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Ionospheric Effects Observed by Radio Tomography during Severe Geomagnetic Storms

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The geomagnetic storms are an important element of space weather. As known, the distributions of all ionospheric parameters are determined by the interplay of many complex diverse processes of solar-terrestrial coupling. The intervals of geomagnetic storms are marked by dramatic changes in the dynamics of the ionosphere, whose parameters experience significant disturbances. The ionospheric signatures of geomagnetic perturbations are highly diverse in both spatiotemporal scales, ranging from a few seconds to few days and from a few meters to dozen thousand kilometers, and intensity. The methods of GNSS-based radio tomography (RT) are suitable for diagnosing the spatiotemporal structure of ionospheric disturbances caused by different space-weather factors. GNSS comprise the first-generation satellite navigation systems such as low-orbiting (LO) Russian Tsikada and American Transit satellites and second-generation satellite systems such as high-orbiting GPS and GLONASS constellations. The LORT methods reconstruct two-dimensional (2D) structure of the ionospheric electron density distribution in the vertical (altitude-latitude) plane within a spatial sector spanning a few thousand km and a time interval of 10-15 min. The horizontal and vertical resolution of LORT is typically 15-25 km and 25-30 km, respectively. The HORT methods use radio transmissions from HO satellites recorded at the receiving ground network of the International Geodetic Service (IGS), which currently comprises about 2000 receivers. The HORT methods are capable of reconstructing the four-dimensional (4D) (three spatial coordinates and time) structure of the ionosphere. Generally, HORT has a spatial resolution of 100 km at best and a time step of 60-20 min. In the regions covered by dense receiving networks (e.g., in Europe, Alaska, USA), the resolution can be improved to 30-50 and the time step reduced to 30-10 min. The resolution of 10-30 km in space and up to 2 min in time is only achievable in Japan and California, where the receiving networks are very dense.

We present the results of HORT and LORT imaging of the ionosphere during the periods of geomagnetic storms of 2003-2013 in different regions of the world – in the European part of Russia and North America. Different factors acting during the storm time make the ionosphere complexly structured. Radio tomography reveals multi-extremal distributions of the ionospheric plasma with the spots of enhanced ionization, wall-like steep gradients of electron concentration; a complex structure of the ionization trough with the polar wall shifted equatorwards is observed. Many reconstructions show various wavelike structures, travelling ionospheric disturbances, wave effects caused by corpuscular emissions, etc. We demonstrate the comparisons of radio tomography with the ionosonde measurements. In contrast to the ionosondes, which use short radio waves, the RT methods are suitable for diagnosing the ionosphere even during the periods of strong geomagnetic storms, since absorption can typically be neglected in the RT problems due to the high frequencies used.

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