ISSN 0016-7932, Geomagnetism and Aeronomy, 2013, Vol. 53, No. 1, pp. 73–84. © Pleiades Publishing, Ltd., 2013.
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Three-Dimensional Assimilation Model of the Ionosphere for the European Region

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Received March 2, 2011; in final form, August 18, 2011

Abstract—We consider a three-dimensional assimilation model of the ionosphere. We discuss the governing equations of the physical model and the data assimilation technique. We provide examples of the model results: plots of the calculated ionospheric parameters, such as the density and temperature of electrons and ions. We compare the model results with independent sources of data on the state of the ionosphere. We make some conclusions regarding the model accuracy and possible areas of its practical application.

DOI: 10.1134/S0016793212060114

1. INTRODUCTION

The development of methods for monitoring geophysical processes in the Earth's ionosphere is one of the important problems in the physics of the upper atmosphere. The monitoring of the state of the ionosphere and subsequent short-term forecasts of changes in its state are needed for treating a wide range of applications. Operational data on changes in the state of cosmic plasma make it possible to increase the reliability of long-haul radio communication, improve the precision characteristics of space navigation systems, and make a framework for the control of intentional and unintentional impacts on the upper atmosphere.

A line of research on the problem of ionospheric monitoring is the use of theoretical and empirical models. For example, the models described in (Vlasov et al., 1994; Grigor'ev et al., 2006; Fatkullin et al., 1981; Huba et al., 2000; Millward et al., 1996) are needed to study the physics of processes in the near-Earth cosmic space and to assess the impact of various geophysical effects on the characteristics of ionospheric plasma. Purely theoretical modeling has a limited capability for getting data on the current state of the ionosphere and short-term forecasts of its changes. The past two decades have witnessed the successful use of data assimilation techniques for solving problems regarding the monitoring of the state of the ionosphere. The assimilation method is based on numerical theoretical calculations of the current state of a physically justified model describing a given system, which can be adjusted online using available experimental data. It is known that methods of measurement data assimilation into model calculations have already been applied to solve a number of problems in atmospheric physics. These include the development of precision methods for short-term weather forecasts on the basis of global hydrodynamic models of the atmosphere with the assimilation of satellite, aircraft, and upper atmospheric observational data on the fields of meteorological parameters at different atmospheric heights and the development of global models of the chemical composition and structure of the troposphere and stratosphere.

The assimilation approach can be applied to ionospheric modeling by using operational measurement data on the total electron content (TEC) with the help of ionospheric radio sounding by signals of space navigation systems. The efficiency of new methods for monitoring and forecasting "space weather," as well as for weather forecasting, depends largely on the ability to obtain global and continuous measurement data on key ionospheric parameters and on the capacity to assimilate these diverse measurement data into physically reasonable self-consistent numerical models. Assimilation models of the ionosphere (AMI) are considerably superior to conventional theoretical models in terms of accuracy, because the computations at each step are based on the data of experimental observations. The assimilation methods for operational monitoring of the current state of the ionosphere have been successfully used in recent years in the United States (Khattatov et al., 2005; Wang et al., 2004).

The aim of this paper is to describe a three-dimensional assimilation model of the ionosphere for the operational monitoring and forecasting of its state over the European region. The proposed AMI model solves the momentum and mass energy conservation equations. Also, it uses an assimilation scheme for TEC measurement data in the ionosphere obtained in a quasi-real-time mode via the Internet from an extensive network of ground-based GPS (Global Positioning System) stations, as well as continuous data on variations in solar radiation in the ultraviolet spectral