $R(f_oF2)$ hardly reach −0.2 and are not significant even at the 95% level. Moreover, variations of $R(f_oF2)$ during 1986 at different stations do not agree, contrary to a very coordinated picture in Figure 14. All this allows us to state that in 1986, there is no statistically significant correlation between daytime and nighttime values of f_oF2 in either period of the year.

We deliberately took for the comparison the years with high and low solar activity. The obtained difference in the $R(f_oF2)$ behavior leads to an assumption that the character of the correlation between the daytime and nighttime values of f_oF2 depends on solar activity. This assumption is confirmed by Figure 15 where $R(f_oF2)$ for Moscow is shown versus the $F_{10.7}$ solar activity index averaged over the March–June period of each year.

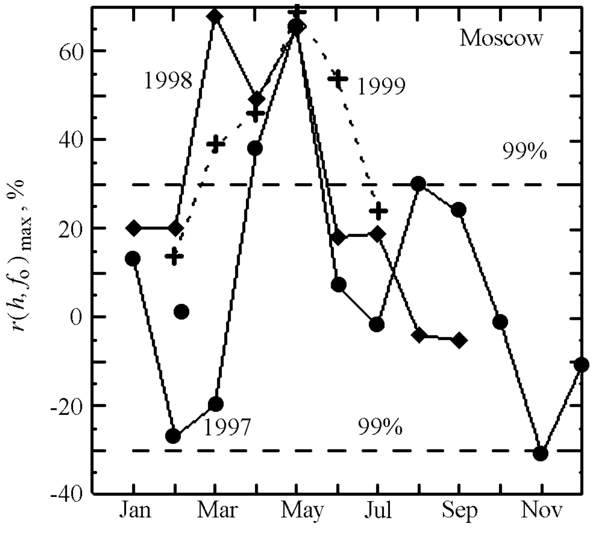

Figure 15. The $-R(f_oF2)$ values versus the $F_{10.7}$ solar index for the March–June period of various years (Moscow).

Table 6. Values of $R(3)$, Number of Points N, and $A(\Phi)$ for Various Stations

Station	N	$R(3)$	$A(\Phi)$
Kaliningrad	11	−0.69	95%
Moscow	11	−0.75	99%
Gorky	10	−0.75	99%
Tomsk	9	−0.50	90%

The correlation coefficient $R(3)$ between $-R(f_oF2)$ and $F_{10.7}$ in Figure 15 is 0.75. With 11 points (years) available this provides the statistical significance of the obtained dependence at the 99% level. The $R(3)$ values for three other stations and corresponding statistical significances $A(\Phi)$ according to the Fisher criterion are shown in Table 6. Table 6 shows that an inverse dependence of $R(f_oF2)$ is observed for all the stations considered (though with different statistical significance).

It should be emphasized that the authors know of no publications on the $F2$-region morphology, where the existence of a negative correlation between the daytime and nighttime values of f_oF2 (with such high statistical significance, well-pronounced seasonal feature, and dependence on solar activity) has been detected.

10. Relation Between $r(h, f_o)$ and $R(f_oF2)$

The results of section 9 show that the March–June period is a special one both for the relation between $h(100)$ and f_oF2 and for the correlation between the daytime and nighttime values of f_oF2. We conventionally indicate these months because this period has been found in the earlier analysis of the relation between $h(100)$ and f_oF2. The real boundaries of this period may shift with allowance for variations of $r(h, f_o)$ and $R(f_oF2)$ to both sides by a month as a maximum, but this fact does not principally change the character of the results obtained.

As far as both values $r(h, f_o)$min and $R(f_oF2)$ have the highest magnitude in the same period of the year, one should expect the existence of a relation between them. Figure 16 confirms this assumption for Moscow station. The relation between $-R(f_oF2)$ and the minimal (daytime) values of $-r(h, f_o)$min is evident. The relation is a direct one: in the years when (in the March–June period) the negative correlation between the daytime and nighttime values of f_oF2 is the highest, the highest is also the negative correlation coefficient between $h(100)$ and daytime values of f_oF2. The correlation coefficient $R(4)$ between $r(h, f_o)$min and $R(f_oF2)$ in Figure 16 is 0.84. With 11 points (years) available the obtained correlation is significant at the 99% level.

Figure 17 shows a similar comparison of $r(h, f_o)$max and

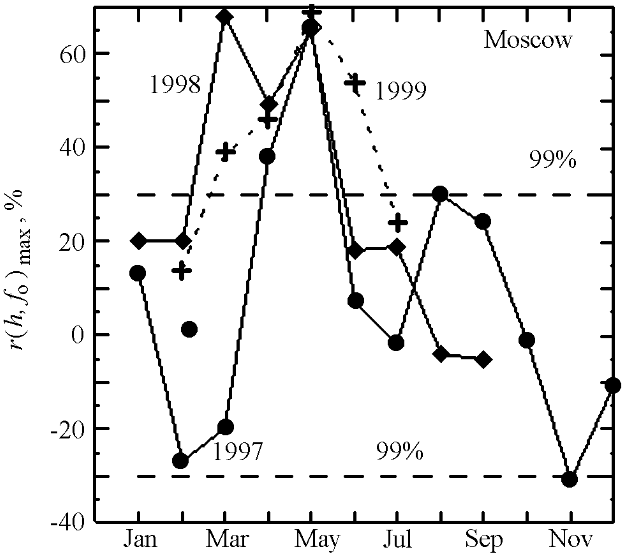

Figure 16. Relation between $-R(f_oF2)$ and $-r(h,f_o)$min for Moscow station. The correlation coefficient $R(4)$ is 0.84.

$-R(f_oF2)$ also for Moscow. One can see that the correlation in this case (night) is less pronounced than for $-r(h,f_o)$min (day). The correlation coefficient $R(5)$ in Figure 17 is 0.55. With 11 points available the significance level is 90%.

The corresponding values of $R(4)$ and $R(5)$ for Gorky and Kaliningrad stations are shown in Table 7. For Tomsk station the compared parameters are jointly available only for 8 years, so the results are statistically insignificant and are not shown in Table 7. The statistical significance of the $R(4)$ and $R(5)$ values shown in Table 7 is 99% and 90%, respectively. It is worth emphasizing again that drawing Figures 16 and 17 and Table 7 the values of $r(h,f_o)$ and $R(f_oF2)$ were taken for the March–June period of each year.

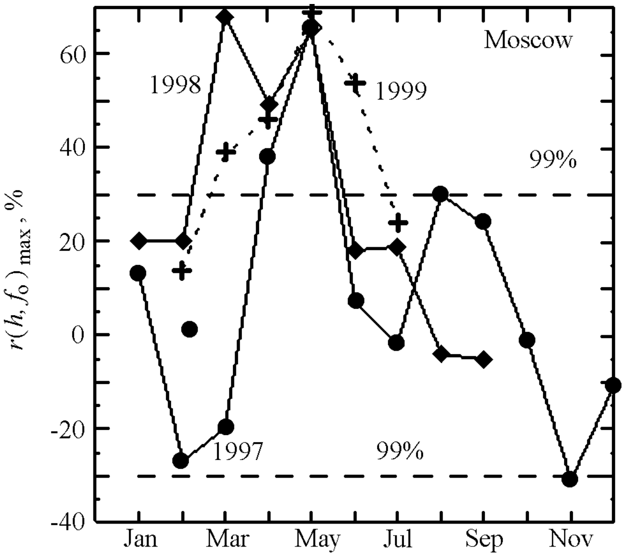

Figure 17. Relation between $-R(f_oF2)$ and $r(h,f_o)$max for Moscow station.

Table 7. Values of $R(4)$ and $R(5)$ for Three Stations

Station	$R(4)$	$R(5)$
Kaliningrad	0.85	0.41
Moscow	0.84	0.55
Gorky	0.81	0.58

11. Discussion

The aim of the series of papers cited above and the study on the whole is the analysis at the statistical level of the possible relation between the behavior of the stratosphere and ionospheric F region. There were no attempts to try to describe such a relation theoretically. There were two reasons for this. First, before describing such a relation one has to prove its existence at a large enough database and a high level of statistical significance. All typical features of the manifestation of this relation (diurnal, seasonal, related to solar activity) should be revealed. Second, a theoretical description of the relations between various atmospheric levels requires absolutely different approaches and instruments than those available for the authors of this study. On the basis of the current ideas one can a prior state that the interlayer interaction is governed by a complicated system of dynamical processes, including tidal and wave-like processes of different scales. A theoretical analysis of this problem requires a usage of sophisticated (most probably, three-dimensional) radiation-photochemical and dynamical models including the complicated schemes of wave processes description. We have neither such models nor schemes.

We summarize what we have succeeded in obtaining in the morphological aspect. First, it is worth emphasizing that, though the value $h(100)$ (i.e., the height of one isobaric level) is used as a stratospheric parameter, we actually are studying the relation of the entire stratosphere (or its major part) to the $F2$ region of the ionosphere, since in the entire interval 300–10 hPa (see above) the correlation coefficients of the isobaric level heights to f_oF2 are close to the coefficient for the 100 hPa level.

The most astonishing, in our opinion, is the result that the signs of the correlation are opposite if we compare $h(100)$ to the daytime or nighttime values of f_oF2 for the same day. Both at night (positive $r(h,f_o)$) and during the day (negative $r(h,f_o)$) the maximal absolute values of the correlation coefficients reach 0.75–0.80, and so the obtained relation is significant at the 99% level according to the Fisher criterion.

The above indicated fact made inevitable a search for the relation between the daytime and nighttime values of the $F2$-layer critical frequencies taken at the same day. The search showed that such a relation actually exists. Moreover, the main morphological features of this phenomenon are that the correlation coefficient between the daytime and nighttime values of f_oF2 is negative (that is, to higher daytime values of the critical frequency correspond lower nighttime values and vice versa) and the effect has a well-pronounced seasonal behavior (it is maximal in spring and in the beginning of summer (March–June)) and also depends on solar activity (it is well pronounced in the years of high activity and almost absent in the years of low activity).

This new conclusion for the morphology of the ionosphere is of special interest. From the point of view of the main aim of this study it is now a subsidiary result; however, it may became very important after further development of studies of the relation between the stratosphere and ionospheric F region because as it has been shown above, all three considered parameters (f_oF2(night), f_oF2(day) and $h(100)$) are interrelated.

Though we stated above in this section that this study is not aimed toward any detailed theoretical explanation of the obtained facts on the relation between $h(100)$ and f_oF2, it is worth looking at this facts under the angle of their relation to other known phenomena in the ionospheric physics. The value of $h(100)$ correlates directly to the nighttime values of f_oF2. It is widely known [*Ivanov-Kholodny and Mikhailov*, 1980; *Rishbeth and Barron*, 1960] that the latter value depends strongly on the horizontal wind which (due to the inclination of the magnetic field lines at middle latitudes) lifts the $F2$ layer into the region of slower recombination. The horizontal wind at $F2$-layer heights in quiet geomagnetic conditions is a part of the global circulation system involving all atmospheric layers including the stratosphere. Thus qualitatively one can suggest that changes in the circulation lead both to a density increase in the stratosphere (i.e., to a lifting of the 100 hPa level) and to an increase of the nighttime values of [e] in the $F2$ layer. Apparently, solar activity plays a secondary role here. That is why the amplitudes of $r(h, f_o)$max vary within a solar activity cycle from about 0.8 to 0.6. Why the relation between $h(100)$ and f_oF2 weakens with an increase of $F_{10.7}$ is not yet clear. Probably with an increase of solar activity the dynamical impact on f_oF2 reduces the role of other factors (for example, of additional nighttime sources of ionization).

The daytime values of foF2 are governed first of all by the solar ultraviolet flux. The temperature (and so the density distribution) in the stratosphere is also governed by the solar ultraviolet (but in a different wavelength range). However, the daytime values of f_oF2 depend directly on the ultraviolet flux, whereas T in the stratosphere depends indirectly (via absorption by ozone and the feedback between the ozone amount and temperature). In this case, T in the stratosphere and f_oF2 may vary into opposite directions under an increase in the ultraviolet, i.e., under increase in solar activity. Such a scheme explains the increase of $-r(h, f_o)$min with $F_{10.7}$. At relatively small values of $F_{10.7}$ (<130) the effect (especially in the stratosphere) is evidently small, and so a random scatter of the points is observed. Also, only at high $F_{10.7} = 180 - 220$ are both effects (in f_oF2 and stratospheric temperature) well enough pronounced, and this leads to the significant correlation ($-r(h, f_o)\mathrm{min} = 0.6 - 0.8$)).

The above described quantitative scheme is able to explain two detected facts out of three: different signs of the $h(100)$ correlations to the daytime and nighttime values of f_oF2 and variations of both coefficients with solar activity. The cause of the seasonal effect (that is, appearance of maximal significant values of $-r(h, f_o)$min and $r(h, f_o)$max only in a particular period of the year) still is obscure. Probably, the explanation should be looked for in the physics of the $F2$ layer because the correlation between the daytime and nighttime values of f_oF2 also appears at the statistically significant level in this very time of year (March–June).

Concluding this discussion, one should once more emphasize that in this study, two absolutely independent sets of the initial data obtained by different methods are considered. The fact that close conclusions are obtained (for example, on the seasonal behavior of the effect) and that these conclusions are similar for four strongly spatially separated stations (including the coincidence of the absolute values of the correlation coefficient and its seasonal behavior, see Figure 14) excludes a random coincidence and demonstrate that we actually see a real large-scale manifestation of the stratosphere–ionosphere relation the nature of which is still obscure.

12. Conclusions

The analysis of independent sets of data obtained under vertical ionospheric sounding (f_oF2) and aerological stratosphere sounding ($h(100)$) at four stations for the entire solar cycle (1979–1989) shows the following:

1. There exists a positive correlation between the nighttime (in LT) values f_oF2 and the $h(100)$ value measured at 0000 UT. All values of $r(h, f_o)$max lie mainly within 0.6–0.8 and are statistically significant at the 99% level by the Fisher criterion.
2. There exists a negative dependence between the daytime values of f_oF2 and $h(100)$. The majority of the $-r(h, f_o)$min values lie within the limits 0.4–0.8 and also have the statistical significance at the 99% level.
3. The dependencies indicated above are manifested at the statistically significant level not during the entire year but only in the March–June period.
4. The value of $r(h, f_o)$max decreases with an increase of solar activity from 0.8 at $F_{10.7}$ of about 80 to 0.60–0.75 at $F_{10.7} = 200$.
5. The value of $-r(h, f_o)$min increases with an increase of solar activity reaching at $F_{10.7} = 200$, a value of 0.75–0.85.

In the scope of this study a negative correlation between the daytime and nighttime values of f_oF2 is detected. This correlation also is seen at the statistically significant level in the March–June period and depends on solar activity. The maximal values of the correlation coefficient $R(f_oF2) = 0.5 - 0.8$ are reached at $F_{10.7} = 180 - 200$. The main conclusion of the study is that all three considered parameters (f_oF2(day), f_oF2(night), and $h(100)$) are interrelated at the statistically significant level, the interrelation depending on solar activity.

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References

Danilov, A. D., et al., *Meteorological Effects in the Ionosphere*, 266 pp., Gidrometeoizdat, Leningrad, 1987.

Ivanov-Kholodny, G. S., and A. V. Mikhailov, *Forecasting of the Ionosphere State,* 190 pp., Gidrometeoizdat, Leningrad, 1980.

Mikhailov, E. N., L. B. Vanina, and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters, *Geomagn. Aeron. (in Russian), 38* (1), 166, 1998.

Rishbeth, H., and R. Barron, Equilibrium electron distribution in the ionospheric $F2$ layer, *J. Atmos. Terr. Phys., 18,* 234, 1960.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: The seasonal effect, *Geomagn. Aeron. (in Russian), 39* (3), 129, 1999.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: The fine structure of the effect, *Geomagn. Aeron. (in Russian), 40* (6), 100, 2000.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: Gorky station, *Geomagn. Aeron. (in Russian), 42* (4), 509, 2002.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: The comparison of the Gorky and Kaliningrad stations, *Geomagn. Aeron. (in Russian), 43* (2), 220, 2003a.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: The dependency of the effect on UT, *Geomagn. Aeron. (in Russian), 43* (4), 497, 2003b.

Vanina, L. B., and A. D. Danilov, Interrelation between the daytime and nighttime values of f_oF2 and stratosphere parameter $h(100)$, *Geomagn. Aeron. (in Russian), 43* (5), 660, 2003c.

Vanina, L. B., and A. D. Danilov, The relation of the $F2$ region to stratosphere parameters: The choice of daytime and nighttime values of $r(h, f_o)$, *Geomagn. Aeron. (in Russian), 44*, 2004, (in press).

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