Results of Complex Radiosounding of Ionospheric Disturbances Generated by the Transport Spacecraft "PROGRESS" Onboard Thrusters

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Abstract

Active space experiments (SE) carry out to study spatio-temporal characteristics of disturbances emerging in the ionospheric plasma due to the functionality of transport spacecraft (TSC) "Progress" onboard thrusters. The main research facility is the Irkutsk incoherent scatter radar (ISR). Results showed that small masses of TSC exhaust product generate disturbances in the ionosphere with size of tens kilometers and with lifetime up to 20 minutes. The amplitude of a depression in the plasma density variations reached up to 40%.

1. Introduction

Active SE in the near-Earth outer space are interesting and important for investigations of dynamic processes in the ionospheric plasma. Active effect on ionospheric plasma can be carried out by various ways: plasma-forming and plasma-extinguishing chemical injection from space vehicles (SV), using powerful HF heating facility, ground-based and air explosions, rocket launches, etc. These include controllable launches of onboard thrusters at low-orbiting SV.

Studying artificial ionospheric disturbances associated with SV exhaust product were the objectives of many experiments carried out with Space Shuttle and ISR [e.g., 1-3]. These experiments use large amount of ejected combustion products varied from 87 kg in the experiment over the Jicamarca ISR and to 830 kg over the Millstone-Hill IER which led to formation of bulk domains in the ionosphere with the lowered electron concentration existing from one hour and more.

A distinctive feature of our SE is a slight effect of exhaust jets on the ionosphere when exhaust fume masses are much less than exhaust product in [1-3]. Studying processes of formation, evolution, dynamic characteristics of artificially generated disturbances in the proper site and in due time is extremely important. The implementation of results for developing of theoretical and mathematical models of plasma disturbances in the ionosphere is no less important and is supported also by purely applied needs. It is, for example, the problem of the SV-Earth radio communication since disturbances emerge in the near-field region of the onboard antennas. Therefore, studying all the complex of physical phenomena occurring at the evolution of plasma formations is of great importance to solve scientific and applied problems.

A kind of confirmation for this assumption was the results of computing the total electron content variations from GPS ground stations located close to subionosperic points of the ISS orbit. On May 4, 2006, to lift the ISS orbit, a onboard thrusters long-term start of the "Progress M-56" TSC docked with the ISS was carried out. The data analysis showed the total electron content sharp drop lasting ~150 seconds [4].

2. Space Experiment objective and statement

One of the SE main objectives is studying of ionosphere spatio-temporal disturbances associated with interaction of onboard thrusters exhaust jet with the TSC plasma environment. SE sessions are held at a known combination of the outer orbit conditions, such as: TSC geographical coordinates, TSC orientation in orbit, Sun position and exhaust jet velocity direction. During a flyby across the Irkutsk ISR antenna beam were used: either eight Orientation and Mooring Engines (OME) each with 376 g/sec exhaust product; or one Approach and Correction Engine (ACE) with 1 kg/sec exhaust product. From session to session, we changed the engine type and operation time (5 through 11 sec), start local time. Exhaust jet directions were: 1. towards the Irkutsk ISR ("to ISR"); 2. towards the TSC motion ("braking"); 3. contra the TSC motion ("acceleration"); 4. northward ("north").

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3. Results of complex radiosounding

The main research facility was the Irkutsk ISR [5]. It is designed for measurements of ionosphere plasma parameters, such as electron density *Ne(h)*, electron and ion temperatures, drift velocity in altitude range (170-700 km). First SE in September, 2007 showed significant influence of exhaust products on ionospheric plasma environment and some conclusions were made [6-7]. For example, powerful ACE run was accompanied by significant *Ne(h)* reduction (down to ~40%) from the flight altitude down to 250 km. (Figure 1, 20:42 UT line). After run of less-power OME in the same direction any noticeable *Ne(h)* changes were not observed (Figure 2, 20:07 UT line) or were observed with some delay (Figure 2, 20:16 UT line). However, the same OME run on “breaking” with less exhaust mass (2 kg) caused the *Ne(h)* reduction by ~35%. The disturbances life-time was 15-20 minutes.

Comparing to previous experiments [6], which were carried out during prolonged solar minimum (2007-2009), the electron density in the ionosphere grew in 2010. The session results in April and September, 2010 confirmed the dependence of emerging disturbance scales on the background electron density in the ionosphere. Ionospheric response is decrease with increasing of background *Ne(h).* In Figures 3-4 we present *Ne(h)* prior to and after the start of the powerful ACE with the "north" directions of exhaust jets. Electron density decrease was ~40% (Sep 1, 2010, red line) and ~30% (Sep 4, 2010, red line). It was comparable to previous experiments with smaller decreases.

However, it is necessary to note that in some sessions with the similar SE conditions we did not observe any significant ionospheric disturbances. In Figures 5-6 we present *Ne(h)* profiles under the same SE conditions as in Figures 3-4. The differences between *Ne(h),* before and after ACE run are within a statistical error of measurements. The same results of radar observation were obtained in April, 2010. In each of 5 sessions, ACE ran with "braking" or "to ISR" direction and with exhaust fuel mass from 5,7 to 9,8 kg.

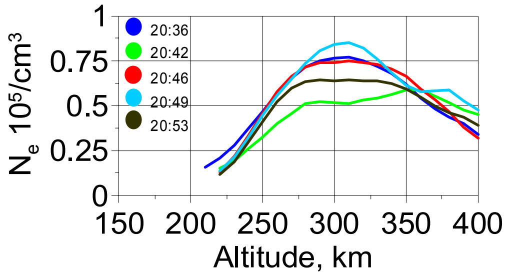

Figure 1 - *Ne(h)* profile dynamics on September 20, 2007 ACE "to ISR" start at 20:39:53 UT, exhaust is 5 kg

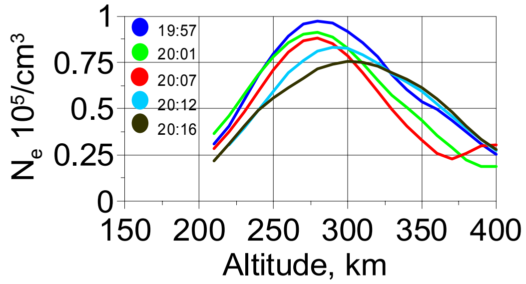

Figure 2 - *Ne(h)* profile dynamics on September 23, 2007 8 OME "to ISR" start at 20:04:18 UT, exhaust is 2,4 kg

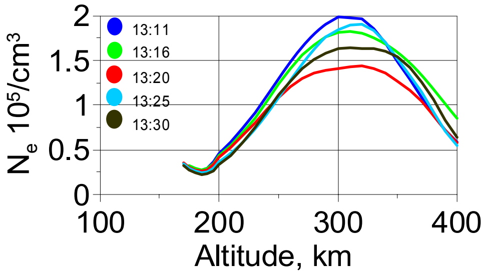

Figure 3 - *Ne(h)* profile dynamics on September 1, 2010. ACE "north" start at 13:20:02 UT, exhaust is 7,5 kg

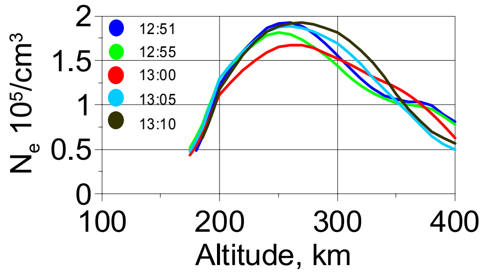

Figure 4 - *Ne(h)* profile dynamics on September 4, 2010. ACE "north" start at 12:59:30 UT, exhaust is 7,44 kg

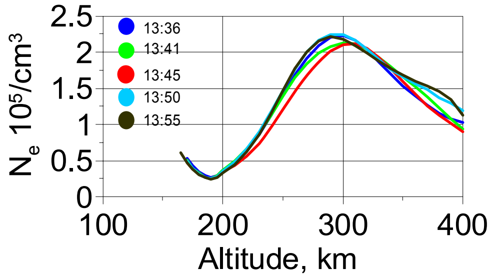

Figure 5 - *Ne(h)* profile dynamics on September 2, 2010. ACE "north" start at 13:44:57 UT, exhaust is 7,0 kg

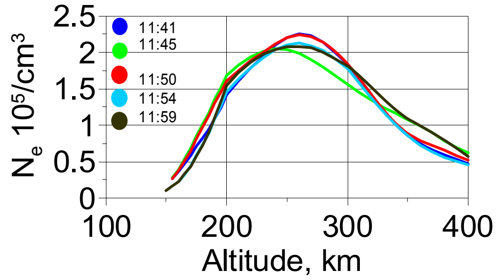

Figure 6 - *Ne(h)* profile dynamics on September 5, 2010. ACE "north" start at 11:49:08 UT, exhaust is 7,52 kg

As an additional radio physical facility, a DPS-4 Digisonde [8] was involved. To detect ionospheric disturbances caused by the TSC thrusters run, we used three methods of Digisonde data analysis of: 1) sky maps obtained; 2) the peak electron density (N_mF2) behavior; 3) vertical sounding (VS) ionograms.

The sky map is a map showing the locations of reflection points. Figure 7 shows the sky map obtained on September 20, 2007 from 20:21:41 to 20:50:38 UT. The white and black circles show the reflection points observed before and after the ACE run, correspondingly. Thick solid line shows the TSC trajectory with the ACE running. Before the ACE start the reflection points are close to north-south direction. This pattern is typical for southward traveling ionospheric disturbances of auroral origin. After the ACE start the reflection points are observed in the southwest sector, i.e. in the TSC trajectory sector. The effect can be explained by the reflection of sounding radiowaves from the disturbances generated by the ACE run. The wide spread of the points can be associated with the interference of the disturbances of anthropogenous and natural origins.

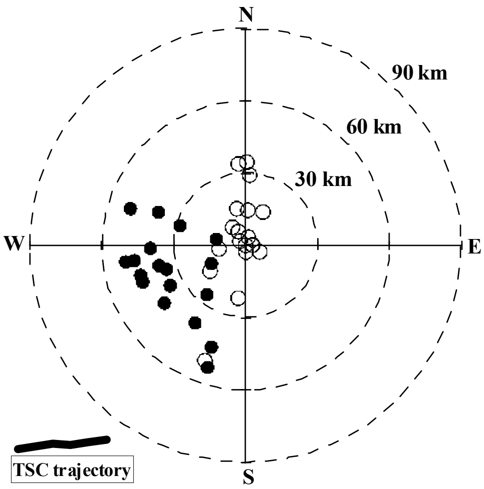

Figure 7 - The sky map obtained on Sep 20, 2007 from 20:21:41 to 20:50:38 UT.

The first ISR observations showed that the onboard thrusters run can be followed by negative N_mF2 disturbances. We have developed the method of detecting the ionospheric effect caused by thrusters run. The N_mF2 disturbances were calculated as the relative differences between observed N_mF2 and N_mF2 31-day median values. The ionospheric effect caused by thrusters run is considered detected if (1) the minimum in ΔN_mF2 variations was observed after the thrusters start time (t_{start}); (2) the delay (τ) between t_{start} and the time of ΔN_mF2 minimum were less than 45 minutes; and (3) the ΔN_mF2 disturbance amplitude were more than 5%. The method showed that the ionospheric effect was detected in ~50% of the cases, and more often the effect was observed in the cases of the "to ISR" direction. The method did not reveal any dependence of detecting the ionospheric effect on N_mF2 and peak height h_mF2 values.

The analysis of VS ionograms during and after the thrusters run showed some interesting results. The return signal can skip from the Earth to the ionosphere and back again, sometimes several times before it is attenuated. These multiple traces appear on an ionogram at multiples of the original trace. Typically, the original trace amplitude exceeds the multiple one. The peculiarity of the ionogram recorded at 10:00 UT on Feb 11, 2008 (Figure 8) is the absence of original trace in the presence of the multiple one for 1,8-3 MHz frequency interval. The oval marks the ionogram peculiarity. During recording the 10:00 UT ionogram, the ACE was running for 5 sec in the "to ISR" direction. One can see that the only 10:00 UT ionogram is characterized by the absence of original trace in the presence of the multiple one. The similar effect was observed on Feb 11, 2008 during 5 sec ACE run. On Sep 5, 2009 we observed the ionograms with additional $F1$-layers 11 minutes later after the 7,5 sec ACE "north" run.

4. Conclusion

The results of the active SE sessions have showed that small exhaust mass injected by the TSC onboard thrusters can be accompanied by negative disturbances of electron density. The height size of disturbed area can be tens of kilometers and the lifetime being 10-20 minutes. The ionosperic disturbance amplitudes reached 20-40% of the background value. Observational possibility and disturbance parameters depend on helio-geophysical conditions, ionospheric background, the mass and the direction of the exhaust velocity. The greatest amplitudes of ionospheric disturbances were observed during the sessions when the jets of more powerful ACE had the "to ISR" direction almost parallel to the magnetic field lines. The Digisonde data analysis showed that ACE can be followed by moving the reflection points to the TSC trajectory sector; the negative N_mF2 disturbances and abnormal ionograms.

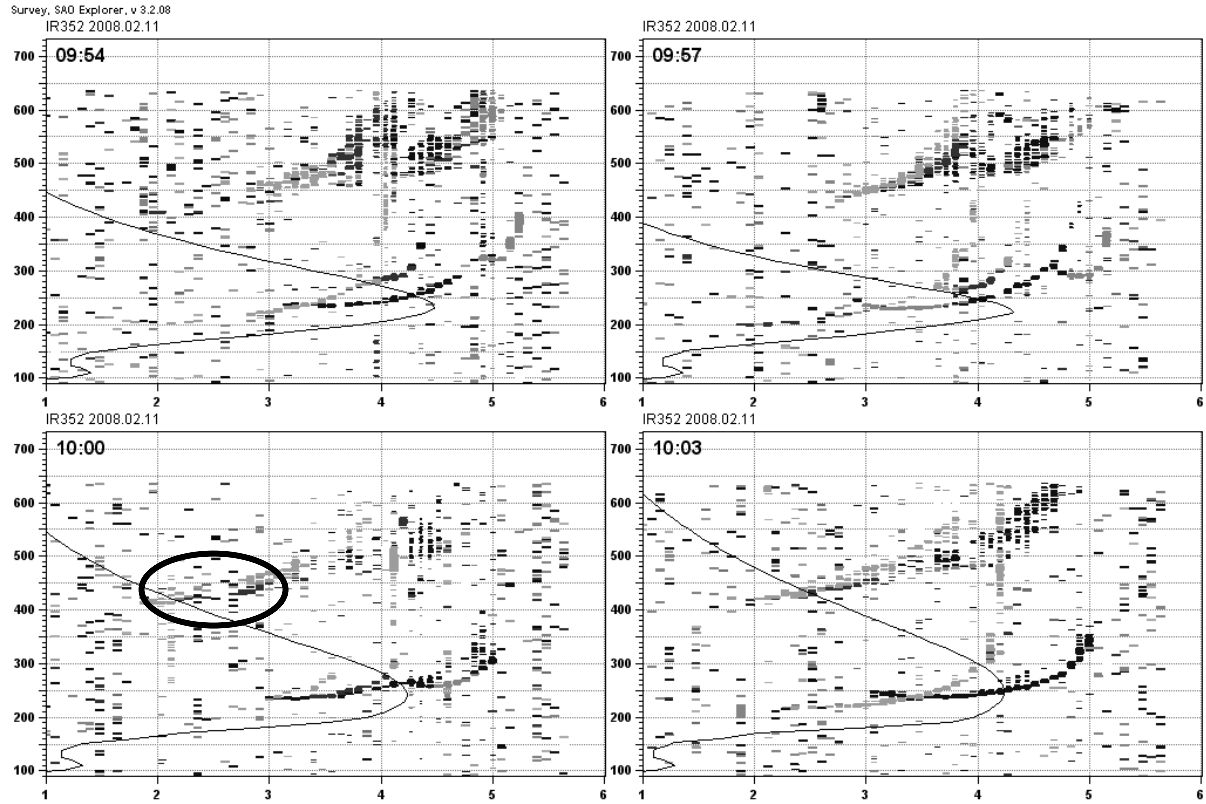

Figure 8 – The VS ionograms recorded from 09:54 to 10:03 UT on Feb 11, 2008

5. Acknowledgment

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