Pre-storm F_2-layer Q-disturbances at middle latitudes: Do they exist?

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Abstract Available manually scaled f_oF_2 observations over 50 years on Juliusruh, 33 years on Slough, and 37 years on Rome stations were used to check the association between quiet-time f_oF_2 disturbances (Q-disturbances) and following on isolated magnetic storms. Of course, such cases exist, however Pearson's contingency coefficient, Chi-square and Odds ratio tests applied to check a measure of association gave the absence of relationship even at the 95% confidence level. The lack of association makes it impossible to use F_2-layer disturbances as precursors for magnetic storms. The observed cases of apparent relationship between two events should be considered as random and physically unconditioned. The published cases indicating the relationship between two events can be explained in the framework of regular F_2-layer variations not related by any means to the following on magnetic storms.
Plain Language Summary The Earth's upper atmosphere, including the ionosphere, is under total solar control – direct or indirect. F_2-layer disturbances occurring during magnetically disturbed periods are due to these magnetic disturbances and they are not discussed in the paper. However there are quiet-time F_2-layer disturbances (Q-disturbances) occurring under low and very low level of geomagnetic activity. The relationship of such Q-disturbances with following on isolated magnetic storms is analyzed in the paper. All available manually scaled hourly f_oF_2 observations on Juliusruh (50 years), on Rome (37 years), and Slough (33 years) have been analyzed to estimate a measure of association between two binary variables: F_2-layer Q-disturbances and isolated magnetic storms. Pearson's contingency coefficient, Chi-square and Odds ratio tests applied to check a measure of association gave the absence of relationship even at the 95% confidence level. This is an expected result as from physical point of view such relationship has no physical explanation. The lack of association makes it impossible to use f_oF_2-layer disturbances as precursors for magnetic storms – the idea being discussed in the literature. The observed cases of apparent relationship between two events should be considered as random and physically unconditioned. The published cases indicating the relationship between two events can be explained in the framework of regular F_2-layer variations not related by any means to the following on magnetic storms.

1. Introduction

The Earth's upper atmosphere, including the ionosphere, is under direct or indirect solar control. Geomagnetic activity is a reaction to varying solar activity. During magnetic storms energy deposits in the auroral zone via electric fields and particle precipitations and heats the thermosphere. This heating results in upwelling of neutral atmosphere in the auroral zone and changes the global solar driven circulation. The increased pressure creates TAD which spreads from the auroral zone equatorward producing a positive F_2-layer storm phase in the daytime sector. This first impulse of equatorward wind is followed by the equatorward thermospheric wind which transfers the disturbed neutral composition from the auroral zone to middle and lower latitudes. The perturbed neutral composition with low O/N_2 ratio creates F_2-layer negative storm phase. High-latitude penetrating electric fields can also contribute to F_2-layer storm effects but their presence is always seen in geomagnetic index variations. This is a well-known F_2-layer storm scenario and this sequence of events is accepted at present (e.g. Akasofu & Chapman, 1972; Prölss, 2004). However ionospheric disturbances preceding magnetic storms which are related to these disturbances are being reported (Kane, 2005; Buresova & Laštovička, 2007, 2008; Blagoveshchensky & Kalishin 2009; Mansilla & Zossi, 2012; Liu, 2014; Mansilla, 2014;

Buresova et al., 2014; Blagoveshchensky et al., 2017) and a recent review by Danilov & Konstantinova (2019) is devoted to this topic.

In our previous paper (Mikhailov & Perrone, 2009) on this problem it was shown that all published cases of F_2-layer pre-storm disturbances were related either to elevated auroral activity or to quiet time F_2-layer disturbances (Q-disturbances) which had nothing common with the following magnetic storms. The term "Q-disturbances" is included into the title of the paper to stress that only Q-disturbances preceding magnetic storms should be analyzed as F_2-layer perturbations taking place under elevated auroral activity are related to this activity rather than to the following on magnetic storms. Unfortunately, in the majority of published cases the researchers do not pay much attention to the choice of preceding F_2-layer disturbances which may take place under elevated auroral activity. It should be also mentioned that no plausible mechanism relating F_2-layer disturbances to the following magnetic storms has been yet proposed and all published analyses are just case studies when pairs of events (f_oF_2 deviation from the monthly median background level and a following on magnetic storm) are formally put together without any attempts to explain the observed f_oF_2 deviation using known F_2-layer formation mechanisms.

The aim of our paper is to check the statistical significance of the relationship between strong ($devf_oF_2=f_oF_{2obs}/f_oF_{2med} \geq 30\%$, $\delta N_mF_2 > 60\%$) F_2-layer Q-disturbances with a duration of ≥ 2 hours and following on isolated magnetic storms with the minimal Dst ≤ -30 nT. The f_oF_2 manually scaled observations over 50 years on Juliusruh (54.6^{0}N; 13.4^{0}E), 33 years on Slough (51.5^{0}N; 359.4^{0}E) and 37 years on Rome (41.9^{0}N; 12.5^{0}E) stations were used in our analysis. Some recent publications on this problem are analyzed in the Discussion section.

2. Method description

The selection and preparation of the observations for the statistical analysis is a very important step and it is considered in details.

2.1. Isolated storms selection

The selection of isolated magnetic storm is based on hourly Dst and AE index variations (http://wdc.kugi.kyoto-u.ac.jp/dstae/index.html). A combination when positive Dst is changed for negative one followed by the first minimum with Dst <-30 nT is searched for. Only the day with this minimal Dst and previous 2 days are checked to find the UT moment when Dst has changed the sign. This UT moment is taken as the storm onset (SO) and previous 72 hours are analyzed. For each 24-hour period (3x24=72 h) averaged AE are calculated and each of them should be <=120 nT. Such average AE index of 120 nT corresponds to Ap=4-6 nT and this may guarantee that the selected storm was an isolated one.

2.2. Quite days selection

Magnetically quiet days with daily AE <=120 nT for the current and one previous days are selected for all years in question.

2.3. f_oF_2 Q-disturbances selection

According to Danilov & Konstantinova (2019) the analyzed F_2-layer disturbances should have $devf_oF_2 \geq 30\%$ and a duration ≥ 2 hours and they should precede the magnetic storm onset by 0-3 days (i.e. up to 72 hours). The monthly median background f_oF_2 values used in our analysis are model ones obtained for each ionosonde station by averaging of many monthly medians obtained under various geomagnetic conditions but similar levels of solar activity (Mikhailov & Perrone, 2014). The ionospheric monthly T-index (Turner, 1968; Caruana, 1990) is used as an indicator of solar activity level. It is well-known that effective ionospheric indices of solar activity provide the best correlation with monthly median f_oF_2 (e.g. Mikhailov & Mikhailov, 1999).

Daily AE index should be <=120 nT for the current and previous days. Hourly AE indices should be also <=120 nT for the selected 2-hour period. There may be some (not one) 2-hour f_oF_2 Q-disturbed periods preceding the analyzed magnetic storm. In this case the nearest to SO moment disturbance is left and others are ignored in the "yes-yes" analysis (see later).

Examples of selected f_oF_2 Q-disturbances followed by magnetic storms and without storms are given for positive (Fig. 1) and negative $devf_oF_2$ (Fig. 2) cases.

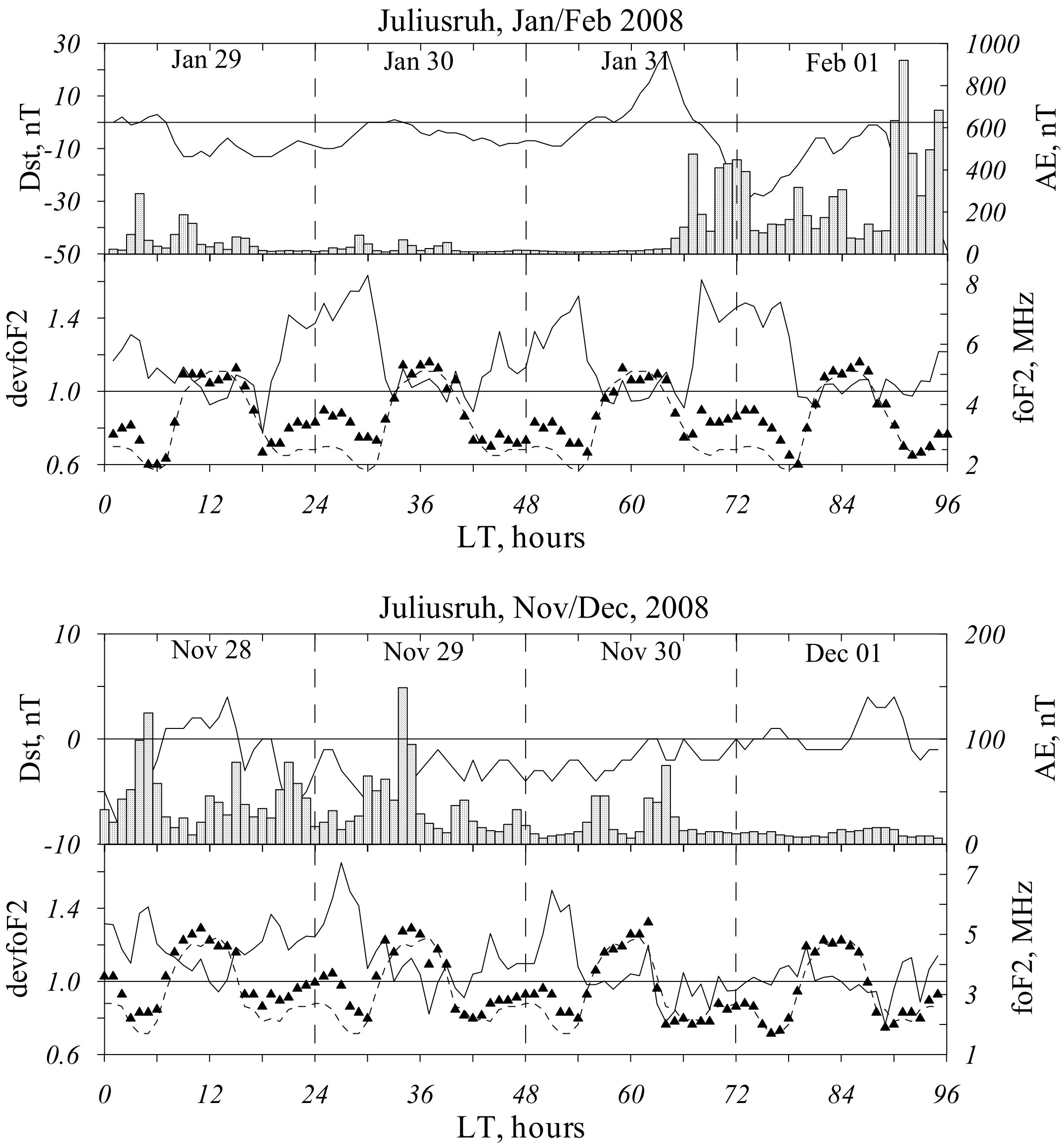

Figure 1. Examples of positive F_2-layer Q-disturbances at Juliusruh preceding a magnetic storm (top panel) and without following on magnetic storms (bottom panel). Hourly Dst and AE index variations are given in the top of the plots.

Figure 1 (top panel) gives an excellent example of strong ($devf_oF_2 \geq 40\%$) nighttime F_2-layer Q-disturbances which took place during two nights preceding the magnetic storm as well as on the night of the storm onset on February 01, the type of $devf_oF_2$ variation being practically the same. Similar positive nighttime $devf_oF_2$ deviations took place during magnetically quiet (AE < 100 nT) nights on November 28-30, 2008 without any following on magnetic storms while f_oF_2 variations during daytime just coincide with the monthly median (Fig. 1, bottom panel). In both cases these are long-lasting f_oF_2 disturbances covering all nighttime hours. According to the accepted rules only the disturbance on January 30/31 was used for the "yes-yes" sampling. The disturbance on January 31/February 01 was ignored as AE index was > 120 nT on that night while the disturbance on January 29/30 was also ignored for the "yes-no" sampling (see later) as it was followed by a magnetic storm within 72 hours. Both Q-disturbances on November 29-30 can be used for the “yes-no” selection as they were isolated from magnetic storms within 72 hours.

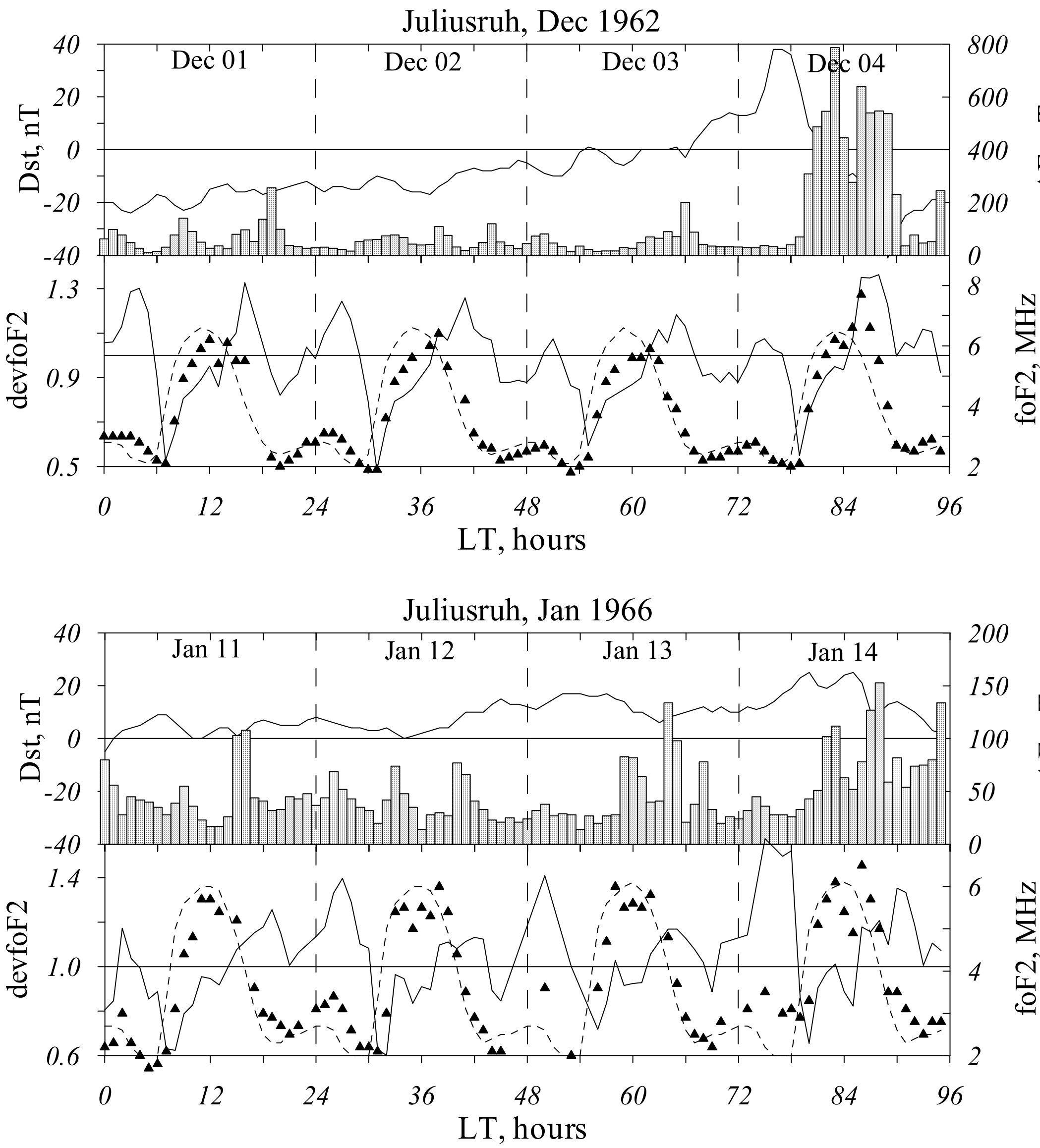

Figure 2. Same as Fig. 1 but for negative F_2-layer Q-disturbances.

Negative F_2-layer Q-disturbances are much less in number and the majority of them are related to the periods of sunrise and sunset. A shift in time of observed f_oF_2 with respect to monthly median variations during sunrise hours takes place four days including the storm day of December 04, 1962 (Fig. 2, top panel). The same peculiarity is seen for the days isolated from magnetic storms within 72 hours (Fig. 2, bottom panel). Days given in Fig. 2 (bottom panel) also manifest well-pronounced positive disturbances during nighttime hours and they were used for the “yes-no” selection in our analysis.

Thus we have got two arrays: isolated magnetic storms and F_2-layer Q-disturbances over the 50-year (from 1958-2017) period for Juliusruh., 33-year period for Slough (from 1958-1995) and over a 37-year (from 1976-2017) period for Rome. There are some gaps as AE indices and f_oF_2 observations therefore not all years could be used.

Pearson's mean square contingency coefficient and Chi-square test (
(https://www.statisticshowto.datasciencecentral.com/phi-coefficient-mean-square-contingency-coefficient/, https://www.statisticshowto.datasciencecentral.com/contingency-coefficient/) as well as odds ratio by Cornfield (1951) https://www.ncbi.nlm.nih.gov/pmc/articles/PMC2938757) may be used to estimate a measure of association between two binary variables: A – isolated magnetic storms (as this is explained earlier) and B – F_2-layer Q-disturbances defined earlier. A contingency table should be filled out for this analysis

Table 1. Contingency table.

Feature	A(Yes)	A(No)	Sum
B(Yes)	*a*	*b*	*a+b*
B(No)	*c*	*d*	*c+d*
Sum	*a+c*	*b+d*	*a+b+c+d*

where:
a (yes-yes) - number of F_2-layer Q-disturbances with dev$f_oF_2 \geq 30\%$ and a duration ≥ 2 hours which are followed by isolated magnetic storms within 72 hours;
b (yes-no) - number of F_2-layer Q-disturbances with dev$f_oF_2 \geq 30\%$ and a duration ≥ 2 hours which are not followed by isolated magnetic storms within 72 hours;
c (no-yes) - these are all F_2-layer Q-disturbances with any devf_oF_2 which are followed by isolated magnetic storms within 72 hours without "yes-yes" cases;
d (no-no) - these are all F_2-layer Q-disturbances except "yes-yes" cases which are not followed by isolated magnetic storms within 72 hours.

Pearson's contingency coefficient

$$K = \frac{a \times d - b \times c}{\sqrt{(a+b)(c+d)(a+c)(b+d)}}$$

Chi-square test

$$\chi^2 = \sum_{i=1}^{m} \sum_{j=1}^{n} \frac{(O_{ij} - E_{ij})^2}{E_{ij}}$$

where i-row, j-column in Tables 1 and 2.
O_{ij} - actual number of events in a cell from Table 1.
E_{ij} – expected number of events in a cell from Table 2 under zero hypothesis.

Table 2. Expected number of events under zero hypothesis.

Feature	A(Yes)	A(No)
B(Yes)	$\frac{(a+b)\times(a+c)}{(a+b+c+d)}$	$\frac{(a+b)\times(b+d)}{(a+b+c+d)}$
B(No)	$\frac{(c+d)\times(a+c)}{(a+b+c+d)}$	$\frac{(c+d)\times(b+d)}{(a+b+c+d)}$

The degree of freedom in our case $f = (m - 1)\times(n - 1) = 1$.

Odds ratio

$$OR = \frac{a \times d}{b \times c}$$

The upper and lower boundaries of 95% confidence interval

$$CI_{upp} = \exp\{\ln OR + 1.96\sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{c}}\}$$

$$CI_{low} = \exp\{\ln OR - 1.96\sqrt{\frac{1}{a} + \frac{1}{b} + \frac{1}{c} + \frac{1}{c}}\}$$

3. Results

Pearson's contingency coefficients K, Chi-square, and OR along with upper and lower limits are given in Table 3. Due to small amount of negative Q-disturbance cases (only some "yes-yes" cases have been found at Rome and Slough Table 3 includes results on negative disturbances only for Juliusruh.

Table 3. Pearson's contingency coefficient, Chi-square, and Odds ratio along with upper and lower limits. All available years were used.

Station	a	b	c	d	$K\times10^{-2}$	χ^2	OR upper & lower limits
Rome	19	84	437	2564	1.97	1.199	1.327 2.206; 0.798
Slough	41	188	301	1885	3.48	2.915	1.366 1.956; 0.954
Juliusruh Positive devfoF2	95	528	537	3680	2.50	3.239	1.242 1.573; 0.981
Juliusruh Negative devfoF2	21	132	609	3708	-1.99	0.018	0.969 1.547; 0.606

Table 3 shows that all K values are < 0.2 and this corresponds to no or negligible relationship, i.e. two variables: isolated magnetic storms and preceding F_2-layer Q-disturbances are not related to each other. However K coefficient gives more a qualitative rather than a quantitative estimate for a measure of association between two binary variables. Odds ratio and Chi-square test can provide more detailed information on a measure of association.

Chi-square test shows that all calculated $\chi^2 < 3.841$ (critical value at 95% confidence level) and this agrees with OR testing results: confidence intervals include 1.0 telling us about the absence of a statistically significant association at the 95% confidence level. Therefore three undertaken tests indicate no statistically significant association between isolated magnetic storms and preceding F_2-layer Q-disturbances.

3. Discussion

The absence of any statistically significant association between magnetic storms and preceding F_2-layer disturbances is not a surprise as there is an order of events in nature which cannot be violated and F_2-layer Q-disturbances preceding a magnetic storm and related to this storm do not occur. Therefore a suggestion by Blagoveshchensky and Kalishin (2009) to use F_2-layer disturbances as a precursor for future magnetic storms looks at least as not a serious one. On the other hand our statistical analysis has shown that results may depend on the year sampling. The results of such analysis for Juliusruh are given in Appendix. Removing one-by-one years from the initial set of 50 years it is possible to find combinations of years which formally manifest the association at least at the 95% confidence level (e.g. results obtained without 1962, 1965, 2005, and 2006). The calculated χ^2 > 3.841 (critical value at 95% confidence level) and formally this indicates a statistically significant association. However if we accept the 97.5% confidence level with critical χ^2 = 5.024 then no association can be found. From physical point of view a random coincidence may take place as F_2-layer Q-disturbances have a tendency to repeat for some days (e.g. Fig.1) and if magnetic storms occur rather often the probability of coincidence may be high enough.

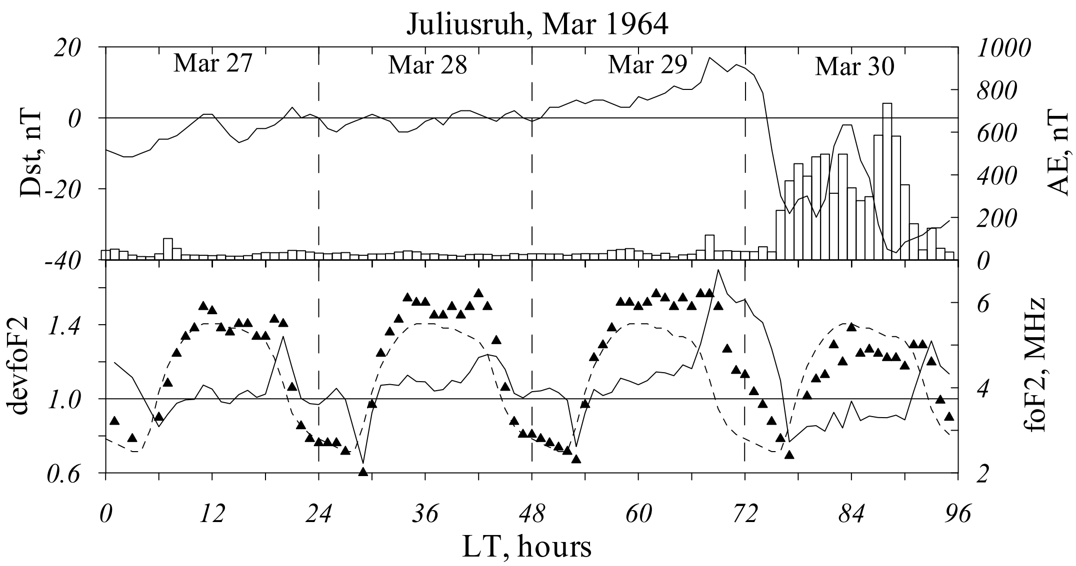

Figure 3. An example of Q-disturbance coinciding in time with SSC.

Another explanation may be related to our SO definition as the UT moment when Dst changes the sign from positive to negative. Normally this takes place later in time than SSC when it exists. Such an example is given in Fig. 3. Formally F_2-layer Q-disturbance on March 29 will be prescribed to the "yes-yes" data sample (see earlier formulated sampling rules) but in fact we have effects of the storm which has already started by that time. Q-disturbances of moderate magnitude (20-30)% during evening hours took place two previous days as well but the magnitude of Q-disturbance was strongly increased on March 29 and this should be related to the storm onset.

Theoretically a positive F_2-layer Q-disturbance followed by a magnetic storm in 40-50 hours could take place in the case of a solar flare. However all solar flares are registered and documented and it would not be a problem to analyze such a relationship. But solar EUV emission during solar flares mainly increases in the X-ray (λ < 100Å) range which ionize the lower ionosphere while the F_2-layer flare effects are very small (5-15)% in electron concentration (Mitra, 1974). Moreover such f_oF_2 increase can be seen only on the dayside and its duration is rather short in time – both features contradict the morphology of the analyzed Q-disturbances. Therefore this theoretical possibility should be discarded. The formation mechanism of mid-latitude daytime F_2-layer Q-disturbances has been recently discussed by Perrone et al., (2020).

The difference between two classes of events (F_2-layer Q-disturbances and magnetic storms) is also seen comparing their distributions on season and UT (Fig. 4). Magnetic storms, as this is expected, are rather evenly distributed in UT independently on season, while F_2-layer disturbances manifest a well-pronounced diurnal variation in their occurrence. Positive Q-disturbances are more numerous compared to negative ones and they are clustering in the evening-early morning and nighttime (LT≈UT+1) sectors. Negative Q-disturbances manifest a pronounced winter sunrise maximum at Juliusruh and they are practically absent in summer. Both types of disturbances do not practically occur during daytime hours. The morphology of F_2-layer Q-disturbances was earlier analyzed by Mikhailov et al., (2004).

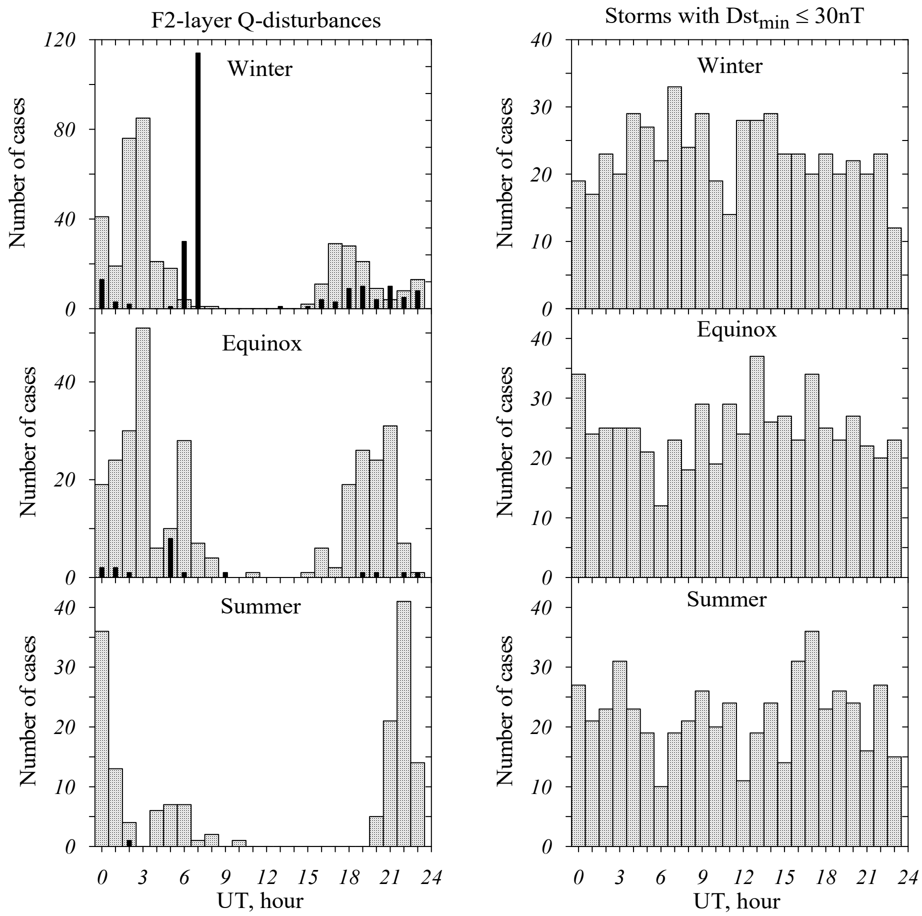

Figure 4. Distribution on season and UT of F_2-layer positive (light bars) and negative (dark bars) Q-disturbances observed at Juliusruh (left panels) along with isolated magnetic storms used in the analysis (right panels).

Some examples of the most frequently occurring positive and negative Q-disturbances in f_oF_2 variations are given in Fig. 5. All f_oF_2 deviations from monthly median variations given in Fig. 5 reflect the peculiarities of F_2-layer formation under various geophysical conditions.

Global morphology of nighttime f_oF_2 enhancements (positive Q-disturbances) may be found in Farelo et al., (2002). The formation mechanism is related to two processes: the F_2-layer uplift by equatorward thermospheric wind and plasma influx from the plasmasphere (Mikhailov et al., 2000). The downward plasmaspheric flux is the only source of fresh plasma in the nighttime F_2-region and the balance between this influx and the total number of recombinations in the ionospheric column explains both positive and negative nighttime F_2-layer Q-disturbances (Mikhailov & Förster, 1999; Mikhailov et al., 2000).

Summer pre-noon and evening peaks in f_oF_2 diurnal variations (Fig. 5, b) are related to meridional thermospheric wind V_{nx} which is directed equatorward in summer during the main part of the day (Buonsanto & Witasse, 1999). The equatorward wind uplifts the F_2-layer from the area of strong recombination and under sunlit conditions this results in f_oF_2 increase. Near noontime V_{nx} becomes northward for some hours and this decreases f_oF_2 producing a noontime 'bite-out' in f_oF_2 diurnal variations. This mechanism was proposed long ago (Kohl et al., 1968, Eccles et al., 1971; Eccles & Burge, 1973).

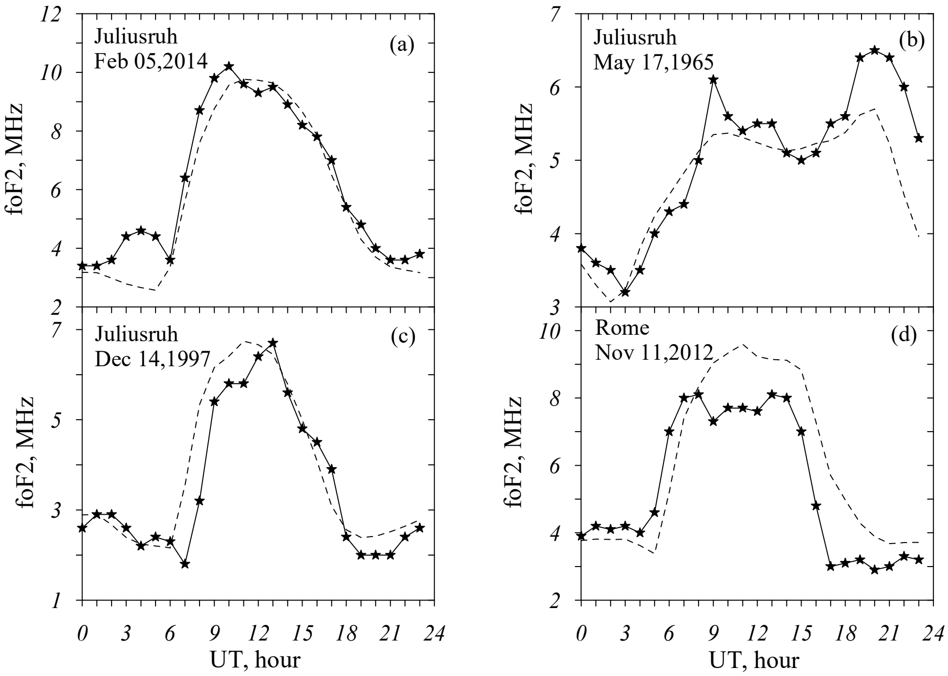

Figure 5. The examples of the mostly frequently occurring Q-disturbances in f_oF_2 variations: (a) – winter nighttime-early morning positive disturbance, (b) – summer sunset positive disturbance, (c) - winter morning negative disturbance, and (d) - winter evening negative disturbance. Dashes – model monthly median f_oF_2.

Large devf_oF_2 near sunrise and sunset (Fig. 5 c, d) may be related to large df_oF_2/dt in winter and equinox during sunrise and sunset hours. Day-to-day changes in the meridional wind velocity and atomic oxygen concentration may result in negative f_oF_2 disturbances (Mikhailov et al., 2007). A moderate f_oF_2 decrease (a shift) near noontime hours corresponds to large f_oF_2 deviations during the sunrise and sunset hours when df_oF_2/dt is large (Fig. 5 c, d).

Therefore large devf_oF_2 are related to F_2-layer formation mechanism and have nothing common with magnetic storms which may or may not follow such Q-disturbances. Moreover such Q-disturbances may occur for some consecutive days manifesting similar daily f_oF_2 variations and this was stressed in our previous paper (Mikhailov & Perrone, 2009).

Now let us analyze some recent publications appeared after 2008 and not mentioned in our previous paper in which the authors relate F_2-layer disturbances with the following magnetic storms. We will consider only cases with f_oF_2 deviations as much more reliable in a comparison with TEC observations. The latter includes the plasmaspheric part which contributes a lot to TEC but lives its own life not related to the underlying F_2-region.

Blagoveshchensky (2014) and Blagoveshchensky et al., (2017) have analyzed some storm periods at Sodankylä ionosonde station (67.4^{0}N; 26.6^{0}E) located in the auroral zone. They have revealed pre-storm positive f_oF_2 deviations 1-3 days before the storm onset. All five cases given with dates of particular storms belong to summer period when the ionosphere at Sodankylä is sunlit practically round o'clock. Figure 6 gives one (15-20 July, 2011) of considered cases with devf_oF_2= f_oF_{2obs}/f_oF_{2med} ratio variations when gaps in f_oF_2 observations were not numerous.

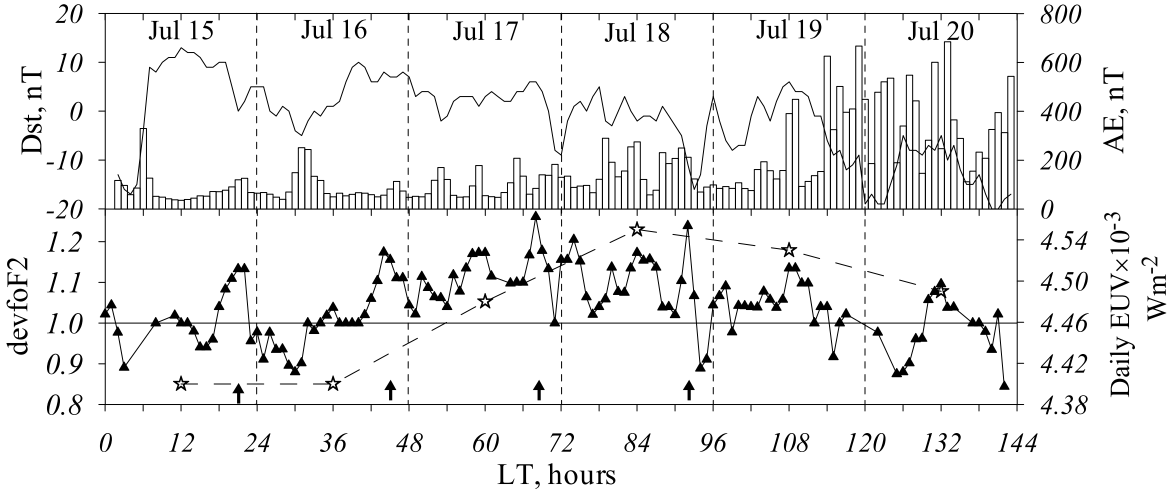

Figure 6. July 15-20, 2011 devf$_o$F$_2$ (triangles) at Sodankylä along with Dst and AE index variations (top panel). Arrows indicate LT moments of the largest positive f$_o$F$_2$ deviations. Asterisks – daily variations of solar EUV radiation.

Figure 6 shows that during four days (July 15-18) before the magnetic storm F$_2$-layer did demonstrate f$_o$F$_{2obs}$/f$_o$F$_{2med}$ ratio increases up to ~20% around (20-21)LT. This effect has a simple explanation. The sunset at Sodankylä in the middle of July takes place around 22.5 LT. The thermospheric meridional wind reversal from northward to equatorward one takes place around (18-19) LT (Hedin et al., 1996). The F$_2$-layer is uplifted from the strong recombination area and being sunlit manifests a f$_o$F$_2$ increase. Other three summer storm cases: 17/06/2012, 04/08/2010, and 03/09/2012 have the same explanation. Therefore the f$_o$F$_2$ pre-storm increase discussed by Blagoveshchensky (2014) has nothing common with following geomagnetic storm, moreover such f$_o$F$_2$ increases took place during some preceding days but not one (Fig. 6). In the case of July 15-20, 2011 (Fig. 6) the f$_o$F$_{2obs}$/f$_o$F$_{2med}$ ratio is seen to increase in time but this is due to solar EUV increase from July 15 to July 18 (Woods et al., 2018, asterisks in Fig. 6).

A somewhat different effect took place on the July 22, 2009 storm (Fig. 7) also analyzed by Blagoveshchensky et al., (2017). The devf$_o$F2 increase 1.5 days before the storm onset may be

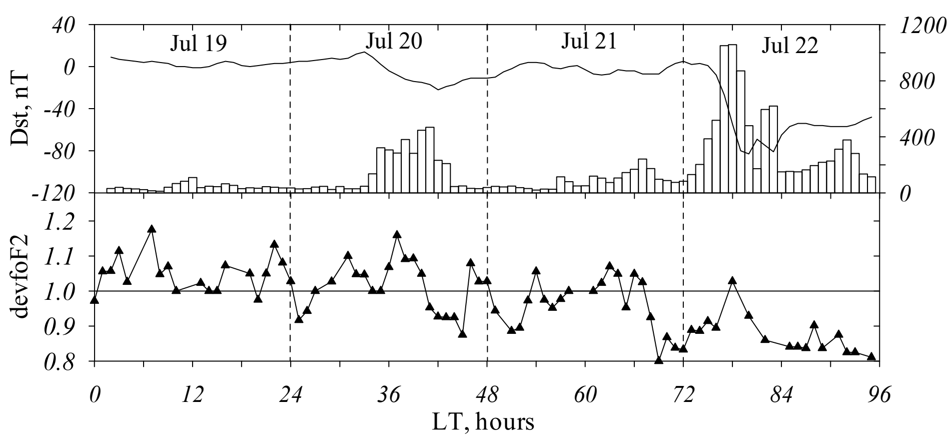

Figure 7. July 19-22, 2009 f$_o$F$_{2obs}$/f$_o$F$_{2med}$ ratio (triangles) at Sodankylä along with Dst and AE index variations.

related to the splash of auroral activity with AE index up to 400 nT during daytime hours on July 20. Along with this daytime increase morning and evening devf$_o$F2 increases are also seen which are due to the earlier discussed mechanism – the sunlit F_2-layer plus the equatorward thermospheric wind. Therefore all pre-storm devf$_o$F$_2$ increase cases given in the papers by Blagoveshchensky just reflect the peculiarities of the F_2-layer formation under specific geophysical conditions.

Selection of the background level is a crucial point dealing with f$_o$F$_2$ deviations. Various approaches are used to specify the background level. Monthly median or running medians calculated over previous ~ 30 days are often used as the background (e.g. Marin et al., 2000; Kutiev & Muhtarov, 2001; Tsagouri & Belehaki, 2008). However any median includes the effects of geomagnetic disturbances occurred during the analyzed period. Better results should give a selection of magnetically quiet days at a station with binning them in terms of hour, month and range of solar activity. The mean value for each bin provides a quiet-time background level which can be applied with suitable interpolation to any day of a month (Wrenn et al., 1987; Perrone et al., 2007; Pietrella and Perrone, 2008; Pietrella, 2012). But quiet-time disturbances (Mikhailov et al., 2004) inevitably contribute to such background level. Our approach (as this was mentioned earlier) is based on using model monthly median f$_o$F$_2$ as the background level. After averaging (in the model for each particular station) of many monthly medians obtained under various geomagnetic conditions but similar levels of solar activity one may hope that such average median presents a background level corresponding to a given level of solar activity (Mikhailov & Perrone, 2014).

Adekoya et al. (2012) analyzed ionospheric pre-storm (October 21, 2001) ionospheric effects using the worldwide ionosonde network observations. They used an average f$_o$F$_2$ over four (October 15-18) quiet previous days as the background f$_o$F$_2$ level and found a 62% f$_o$F$_2$ decrease at Juliusruh (54.6^{0}N; 13.4^{0}E) at 1900 UT on the pre-storm October 20 day (Fig. 8).

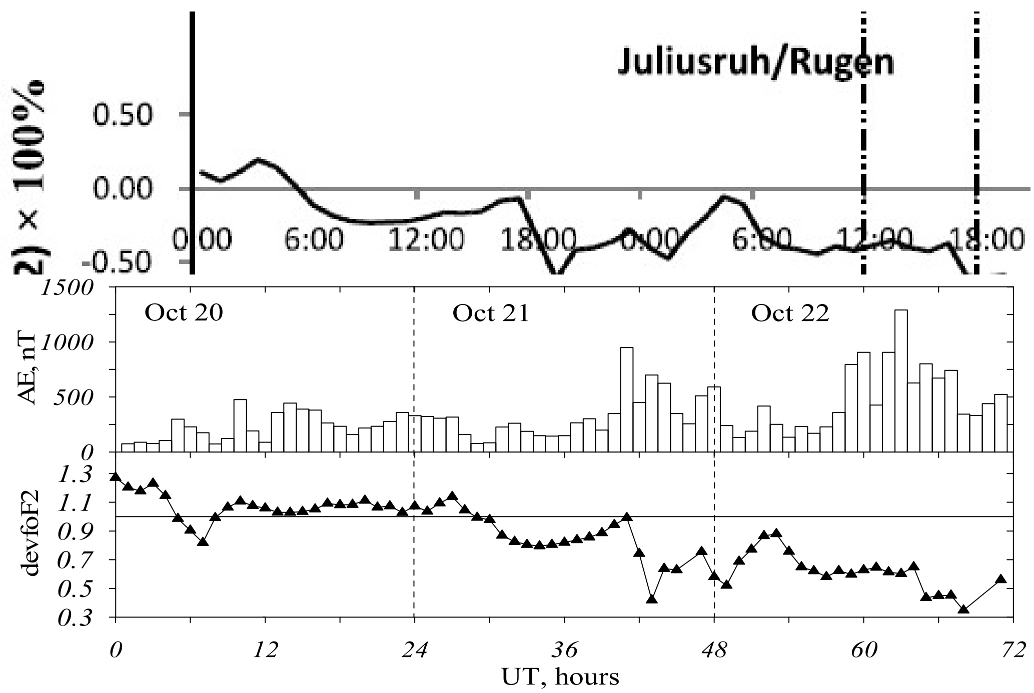

Figure 8. Juliusruh devf$_o$F$_2$ during the October 21, 2001 storm from Adekoya et al. (2012) (top panel) along with AE index variations and devf$_o$F$_2$ calculated with our background (bottom panel).

Our method of devf$_o$F$_2$ calculation is seen to give different results (Fig. 8). Contrary to large negative devf$_o$F$_2$ we have small (< 10%) positive devf$_o$F$_2$ during daytime and evening hours on October 20 as a reaction to elevated auroral activity. Strong during daytime hours northward thermospheric wind is damped due to elevated auroral heating and this results in a positive devf_oF_2 (Mikhailov et al., 2007). During nighttime hours when the thermospheric wind is equtorward the disturbed neutral composition is moved from the auroral zone to lower latitudes resulting in negative devf_oF_2 during daytime hours on October 21 (Fig. 8). This is a well-know process described in the literature (Prölss, 1995; Rishbeth, 1998; Fuller-Rowell et al, 1994, 2000). Therefore, an incorrect specification of the background level may induce false pre-storm f_oF_2 effects.

Danilov & Konstantinova (2019) in their review give some examples of positive and negative f_oF_2 disturbances preceding the magnetic storm onset. All cases took place in winter during nighttime hours. Figure 9 gives one of them observed at Slough on January 25-28, 1995. A larger devf_oF_2 of ~ 50% is seen on January 28 around 06 UT before the storm onset (SO – dashed vertical line in Fig. 9). However similar devf_oF_2 took place on three previous days exactly at the same time telling us that these f_oF_2 deviations reflect the F_2-layer formation mechanism in the particular geophysical conditions rather than a connection with following on magnetic storm (see later).

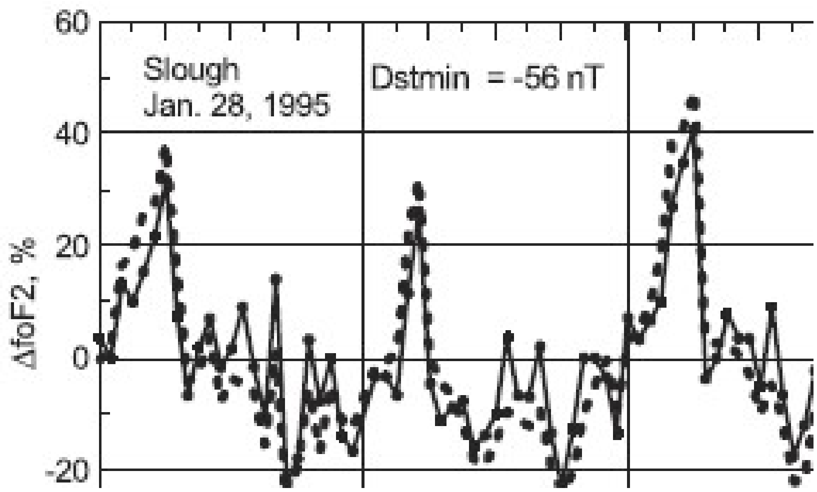

Figure 9. Slough devf_oF_2 variations during the days preceding the January 28, 1995 magnetic storm. Daily average AE and ΣKp are also given to show that the period was magnetically quiet (from Danilov & Konstantinova, 2019).

Figure 10 gives devf_oF_2 and h_mF_2 (http://giro.uml.edu/didbase/scaled.php) variations at Juliusruh for a magnetically quiet (December 06-11, 2009) period which was not followed by any magnetic storm. Similar to January 25-28, 1995 (Fig. 9) this is also a winter time period under solar minimum. A similarity in nighttime devf_oF_2 variations during the two periods is obvious while the magnitude of devf_oF_2 variations on December 06-11, 2009 is larger (up to 80%). Nighttime devf_oF_2 with a ~ 2-hour delay (a characteristic time of f_oF_2 reaction to vertical drift changes) mainly follow h_mF_2 variations. In its turn h_mF_2 just reflects the variations of vertical plasma drift W related to the equatorward thermospheric wind V_{nx}. Naturally, the wind velocity exhibits day-to-day variations resulting in different diurnal devf_oF_2 variations during nighttime hours. Normally two-hump devf_oF_2 variations with peaks before and after midnight take place with a 'bite-out' around midnight (Fig. 10). Observations by Behnke and Harper (1973) at Arecibo show that usual strong pre-midnight equatorward wind maximizing around 22 LT inverses around midnight. Downward drift increases the recombination producing a two-hump nighttime f_oF_2 variation. Computer simulation by Förster and Jakowski (1986, 1988) with a short reversal of the meridional wind around midnight similar to observations by Harper (1973) and Behnke and Harper (1973) confirmed the two peak f_oF_2 variation under this wind reversal mechanism.

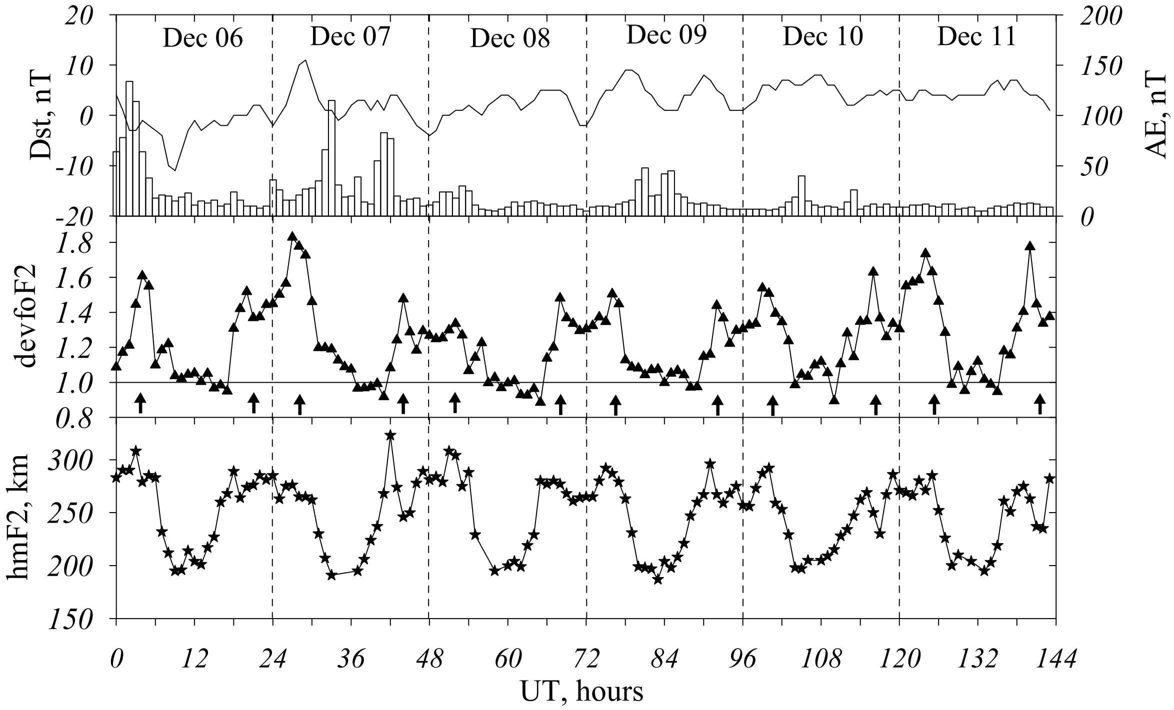

Figure 10. Juliusruh $devf_oF_2$ and h_mF_2 variations for a magnetically quiet (December 06-11, 2009) period along with AE and Dst index variations. Arrows indicate the pre-midnight and post-midnight maxima.

The dependence of nighttime N_mF_2 on vertical plasma drift W has a simple explanation (Mikhailov et al., 2000). During nighttime the diffusion velocity of O^+ ions is always downward from the plasmasphere to the F_2-region to restore the barometric distribution of O^+ ions which is being violated by recombination. Vertical plasma velocity in the ambipolar approximation is given by the expression (Banks & Kockarts, 1973)

$$V_z = -D_a \sin^2 I \left[\frac{d \ln N}{dz} + \frac{m_i g}{k(T_e + T_i)} + \frac{d \ln(T_e + T_i)}{dz} \right] + W \quad (1)$$

where N = $[O^+]$ is the electron density, Te and Ti - plasma temperatures, I -magnetic inclination, $W=V_{nx}sinIcosI$ - vertical plasma drift due to thermospheric winds, and D_a - ambipolar diffusion coefficient. The upward plasma drift W (the equatorward thermospheric wind) subtracting from the diffusion velocity in (1) decreases the plasma flow down to heights where recombination is strong. Under a permanent plasma influx of $(1\text{-}2)\times10^8$ cm^{-2} s^{-1} from the plasmasphere the stronger upward plasma drift the less plasma drains to the area of strong recombination accumulating at F_2-layer heights. A decrease of W leads to the opposite result. Observed h_mF_2 variations (Fig. 10) which are directly related to W variations (Ivanov-Kholodny & Mikhailov, 1986) clearly confirm this mechanism.

Therefore winter nighttime positive F_2-layer disturbances given by Danilov & Konstantinova (2019) just present regular N_mF_2 variations which may or may be not be followed by a magnetic storm – these two events are not related to each other. Anyway nobody has yet proposed any plausible mechanism relating such regular F_2-layer variations with the following on magnetic storms.

4. Conclusion

Using available manually scaled f_oF_2 observations over 50 years on Juliusruh, 33 years on Slough, and 37 years on Rome stations the relationship between F_2-layer Q-disturbances with $devf_oF_2=f_oF_{2obs}/f_oF_{2med} \geq 30\%$ and following on isolated magnetic storms with the minimal Dst ≤ 30 nT has been analyzed. The results may be formulated as follows.

1. Cases of F_2-layer Q-disturbances followed by magnetic storms do exist but Pearson's contingency coefficient, Chi-square and Odds ratio tests applied to check a measure of association between isolated magnetic storms and preceding f_oF_2 Q-disturbances (both positive and negative) gave the absence of association even at the 95% confidence level. This is an expected result as from physical point of view such relationship has no physical explanation.

2. The lack of association makes it impossible to use f_oF_2-layer disturbances as precursors for magnetic storms – the idea being discussed in the literature.

3. The occurrence of Q-disturbances reflects their morphology which in its turn reflects the F_2-layer formation mechanism under magnetically quiet conditions. For this reason the observed cases of apparent relationship between two events should be considered as random and physically unconditioned.

4. Recently published as well as earlier analyzed by Mikhailov & Perrone (2009) cases of the association between f_oF_2-layer Q-disturbances and following on isolated magnetic storms can be explained in the framework of regular f_oF_2-layer variations not related by any means to these magnetic storms. The f_oF_2-layer disturbances mentioned in those publications are due to:
i) elevated auroral activity; ii) an incorrect selection of the background level the f_oF_2 deviations are counted from; iii) regular quiet-time f_oF_2-layer variations.

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Appendix. Chi-square and OR results for Juliusruh F_2-layer positive Q-disturbances.

χ^2 = 3.273 without year= 1958 a= 95. b= 522. c= 536. d=3663. OR= 1.244 CI_upp= 1.576 CI_low= .982	χ^2 = 2.902 without year= 1980 a= 93. b= 528. c= 521. d=3639. OR= 1.230 CI_upp= 1.562 CI_low= .969
χ^2 = 3.066 without year= 1959 a= 93. b= 522. c= 527. d=3660. OR= 1.237 CI_upp= 1.571 CI_low= .975	χ^2 = 2.977 without year= 1981 a= 94. b= 526. c= 533. d=3675. OR= 1.232 CI_upp= 1.563 CI_low= .972
χ^2 = 2.154 without year= 1960 a= 89. b= 518. c= 525. d=3664. OR= 1.199 CI_upp= 1.529 CI_low= .941	χ^2 = 3.326 without year= 1982 a= 95. b= 524. c= 537. d=3690. OR= 1.246 CI_upp= 1.578 CI_low= .983
χ^2 = 2.724 without year= 1961 a= 90. b= 508. c= 522. d=3612. OR= 1.226 CI_upp= 1.562 CI_low= .962	χ^2 = 2.902 without year= 1983 a= 93. b= 526. c= 531. d=3694. OR= 1.230 CI_upp= 1.561 CI_low= .969
χ^2 = 3.937 without year= 1962 a= 91. b= 505. c= 510. d=3613. OR= 1.277 CI_upp= 1.626 CI_low= 1.002	χ^2 = 3.308 without year= 1984 a= 95. b= 528. c= 534. d=3695. OR= 1.245 CI_upp= 1.577 CI_low= .983
χ^2 = 3.149 without year= 1963 a= 90. b= 491. c= 524. d=3560. OR= 1.245 CI_upp= 1.587 CI_low= .977	χ^2 = 3.581 without year= 1985 a= 95. b= 526. c= 527. d=3666. OR= 1.256 CI_upp= 1.592 CI_low= .991
χ^2 = 2.307 without year= 1964 a= 89. b= 504. c= 521. d=3562. OR= 1.207 CI_upp= 1.540 CI_low= .946	χ^2 = 3.165 without year= 1986 a= 94. b= 524. c= 528. d=3651. OR= 1.240 CI_upp= 1.573 CI_low= .978
χ^2 = 4.122 without year= 1965 a= 92. b= 478. c= 530. d=3533. OR= 1.283 CI_upp= 1.633 CI_low= 1.008	χ^2 = 3.577 without year= 1987 a= 95. b= 525. c= 525. d=3645. OR= 1.256 CI_upp= 1.592 CI_low= .991
χ^2 = 3.496 without year= 1966 a= 93. b= 501. c= 533. d=3606. OR= 1.256 CI_upp= 1.595 CI_low= .989	χ^2 = 3.082 without year= 1990 a= 94. b= 528. c= 528. d=3668. OR= 1.237 CI_upp= 1.569 CI_low= .975
χ^2 = 3.095 without year= 1967 a= 93. b= 516. c= 528. d=3629. OR= 1.239 CI_upp= 1.573 CI_low= .975	χ^2 = 3.355 without year= 1991 a= 95. b= 523. c= 535. d=3673. OR= 1.247 CI_upp= 1.580 CI_low= .984
χ^2 = 3.569 without year= 1968 a= 94. b= 520. c= 528. d=3672. OR= 1.257 CI_upp= 1.595 CI_low= .991	χ^2 = 3.390 without year= 1995 a= 93. b= 522. c= 518. d=3638. OR= 1.251 CI_upp= 1.589 CI_low= .985
χ^2 = 3.528 without year= 1969 a= 95. b= 515. c= 535. d=3638. OR= 1.254 CI_upp= 1.590 CI_low= .990	χ^2 = 3.112 without year= 1997 a= 91. b= 512. c= 517. d=3613. OR= 1.242 CI_upp= 1.581 CI_low= .976
χ^2 = 2.902 without year= 1970 a= 92. b= 518. c= 526. d=3647. OR= 1.231 CI_upp= 1.565 CI_low= .969	χ^2 = 3.330 without year= 1999 a= 95. b= 526. c= 529. d=3650. OR= 1.246 CI_upp= 1.579 CI_low= .983
χ^2 = 2.656 without year= 1971 a= 91. b= 521. c= 524. d=3664. OR= 1.221 CI_upp= 1.554 CI_low= .960	χ^2 = 2.857 without year= 2000 a= 94. b= 528. c= 534. d=3680. OR= 1.227 CI_upp= 1.556 CI_low= .968
χ^2 = 2.869 without year= 1972 a= 91. b= 518. c= 522. d=3658. OR= 1.231 CI_upp= 1.566 CI_low= .968	χ^2 = 3.287 without year= 2001 a= 95. b= 527. c= 527. d=3638. OR= 1.244 CI_upp= 1.577 CI_low= .982
χ^2 = 3.322 without year= 1973 a= 95. b= 523. c= 535. d=3669. OR= 1.246 CI_upp= 1.578 CI_low= .983	χ^2 = 3.720 without year= 2002 a= 94. b= 524. c= 520. d=3662. OR= 1.263 CI_upp= 1.603 CI_low= .996
χ^2 = 3.445 without year= 1974	χ^2 = 3.318 without year= 2003

a= 95. b= 525. c= 533. d=3684. OR= 1.251 CI_upp= 1.585 CI_low= .987	a= 95. b= 526. c= 536. d=3696. OR= 1.245 CI_upp= 1.578 CI_low= .983
χ^2 = 3.354 without year= 1975 a= 94. b= 521. c= 530. d=3667. OR= 1.248 CI_upp= 1.583 CI_low= .984	χ^2 = 3.146 without year= 2004 a= 93. b= 526. c= 525. d=3684. OR= 1.241 CI_upp= 1.575 CI_low= .977
χ^2 = 3.216 without year= 1978 a= 94. b= 523. c= 530. d=3664. OR= 1.243 CI_upp= 1.576 CI_low= .980	χ^2 = 3.915 without year= 2005 a= 94. b= 526. c= 516. d=3670. OR= 1.271 CI_upp= 1.613 CI_low= 1.002
χ^2 = 3.235 without year= 1979 a= 95. b= 525. c= 536. d=3679. OR= 1.242 CI_upp= 1.574 CI_low= .980	χ^2 = 4.031 without year= 2006 a= 95. b= 520. c= 516. d=3600. OR= 1.275 CI_upp= 1.616 CI_low= 1.005