URSI GASS 2020, Rome, Italy; 29 Aug. – 5 Sep. 2020

The effects of severe troposphere weather on ionosphere on the Baltic region

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Abstract

The results of observations and modeling of the ionosphere parameters in periods of the severe troposphere weather events in October 2017, 2018 are presented. We analyze variations in the F2-layer critical frequency (foF2), in the total electron content (TEC), in the sporadic E-layer critical frequency during meteorology disturbances in the troposphere. It was shown that the meteorology storms can influence on the ionosphere parameters through the gravity waves (GWs). The GWs generated in the meteorology storm area can propagate into upper atmosphere and ionosphere. The GWs dissipation leads to the formation of disturbances in the thermospheric state at spatial scales that are determined by the duration and spatial dimensions of the region located in the meteorological disturbance zone. To interpret the observed disturbances in the upper atmosphere, the experimental measurements are compared with the results of model calculations obtained with the Global Self-Consistent Model of Thermosphere—Ionosphere—Protonosphere (GSM TIP).

1. Introduction

Despite notable success in interpreting the irregular ionospheric phenomena, the physical mechanisms for the formation of ionospheric inhomogeneities caused by disturbances in the lower atmosphere remain poorly understood. There has been a maturing realization that neutral atmosphere-ionosphere coupling via neutral waves propagating into the ionosphere from the lower atmosphere plays a critical role in driving the dynamical behavior and day-to-day variability of the ionosphere. Natural hazards, such as earthquakes, tsunamis, volcanic eruptions, and severe tropospheric weather events, generate acoustic and gravity waves (GWs) that propagate upward and cause perturbations in the upper atmosphere and ionosphere. The importance of severe tropospheric weather on the overall variability of the ionosphere is noted in [1-5].

The purpose of this work is to study the impact of meteorological storms in the southern part of the Baltic sea in 2017-2018 on the ionosphere variability.

The relevance of the proposed research is due to the following points: (1) GNSS are sensitive to various types of disturbances in the atmosphere and ionosphere, which can lead to a significant decrease in the accuracy of solving navigation and positioning problems, failures in communication systems, etc.; (2) understanding the impact of processes from below can improve current ionosphere models for the most accurate prediction of its state.

2. Data and research method

For a comprehensive study of the severe troposphere weather impact on the Earth's ionosphere, we focused on the E and F regions of the ionosphere. Meteorological storms are sources of acoustic and gravity waves of a wide spectral range, which can propagate to the heights of the ionosphere and have a significant impact on its parameters. In the E region the gravity wave investigation have been focused on the Es layers, because gravity waves play some role in their formation [6].

For the description of severe tropospheric weather events we use 1-hour troposphere pressure and wind reanalysis ERA5 data (https://cds.climate.copernicus.eu) and 1-minute meteorological ground-based data in Kaliningrad department IZMIRAN (54° N, 20° E).

The paper examines variations in the F2-layer critical frequency (foF2), and critical frequency and frequency of screening sporadic E layer (Es) from ionosonde measurements at Kaliningrad. Time resolution of ionosonde data is 15 min. Besides, we analyze the behavior of the total electron content (TEC), using data from GPS/GLONASS dual-frequency phase receivers of the IGS network [7] located in the nearest points (Kaliningrad (54° N, 20° E) and Olsztyn (53° N, 20° E)). Averaged measurements of the TEC over a 10-minute interval were used as data for analyzing the ionosphere response. To interpret disturbances in the upper atmosphere, experimental measurements were compared with the model calculations from the Global Self-Consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) [8].

To exclude the influence of geomagnetic factors, events were selected in quiet geomagnetic conditions and low solar x-ray activity. The criteria for quiet conditions were the value of the geomagnetic activity index Kp ≤ 3 on the day of the event and on the previous 2 days, the value of the Dst index -20 ≤ Dst ≤ 20 nT, and did not change by more than 20 nT during the day.

Two events with a duration more than 12 hours in 2017-2018 were selected for final analysis based on these criteria: October 29, 2017, and October 23, 2018.

3. Variations in the ionosphere during severe troposphere events

Fig. 1 shows observations of atmospheric pressure, maximum wind gusts, TEC and *fo*F2 data in Kaliningrad and Olsztyn from October 27 to November 1, 2017, and October 21-26, 2018.

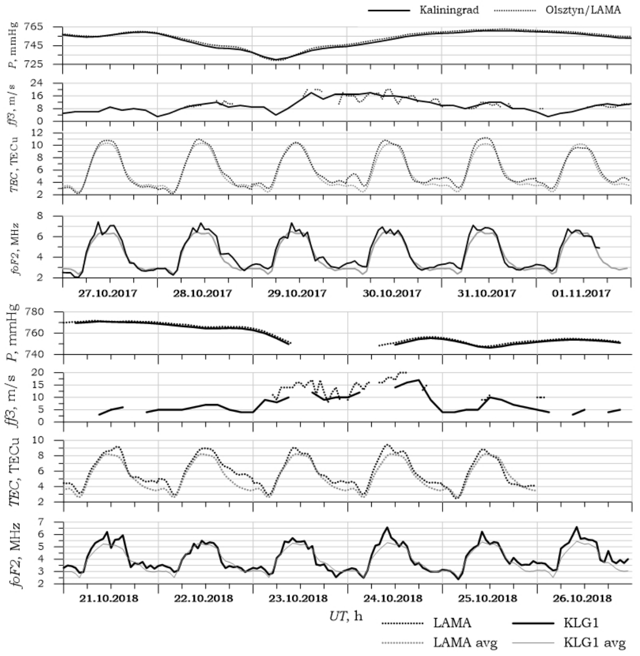

Figure 1. Observations data atmosphere and ionosphere parameters during meteorological disturbances in 2017, 2018.

The table 1 summarizes data for each event: maximum wind gusts (*ff3*), average atmospheric pressure on given sea level (*p*) in Kaliningrad and Olsztyn, TEC and *fo*F2 perturbations from Kaliningrad, expressed in standard deviation values and as a percentage of the median values. For perturbations less than 1.5 σ a dash is indicated in the table.

Table 1. Average atmospheric pressure, maximum speed of wind gusts, deviations of TES and foF2 in Kaliningrad and Olsztyn during the meteorological events.

	Kaliningrad		Olsztyn		ΔTEC		Δ*fo*F2	
	ff3, m/s	*p*, mmHg st.	*ff3*, m/s	*p*, mmHg st.	σ	%	σ	%
29.10.2017	18	737	20	738	-	15	-	24
30.10.2017	18	751	20	754	2,0	64	-	22
23.10.2018	12	757	17	758	-	15	-	20
24.10.2018	17	753	20	753	2,4	20	1,6	16

The analysis of the considered events allows us to conclude that the detected changes in the state of the ionosphere are caused by the processes accompanying the development of meteorological storms. The enhancement of GWs generation processes under such meteorological conditions is the most important factor determining the disturbance of the state of the ionosphere. Vertical propagation and dissipation of GWs can increase turbulent processes in the upper atmosphere, which leads to the formation of local perturbations in the temperature and density in the thermosphere, which in turn affects ionization and recombination processes in the thermosphere [9]. The influence of these processes on the ionosphere are manifested in an increase in recombination processes and a decrease in the ionization processes, which leads to negative effects in the TEC и *fo*F2 variability. Analysis of the observation results on the ionosphere reaction to meteorological disturbances is shown in a decrease in the daily values of TEC and foF2, which is consistent with the ideas about the influence of GWs on the thermosphere and ionosphere.

In the E region the gravity wave investigation have been focused on the Es layers, because gravity waves play some role in their formation, probably via enhanced irregular neutral winds associated with gravity waves [10,11]. The sporadic ionization in the E-region, on days of meteorological fronts sometimes tends to occur more frequently and with higher electron concentration than for the preceding and following days [3].

The ionograms analysis show the disappearance of Es (fig. 2), during the approach of the storm area to the area controlled by ionosonde, which is consistent with the expected times of GWs propagation from the troposphere to the thermosphere and ionosphere directly during a meteorological storm. During both cases the ongoing Es layer activity, monitored by the ionosondes, ceased for part of the time when the severe troposphere weather area passed by. The results implied that the Es layer disappearance relates to a weakening of the electron density of the layer, which corresponds to plasma frequencies lower than the ionosonde frequency threshold of 1 MHz [12].

The GWs can propagate to the mesosphere and lower thermosphere, including the E region, where they can affect the formation of the Es layer. The main mechanism of this interaction is the so-called "windshear" theory [5,13]. Disturbances in the neutral gas temperature caused by GWs dissipation lead to changes in the electronic temperature and, as a result, to changes in the dissociative recombination coefficient.

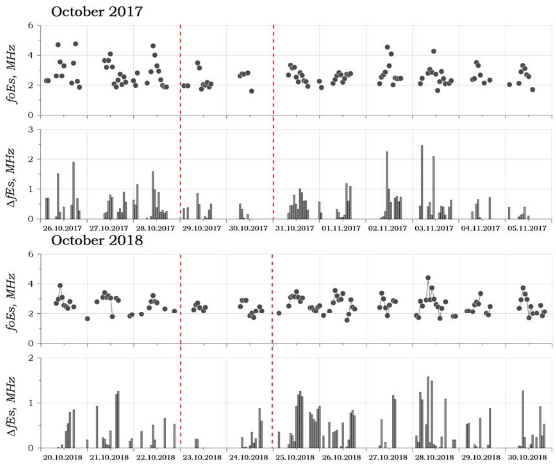

Figure 2. Time variations of the critical frequency of *fo*Es and the variations of the interval of semitransparency Δ*f*Es during severe troposphere weather events in 2017, 2018 according to vertical sensing data at the Kaliningrad station. The high variability of the Δ*f*Es = *fo*Es − *fb*Es parameter characterizes the turbulence of a sporadic layer.

4. Model calculations results

The results of numerical simulation of ionospheric disturbances from spatially localized mid-latitude thermospheric sources that simulate the effect of GWs dissipation generated by natural hazards on the Earth's surface and in the lower atmosphere are presented below. Perturbations of temperature, wind, and density localized by height in a given latitude-longitude region are considered as sources of perturbations of the mid-latitude thermosphere, which simulate the result of GWs dissipation in the upper atmosphere with the periods no more than half an hour [14]. In order to simulate ionospheric effects from the severe troposphere events, a combined source type in GSM TIP was set, in which an atomic oxygen source was added to the heat source, simulating changes in turbulent diffusion associated with the GW propagation.

Figure 3 shows additives to the critical frequency of the F2 layer in October 2017, 2018. The modeling indicates a pronounced negative ionospheric effect directly above from the passage of the storm and a positive one to the south and south–east of it. The decrease in foF2 reached 1 MHz almost over the area of the meteorological disturbance. The maximum ionospheric effect is 16 UT. Negative ionospheric disturbances are associated with changes in the gas composition of the thermosphere: a decrease in the atomic oxygen concentration, which leads to a decrease in the ionization rate. The most effective way to reduce the electron concentration in the ionosphere is through turbulent diffusion processes that lead to a decrease in the concentration of atomic oxygen in the lower thermosphere.

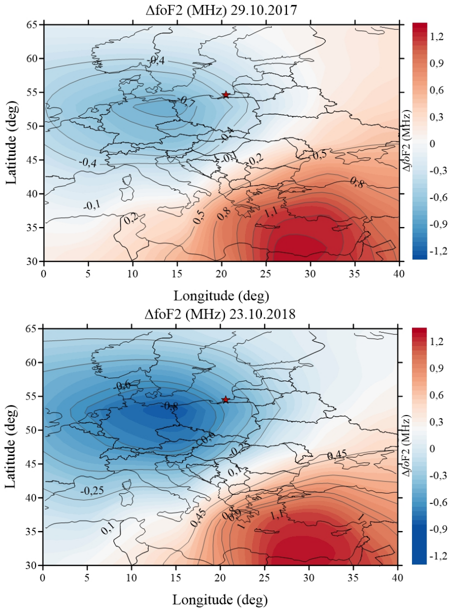

Figure 3. Distribution of the additive to *fo*F2 at 16:00 UT on 29.10.2017 and 23.10.2018 based on simulation results.

5. Conclusion

We have analyzed atmospheric and ionospheric effects induced by severe troposphere weather events at 2017-2018 on the Baltic region. It was suggested that the mechanism responsible for the ionosphere variability is the gravity waves propagating from severe troposphere weather events. The GWs dissipation can lead to the formation of local heating regions in the ionosphere, which affects changes in the thermosphere and ionosphere parameters. In the period of meteorological disturbances, a decrease of TEC and F2-layer critical frequency values down to ~50% and ~25% relative to meteorologically quiet days. The GWs from meteorology sources can propagate in the mesosphere and lower thermosphere and into the E region where they may act to disrupt Es layer formation. This can be done through the GW vertical wind shears which act to reduce plasma accumulation into a layer, in accord with the principles of windshear theory that applies in Es layer generation.

The results of numerical calculations using the GSM TIP model with the inclusion of additional thermospheric sources simulating the processes of GWs dissipation from sources in the lower atmosphere showed that thermosphere disturbances caused by such sources lead to a decrease in the electron concentration directly above the GWs source and an increase in to the south of it.

The modeling shows a good agreement with the experimental data, which will improve the modeling of the severe troposphere weather events influence on the ionosphere.

6. Acknowledgements

This work was supported by the Russian Foundation for Basic Research and the government of the Kaliningrad region, project No. 19-45-390005 (O.P. Borchevkina, M.I.

Karpov) and RFBN grant No. 18-05-00184a (I.V. Karpov, P.A. Vasiliev).

We express gratitude to the Copernicus Atmosphere Monitoring Service for the meteorology data; the International GNSS Service for access to GNSS data used in this study, as well as the OMNIWeb Plus NASA/Goddard Space Flight Center service for the data on geomagnetic and solar flux indices.

7. References

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