ROLE OF CORONAL MASS EJECTIONS AND HIGH-SPEED SOLAR STREAMS IN THE OCCURRENCE OF IONOSPHERIC DISTURBANCES

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Introduction

The influence of solar processes on the state of near-earth space is the subject of constant study. First of all, these are studies of the magnetosphere-ionosphere-atmosphere system and the reaction of this system to changes in solar activity in general. The relevance of the research is also due to the fact that significant climatic changes have been found in the entire thickness of the earth's atmosphere, which include variations not only in meteorological characteristics, but also in the chemical composition of the middle and upper atmosphere.

Short-lived variations in solar activity, mainly powerful solar flares and coronal mass ejections, play an important role in changing the characteristics of near-earth space. At the same time, recent studies also show the important role of high-speed solar wind streams in the occurrence of geomagnetic disturbances.

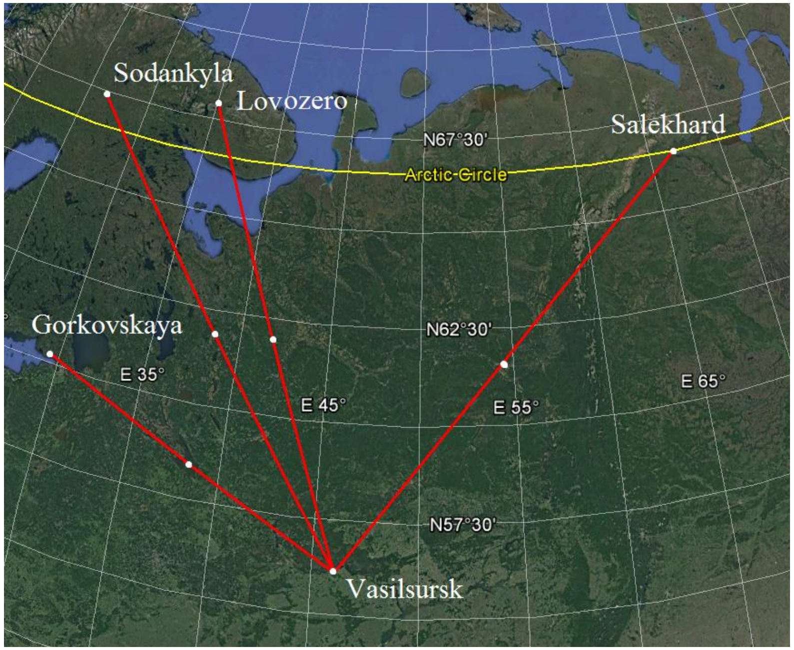
In this report we present illustration of ionospheric response to solar coronal mass emissions and high-velocity solar wind streams.

1. Data

The study uses **vertical** and **oblique sounding** data of the ionosphere obtained in May, September 2017 during the observations of the maximum observed frequency (MOF, in MHz) of ionospheric channels on three subauroral (Lovozero-Vasilsursk, Sodankyulya-Vasilsursk and Salekhard-Vasilsursk) and one mid-latitude (Gorkovskaya, Leningrad region-Vasilsursk) paths, as well as the critical frequency of the ionospheric layer F (*f*0F2, in MHz) from the mid-latitude ionosphere station.

Vertical ionospheric sounding data of *f*0F2 were obtained from regular observations at the NIRFI NNGU Ionospheric and Radio Astronomy Observatory «Vasilsursk» (56.15 °N, 46.10 °E, near Nizhny Novgorod city). Vasilsursk is located in longitude between Sodankyla and Salekhard.

The observations of oblique sounding of the ionosphere were performed on a network of oblique sounding paths shown schematically in Figure. The parameters of the transmit–receive points are given in Table.



Paths	Length, km	Coordinates of chirp transmitting stations
Lovozero – Vasilsursk	1767	68.00°N, 35.02°E
Sodankyla – Vasilsursk	1236	67.4°N, 26.6°E
Salekhard – Vasilsursk	1581	66.52°N, 66.37°E
Gorkovskaya – Vasilsursk	1500	60.27°N, 29.38°E

The MOF for oblique sounding trajectories were determined using an ionosonde-direction finder with chirp signal on 4 chirp-sounding paths mentioned above. In this experiment, the chirp transmitters in Lovozero, Salekhard, and Gorkovskaya were operated 24 hours. The sounding was carried out in the 2–29 MHz frequency range, the frequency tuning rate was 550 kHz/s, and the sounding period was 15 min. The transmitter in Sodankyla was operated in the frequency range 2–16 MHz, the frequency tuning range was 500 kHz/s, and the sounding interval was 5 min. The chirp signals were received in Vasil'sursk (Nizhny Novgorod region), using chirp receiving-transmitting stations manufactured by "SITKOM" LLC – a base radio transceiver station (BRTRS) for diagnostics of the ionosphere and HF radio links with chirp signals. The data of *f*0F2 were obtained using installed Canadian Advanced Digital Ionosonde (CADI) (*www.sil.sk.ca*) and the working program of regular observations allowed to obtain ionograms at least once every 15 min. The accuracy of determining the critical frequency was less than 50 kHz.

To examine the role of high-speed solar wind streams (HSS) and coronal mass ejections (CME) in ionospheric disturbances, correlated with magnetic storms in period of consideration, we use solar wind proton speed data from the ACE RTSW satellite and SOHO LASCO CME CATALOG.

2. Method

The study of disturbances in vertical and oblique sounding data is based on the **deviation** of the critical frequency of the ionospheric layer F2 (Δ*f*0F2) and maximum observed frequency (ΔMOF) for oblique sounding trajectories:

$$\Delta f0F2_{jk} = f0F2_{jk} - \overline{f0F2_j} \qquad \overline{f0F2_j} = \sum_{k=1}^{N} f0F2_{jk} / N$$

Where *f*0F2*jk* – each measured point, *j* is the point number during the day, *k* is the day number in the month. *N* is number of days in a month. A similar procedure is used for ΔMOF.

A joint analysis of ionospheric data and characteristics of coronal mass ejections showed a correlation between the temporal behavior of the Δ*f*0F2 deviation of the F2 layer of the ionosphere and the registration of coronal mass ejections of a certain type (see Figure below).

Δ*f*0F2 Moscow March, 2015 a) b) c)

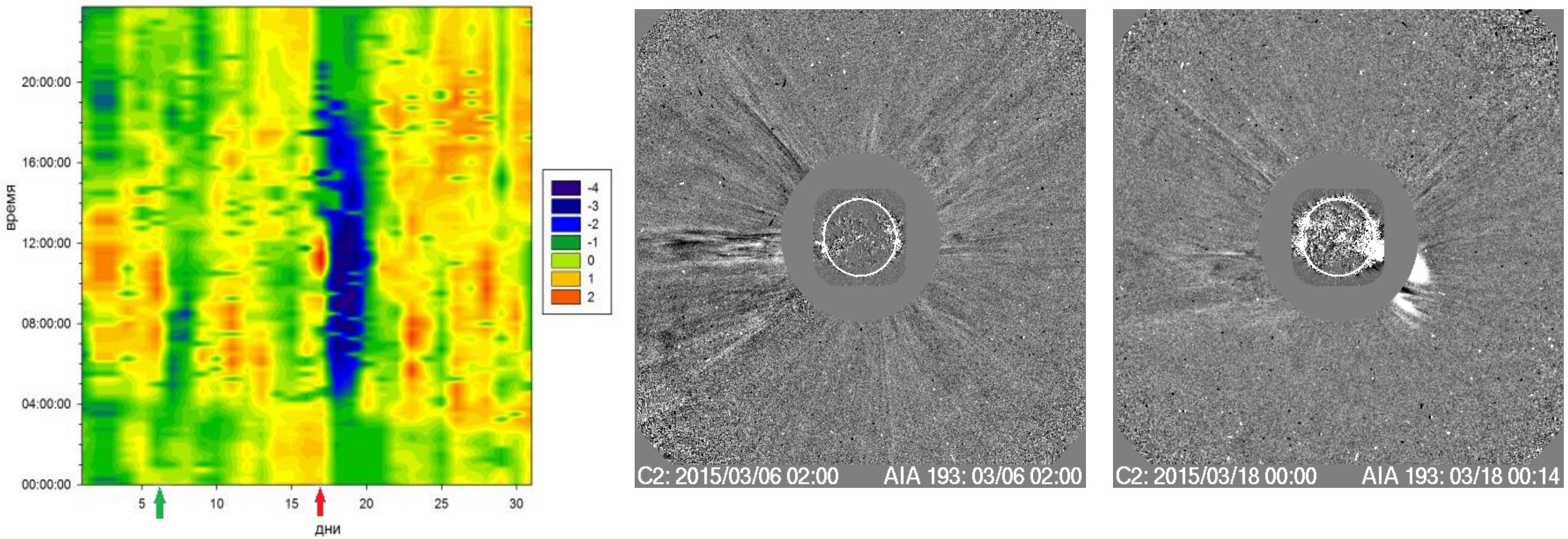
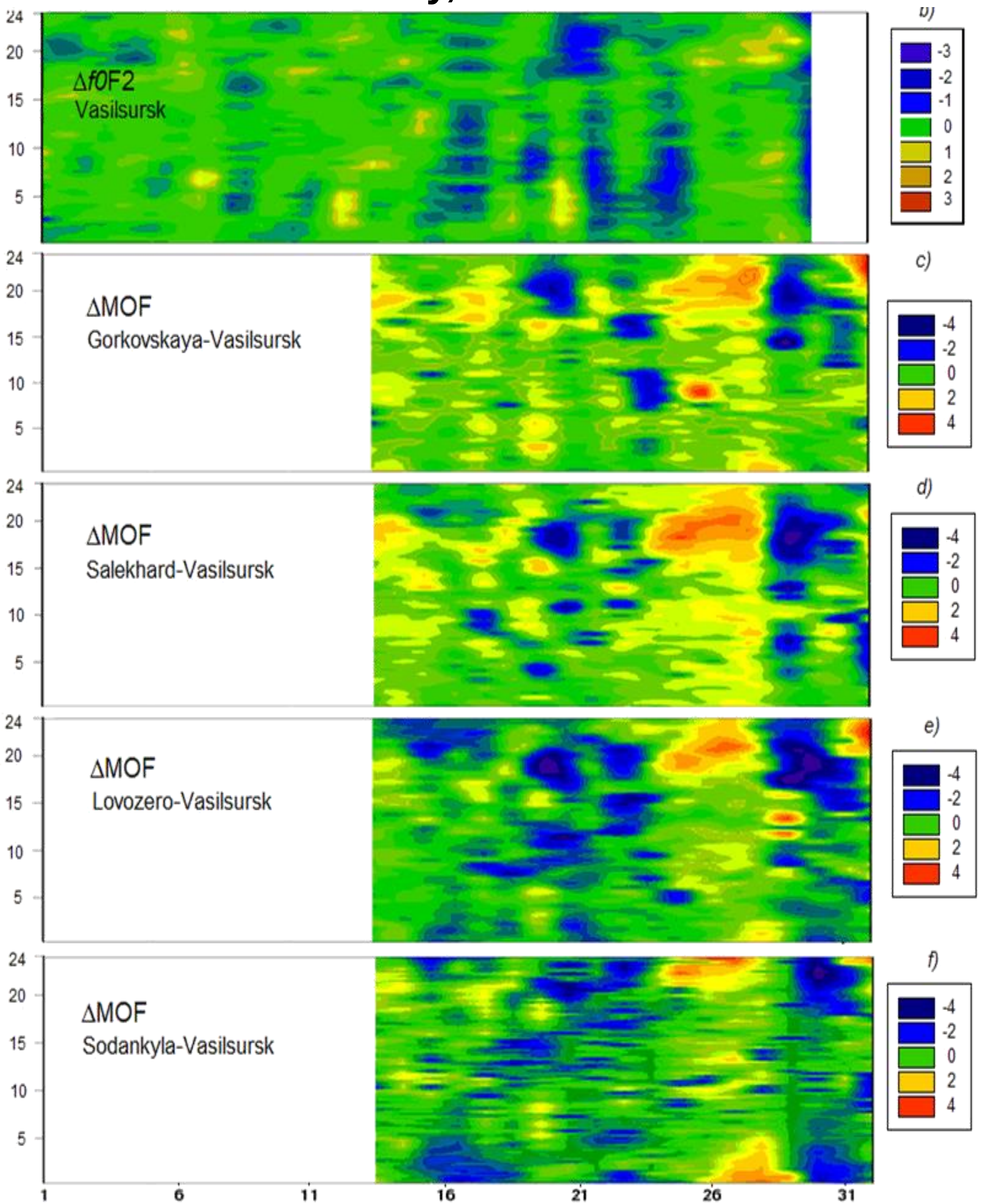


Figure ***a)*** - temporal behavior of Δf0F2 for March 2015, Moscow; horizontal axis - days of the month; the left vertical axis is the time of day (UT). The red arrow indicates the registration time of the Loop type CME, the green one – of the Jet type. The two right panels of the figure are the difference image of CME type Loop ***c)*** and type Jet ***b)*** from the CME SOHO LASCO Catalog. A detailed analysis of the temporal behavior of the f0F2 deviation shows that after the onset of CME (Loop), a prolonged decrease in Df0F2 values is observed (Fig***. a, c***), and no changes are observed after the detection of another type (Fig***. a, b***). A similar effect is recorded in observations of the DMOF deviation.

May, 2017



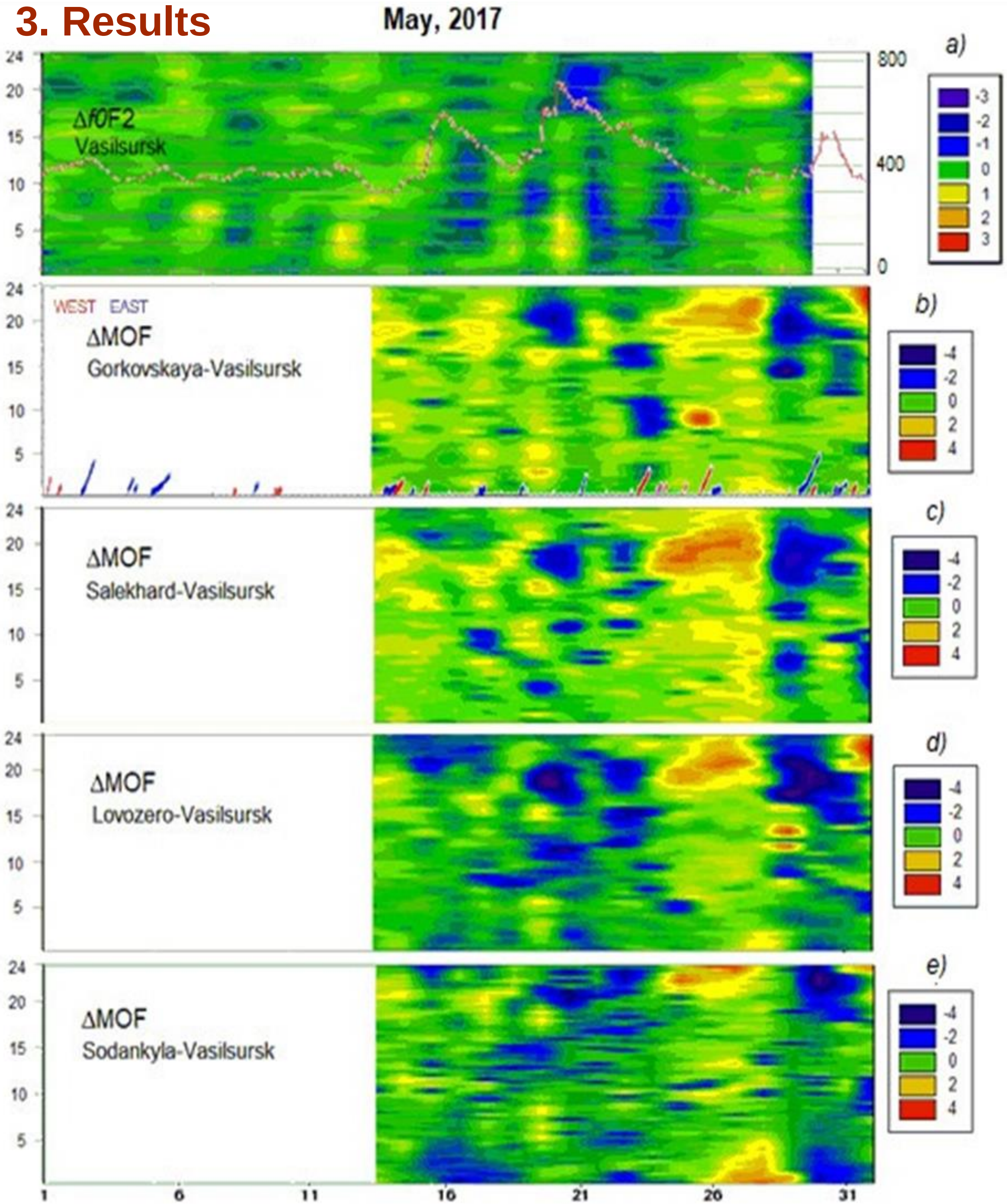
This Figure illustrates the results of joint analysis of ionospheric indexes Δf0F2 and ΔMOF for May 2017: horizontal axis – days of the month; vertical axis – time of the day (UT).

As it can be seen, a decrease by a few MHz (blue) of the instantaneous Δ*f*0F2 and ΔMOF is traced both on the mid-latitude Gorkovskaya-Vasilsursk path and on subauroral paths.

There is a slight increase in the level of depression in the longitudinal direction (see Figs. *b-f*). Moreover, there is no time delay in latitude or longitude on the subauroral and mid-latitude paths.

The increase by a few MHz (orange and red) of the instantaneous Δ*f*0F2 and ΔMOF coincides in time.

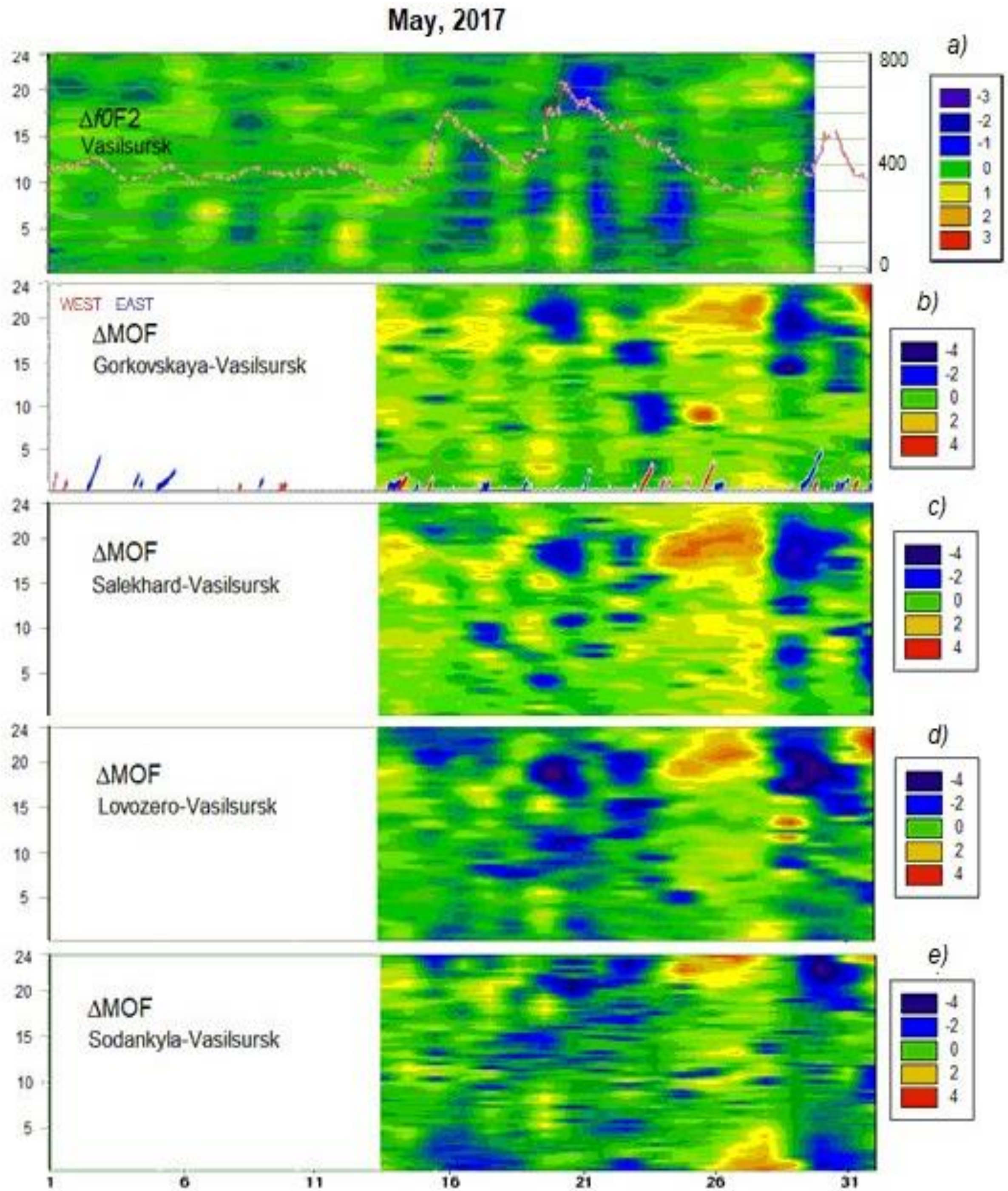
3. Results



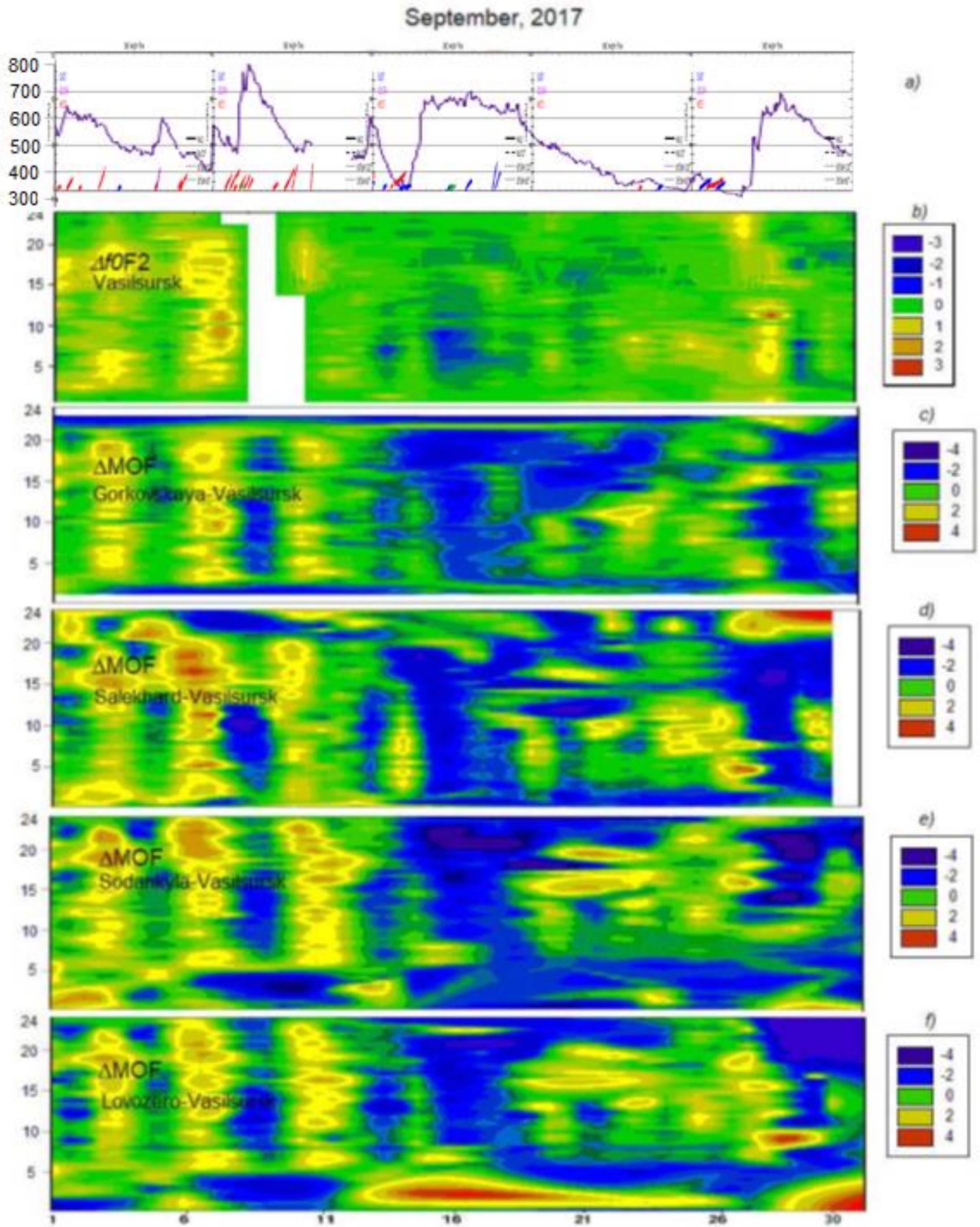
This Figure illustrates the results of joint analysis of ionospheric indexes ΔfOF2 and ΔMOF and HSS and CME temporal behavior on May, 2017: horizontal axis – days of the month; vertical axis – time of the day (UT).

The lilac curve on the ΔfOF2 panel is the average solar wind speed V, the right vertical axis is for V in km/s.

CME registration is marked on the ΔMOF Gorkovskaya-Vasilsursk panel. The color of the segments indicating CME registration illustrates the direction of CME propagation: red - west (the most geoeffective CME), blue – east.



As can be seen from the Figure, the response of the ionosphere to high-speed solar wind streams (HSS) and coronal mass ejections (CME) is ambiguous. A strong decrease in Δf0F2 and ΔMOF on May 20-22 (blue) is observed when there is a high HSS speed (about 700 km/s), while a strong decrease in Δf0F2 and ΔMOF on May 28-30 is observed at a moderate HSS speed, about 300 km/s . Comparison with the CME' registration time suggests that an increase by several MHz in the instantaneous values of Δf0F2 or ΔMOF may be associated with the aftereffect of several non-loop type CMEs that occurred on May 23.



The strong decrease in ΔMOP observed on Sept 8 is a reaction to the arrival of CMEs associated with powerful X flare propagating from the Sun on Sept 6 (Halo) and/or Sept 7 (rec segments), and HSS with a high speed - up to 800 km/s. The most interesting time interval is Sept 12–30, when there was no registration of flare activity in X-rays. At the same time, on all paths and in instantaneous vertical sounding, there is a strong decrease by several MHz in the values of ΔMOF and Δf0F2 during the passage of the HSS at a speed of about 700 km/s. CMEs ejecte from the Sun on Sept 10 or Sept 12 also contributed to the decrease in ΔMOF and Δf0F2 on Sept 16. A sharp decrease in ΔMOF and Δf0F2 on all paths on Sept 28, 29 is also associate with CMEs and HSS.

4. Conclusions

In this report we present illustration of ionospheric response to solar coronal mass emissions and high-velocity solar wind streams.

The results of the experiment on three subauroral (Lovozero-Vasilsursk, Sodankyulya-Vasilsursk, and Salekhard-Vasilsursk) and one mid-latitude (Gorkovskaya station, Leningrad region-Vasilsursk) paths, has been obtained in calm and disturbed conditions.

An analysis is given of the maximum observed frequency (MOF) of ionospheric channels, as well as the critical frequency (*f*0F2) of the ionospheric layer on mid-latitude ionospheric station (Vasilsursk) using the method based on the **deviation** of frequencies proposed by authors earlier.

The results of studies of the influence of coronal mass ejections (CME) and high-speed solar wind streams (HSS) on the characteristics of the ionosphere showed that CME and HSS have approximately the same effect on the parameters characterizing the state of the ionosphere.

Thank you for attention!