Solar proton events as trigger for increase of variability in the upper ionosphere

Klimenko M.V. (1, 2), Klimenko V.V. (1, 2), Bessarab F.S. (1, 2), Sukhodolov T.V. (1, 2), Rozanov E.V. (1, 2)

(1) West Department Pushkov Institute of Terrestrial Magnetism, Ionosphere and Radio Wave Propagation Russian Academy of Sciences, Kaliningrad, Russia

(2) St Petersburg University, Sankt Petersburg, Russia

e-mail: maksim.klimenko@mail.ru

This paper presents the results of studying the response of the parameters of the thermosphere-ionosphere system to Solar Proton Events (SPEs) and precipitation of magnetospheric protons. It is known that the main part of the proton energy is absorbed much below the F and E regions of the ionosphere; therefore, the direct effect of the SPE in the parameters of the ionosphere should also be small. In addition, proton events and significant precipitation of magnetospheric protons occur against the background of geomagnetic disturbances, which significantly affect the ionosphere and thus mask the ionospheric effects of solar and magnetospheric protons in the observational data. An effective study of such phenomena is possible only with the use of self-consistent models of the atmosphere-ionosphere system. Our study was carried out using the recently created Entire Atmosphere GLobal model (EAGLE). The characteristics of solar proton fluxes and their ionization rates were calculated using the AIMOS (Atmospheric Ionization Module Osnabrück) model. Numerical experiments were carried out for January 2005 and September 2017, during which Ground Level Enhancement (GLE) SPEs were observed. Moreover, the SPE of January 20, 2005 was the most powerful in the last more than 50 years that occurred after the GLE of February 23, 1956. In the process of one of the calculation options, only the characteristics of proton fluxes were changed, all other input parameters of the EAGLE model, including the parameters of electron precipitation, corresponded to quiet conditions. Despite the relative transparency of the upper atmosphere for high-energy protons, in numerical experiments, an ionospheric response was obtained to an increase in proton precipitation from the magnetotail and SPE. In the E region of the ionosphere, the maximum increase in the electron density is localized near the poles and is limited by latitude circles of $\pm$ 60°, and at the heights of the F2 ionospheric layer, positive disturbances are formed in the low-latitude region. An analysis of the obtained model results showed that changes in the F2 layer of the ionosphere occurred due to the generation of dynamic processes in the mesosphere and lower thermosphere, which caused the transfer of atomic oxygen directed to the equator, and, ultimately, an increase in the electron density in the F region of the ionosphere. We have shown that, during the recovery phase after SPE, the total electron content and electron density in the F region and in the upper ionosphere/plasmosphere at low and middle latitudes increases due to an increase in the concentration of atomic oxygen. A similar positive ionospheric aftereffect also exists after geomagnetic storms and stratospheric warmings. The main differences between the NmF2 and TEC perturbations in one region are mainly related to the electron temperature perturbations, which have a significant effect on the total electron content perturbations.

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