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Real-Time Monitoring of the Ionospheric State with the Use of a 3D Assimilation Model

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Abstract—The 3D assimilation ionospheric model is improved to assimilate in real time the ionospheric total electron content (TEC) measurement data from the International GNSS Service (IGS) network of ground-based stations of the global positioning system (GPS). This model makes it possible to calculate the space–time electron-concentration distributions of electrons, concentration of the seven main ions, and the temperature and velocity of electrons and ions in the ionosphere at altitudes of 100–1000 km. The model calculations of the ionospheric TEC are compared to the TEC measured on slant paths with the use of two-frequency receivers of the ground-based IGS network of stations not included into the assimilation scheme. The model calculations of ionospheric electron-concentration height profiles are compared to the data measured by an incoherent-scatter radar. It is shown that the ionospheric parameters calculated without using experimental data are in worse agreement with the radar measurement data than the results obtained with the assimilation model of the ionosphere. The model-calculated electron concentrations are compared to the data from the FORMOSAT-3/COSMIC system of medium-Earth-orbit satellites.

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INTRODUCTION

Online monitoring of the Earth's ionospheric state makes it possible to provide a reliable operation of communication systems; take into account the effect of the ionosphere on wave propagation, which depends on the electron-concentration distribution; improve the accuracy of object positioning by the satellite navigation systems (GPS, GLONASS, etc.); and forecast safe operating conditions for electronic devices carried by spacecrafts. One of the most efficient methods for monitoring the current global ionospheric conditions and applying the obtained data to solving the above-mentioned problems is to employ a self-consistent 3D physical model using data assimilation. In the present study, we employ physical modeling of the ionospheric processes combined with assimilation of the data on the ionospheric total electron content (TEC) [1,2]. The essence of the assimilation method used in the present study is in correcting the physical-model calculations in accordance with the online experimental data on the TEC on the ionospheric paths of radio-sighting of GPS and GLONASS signals received from the network of the International GNSS Service (IGS) stations.

A detailed description of the physical model and assimilation scheme were given earlier [3–5]. However, the assimilation scheme developed in the cited studies has significant limitation in monitoring the current state of the ionosphere. This circumstance is due to the fact that the satellite data from the global navigation satellite systems (GNSS) used in assimilation arrive with a certain delay, which varies depending on the type of the ground-based station. During a current observation day, the ratio of the arriving data to the data required to perform the calculation is small and changeable. Such delays in assimilating the ionospheric TEC data from the network of ground-based IGS stations in the computational server of the assimilation model result in an increase of errors in modeling the ionospheric processes. Since the time delays of the data to be assimilated may sometimes be as large as two days (at the characteristic times of changes in the global distributions of concentrations and temperatures of the ionospheric components of the order of several tens of minutes), the results of model calculations cannot be used for high-precision monitoring of the current state of the ionosphere and short-term forecasting (so-called nowcasting) of changes in that state.

1. REAL-TIME PERFORMANCE OF THE ASSIMILATION MODEL OF THE IONOSPHERE

From the above discussion, it follows that one of the most important ways of improving the 3D assimilation model is to develop an algorithm for receiving, processing, and assimilating real-time RTCM (Radio Technical Commission for Maritime Services) satellite data. In the present study, we report the results obtained with an improved assimilation model based on a scheme for real-time reception of experimental TEC data and