DOPPLER RADAR MEASUREMENTS OF BOTTOMSIDE IONOSPHERE PERTURBATIONS ASSOCIATED WITH SPACE VEHICLE LAUNCH AND MANEUVERING SYSTEM BURNS

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ABSTRACT

At distances of $R \leq 2500$ km from launch sites, acoustic disturbances are observed with the speeds $v \approx 500–700$ m/s, and sometimes, wave processes with $v \approx 10–20$ km/s and an ~10 min period. The delays for the U.S. launch sites are 60–80 min. Their propagation speed is no less than 10 km/s. Sixty to eighty minutes before space shuttle landings, ionospheric perturbations appear with tens of minute's durations. The global-scale disturbances could be caused by maneuvering orbit system burns. Generally, the wave processes have apparent speeds of ~0.5 – 0.7, 2–3, and 10–20 km/s.

INTRODUCTION

Many research papers are concerned with the search for ionospheric effects due to space vehicle launch and maneuvering system burns (see, for example, [1 – 3] and references therein). Most of them deal with the effects observed in the vicinity of the trajectory where thruster burns take place. In contrast to those studies, we will be focusing on the processes occurring ~ 1000–10,000 km away from the rocket launch site and its trajectory. These effects are divided into large-scale and global-scale perturbations by a relevant classification scheme.

EXPERIMENTAL TECHNIQUE

To study non-stationary processes in the bottomside ionosphere, the vertical incidence Doppler radar was used [2, 3]. The signal reflected from the ionosphere passes to the mixer whose output is formed by the product of the signal and the reference oscillator output and after low-pass filtering is digitally registered on magnetic tape with a sampling frequency of 10 Hz. The Doppler spectra were then computed within a range of Doppler shifts of –1 to +1.5 Hz over 51.2-sec time intervals (frequency resolution of ~0.02 Hz) by using a Fast Fourier Transform. When quasi-periodic processes with periods of $T \sim 1 – 60$ min occurred in the ionosphere, the spectral analysis was carried out over 128-min or 256-min intervals.

The observations reported here were made for more than 10 types of rocket. The most powerful are the Energiya (USSR) and the Space Shuttle (the U.S.A.). Second most powerful rockets are the Proton (USSR, Russia) and the Arian (France). The least powerful is the Pegasus rocket. The observations were made at the various ranges R from the launching sites: the least R-value is approximately 700 km, and the greatest R is approximately 10,000 km. The observation taken during 142 launches over the 1995 – 2001-yr period have been analyzed.

RESULTS AND DISCUSSION

An additional spectral mode down-shifted by 0.2 – 0.3 Hz is often observed with time delays of 60 – 80 min for day and night correspondingly, or the "spread" of Doppler spectra is registered. The duration of these effects is 5 – 10 min. The propagation speed turns out to be approximately equal to 410 – 570 m/s. These are of the order of the acoustic wave speed. The acoustic wave may be regarded as a wave front, and it is followed by the strongly dispersive acoustic-gravity waves (AGWs) propagating at speeds of a few hundreds of meters per second. In the ionosphere they produce irregularities of various scales that result in the observed spectrum "spreading". This process lasts for tens of minutes to 1 – 2 hr.

In regard to the more fast perturbations associated with rocket launch, this technique does not enable them to be observed regularly. Fig.1 shows Doppler spectra acquired at 3.5 MHz on October 18, 1999 that are associated with the Soyuz rocket launch at 13:22 UT, with Doppler shift in Hz as the abscissa and universal time along the ordinate. The disturbances exhibit speeds of 480 m/s and 2,7 km/s. On March 21, 1999, a quasi-periodic processes arose in the

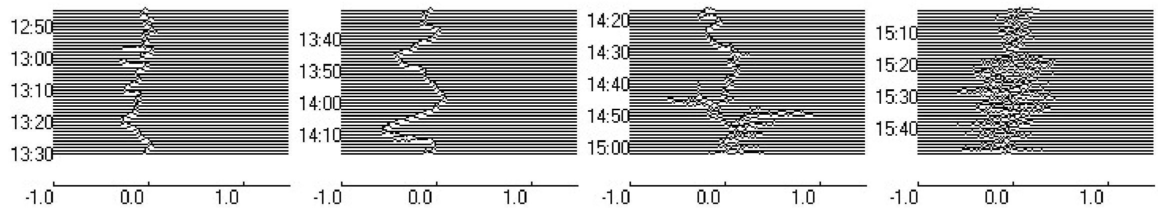

Fig. 1 Doppler spectra associated with the Soyuz rocket launch on October 18, 1999

ionosphere soon (in approximately 2 – 4 min) after the Proton rocket launch. This delay corresponds to a speed of 10 – 20 km/s. The gyrotropic waves propagating in the ionospheric E and F regions in principle exhibit the same speeds [4]. Another example of Proton rocket launch is shown in Fig. 2.

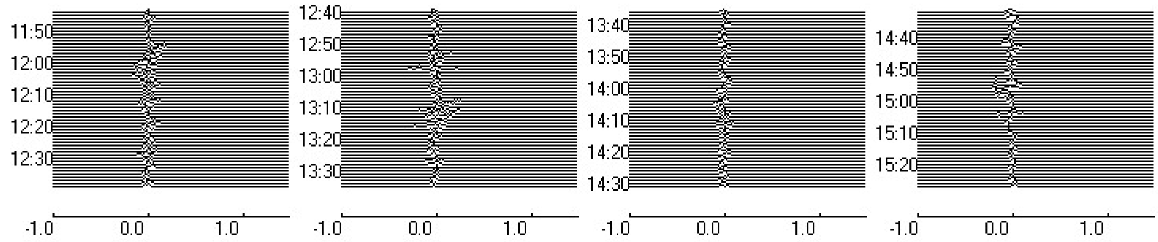

Fig. 2. 3.0 MHZ signal Doppler spectra variations associated with July 5, 1999 emergency Proton rocket launch at 13:22 UT. Response to acoustic bursts from rocket engine burns and rocket explosion is observed

Global-scale perturbations will be discussed further below. Thirty-two launches of various types of rocket have been analyzed, including nineteen from the U.S. launching sites.

A sufficiently persistent ionospheric response to rockets launched from the U.S. and French launching sites was most often observed in 60 – 80 min after the launch. The trajectories of the launch varied, which can explain the variation in the time delays from 60 min to 100 min. Provided $R \sim 10{,}000$ km on the average, the apparent speed is ~ 2 – 3 km/s, shown in Fig. 3–5) The slow MHD waves in the ionosphere have the same values [4].

Finally, possible global-scale effects associated with re-entry of orbiting objects will be discussed further below. Six Space Shuttle re-entries have been analyzed. A sufficiently persistent response arose 70 – 90 min before the landing and persisted for tens of minutes (Fig. 6 and 7). The apparent speed of perturbation progression is a few tens of kilometers per second. The perturbation from re-entry is most likely transferred by the gyrotropic waves.

The second grouping of quasi-periodic perturbations has a time delay of approximately 40 min, and periods

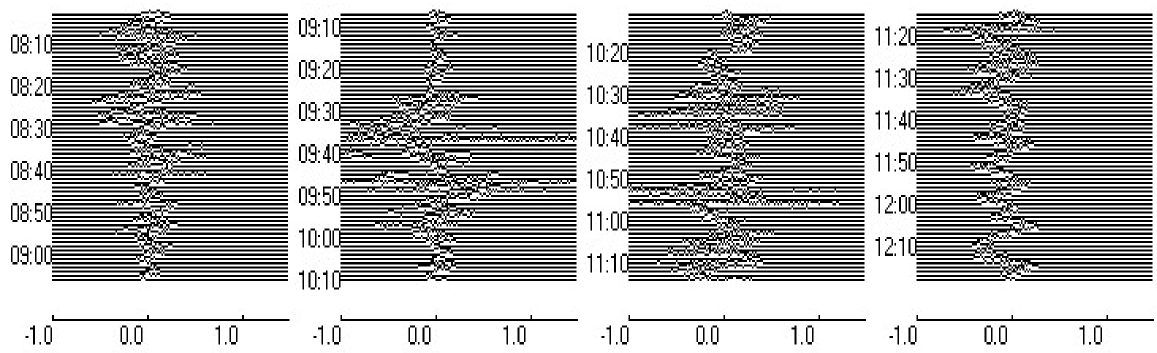

Fig. 3. 2.8 MHZ signal Doppler spectra variations associated with December 4, 1998 Endeavor Space Shuttle at 08:35 UT. The perturbation delay is 60 min, and the speed of propagation is 3 km/s

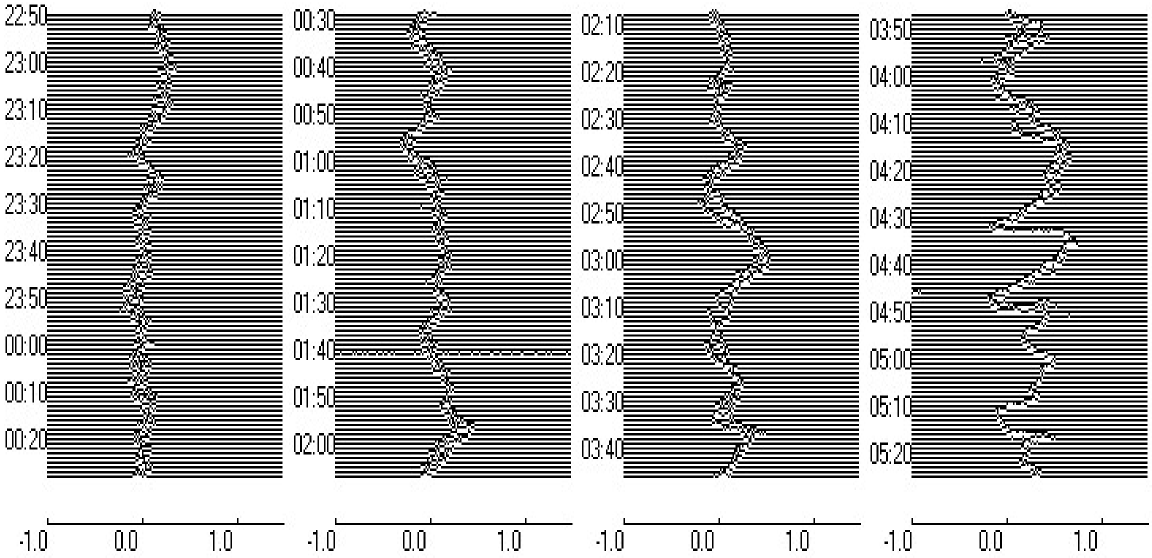

Fig. 4. 3.0 MHZ signal Doppler spectra variations associated with February 16, 1999 Atlas rocket launch at 01:45 UT against the dawn terminator. The perturbation delay is 45 min, and the speed of propagation is 3.7 km/s

of T ~ 10 min and T ~ 20 min. If these processes are associated with the orbital maneuvering subsystem burns, then their apparent propagation speed is of the order of a few units of kilometers per second. The same speed is, as mentioned above, characteristic of the slow MHD waves.

CONCLUSIONS

1. Acoustic perturbations (sound and AGWs) from rocket engine burns at maximum thrust are propagated in the ionosphere over not less than 2,300 km. Often, after the arrival of these perturbations, the ionospheric F region becomes turbulent and the "spread" of Doppler spectra occur. The perturbations faster than acoustic perturbations are quite often observed at distances of up to 2,300 km from the rocket. Their speed amounts to 10 – 20 km/s. They could be transferred by the gyrotropic waves, which require further investigation.
2. During rocket launches, perturbations in the ionosphere are observed at distances of the order of 10, 000 km. The mechanism for their generation could be related to both the main thruster burns in the near-ground atmosphere and the orbital maneuvering subsystem (OMS) burns in the ionosphere. The second explanation is preferable because the mechanism for generating electromagnetic waves and MHD waves by a jet stream in the plasma is well understood.

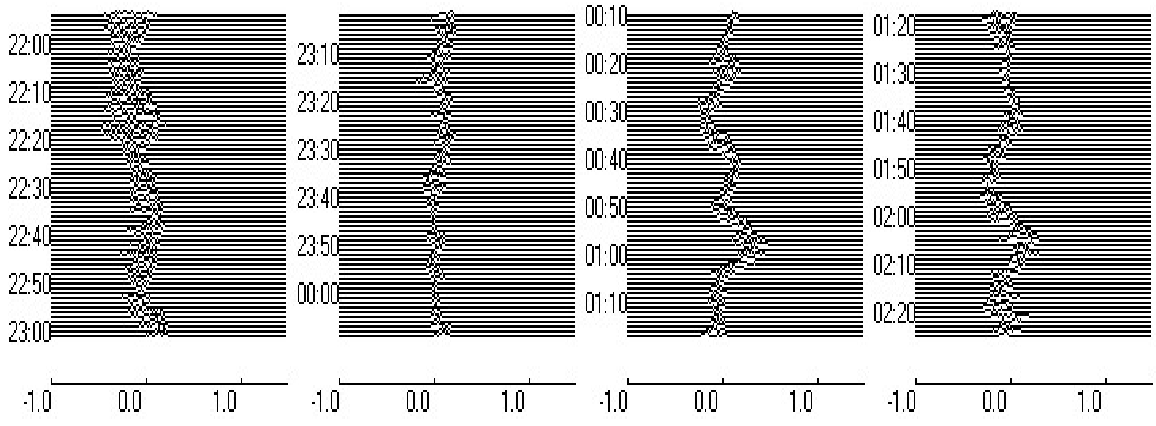

Fig. 5. 3.5 MHZ signal Doppler spectra variations associated with March 22, 2000 Arian rocket launch at 23:28 UT against the dawn terminator. The perturbation delay is 60 min, and the speed of propagation is 2.8 km/s

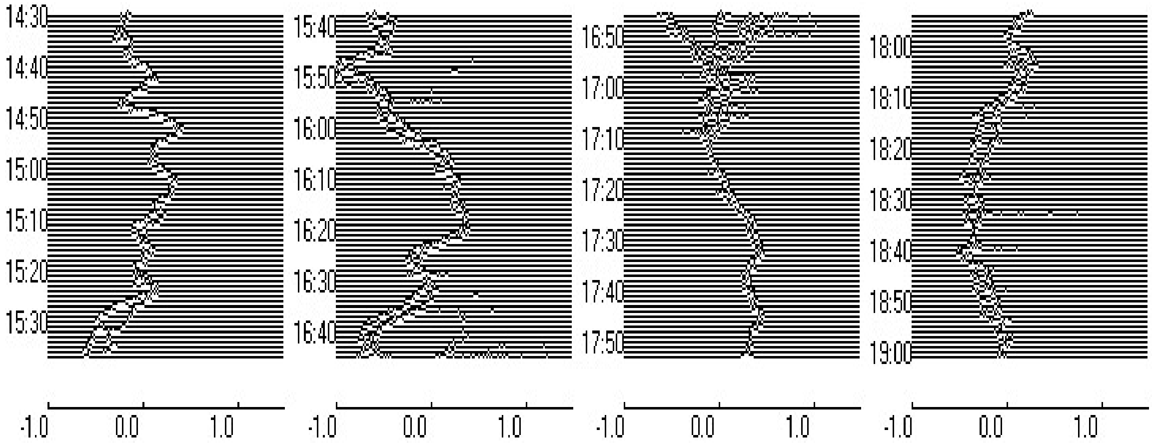

Fig. 6. 3.0 MHZ signal Doppler spectra variations associated with November 7, 1998 Discovery Space Shuttle at 17:04 UT against the dusk terminator

These waves are apparently the gyrotropic waves. Our data reveal speeds of 10 – 25 km/s.
3. Approximately 60 – 80 min before Space Shuttle landings, ionospheric perturbations of a few minutes in duration are recorded. They are most probably associated with the Shuttle OMS engine burns. The perturbation apparent propagation speed is approximately 10 – 20 km/s. The second grouping of perturbations has speeds of ~ 2 – 3 km/s.
4. The experiments reported here exhibit the following three groupings of speeds: 0.5 – 0.7 km/s, 2 – 3 km/s, and 10 – 25 km/s. They apparently correspond to the acoustic-gravity, slow MHD, and gyrotropic waves.

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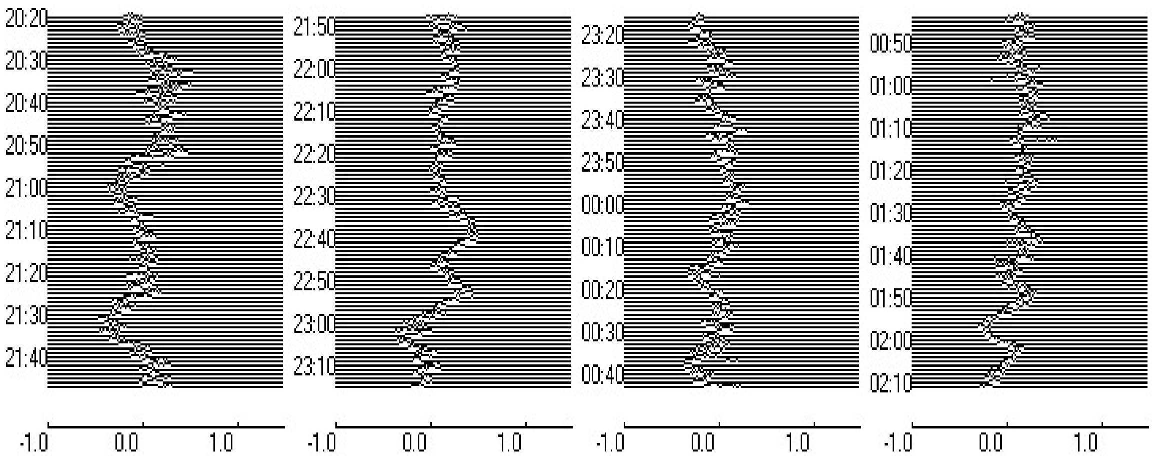

Fig. 7. 3.5 MHZ signal Doppler spectra variations associated with December 27–28, 1999 Discovery Space Shuttle at 00:01 UT