Journal of Atmospheric and Solar-Terrestrial Physics 71 (2009) 2064–2076

Contents lists available at ScienceDirect

Journal of Atmospheric and Solar-Terrestrial Physics

journal homepage: www.elsevier.com/locate/jastp

GCITEM-IGGCAS: A new global coupled ionosphere–thermosphere-electrodynamics model

Zhipeng Ren[a,b,c], Weixing Wan[a,*], Libo Liu[a]

[a] Beijing National Observatory of Space Environment, Institute of Geology and Geophysics, Chinese Academy of Sciences, Beijing 100029, China
[b] Wuhan Institute of Physics and Mathematics, Chinese Academy of Sciences, Wuhan 430071, China
[c] Graduate School of Chinese Academy of Sciences, Beijing 100049, China

ARTICLE INFO

Article history:
Received 27 April 2009
Received in revised form
20 September 2009
Accepted 27 September 2009
Available online 4 October 2009

Keywords:
Thermosphere
Ionosphere
Modeling
Global circulation models

ABSTRACT

The Global Coupled Ionosphere–Thermosphere-Electrodynamics Model developed at Institute of Geology and Geophysics, Chinese Academy of Sciences (GCITEM-IGGCAS), is introduced in this paper. This new model self-consistently calculates the time-dependent three-dimensional (3-D) structures of the main thermospheric and ionospheric parameters in the height range from 90 to 600 km, including neutral number density of major species O_2, N_2, and O and minor species $N(^2D)$, $N(^4S)$, NO, He and Ar; ion number densities of O^+ ,O_2^+, N_2^+, NO^+, N^+ and electron; neutral, electron and ion temperature; and neutral wind vectors. The mid- and low-latitude electric fields can also be self-consistently calculated. GCITEM-IGGCAS is a full 3-D code with 5° latitude by 7.5° longitude cells in a spherical geographical coordinate system, which bases on an altitude grid. We show two simulations in this paper: a March Equinox one and a June Solstice one, and compare their simulation results to MSIS00 and IRI2000 empirical model. GCITEM-IGGCAS can reproduce the main features of the thermosphere and ionosphere in both cases.

1. Introduction

The thermosphere and ionosphere are two tightly coupled, overlapping regions of the upper atmosphere, and form the coupled ionosphere–thermosphere system. In contrast to the lower atmosphere, the thermosphere and ionosphere are strongly driven by a series of external sources. These include solar EUV and UV radiation ($\lambda < 200$ nm), magnetospheric plasma convection, auroral and energetic particle precipitation, and forcing by wave activity penetrating upward from the lower atmosphere (e.g., Rees, 1989). Heating, dissociation, and ionization result from the action of these sources on the coupled system, which in turn drive the global wind system and induce chemical changes in neutral and ionized species. An understanding of both the thermosphere and ionosphere is important for a number of research and space weather applications. The complex aeronomical processes in the coupled ionosphere–thermosphere system have been studied for many years. The background atmospheric and ionospheric properties have usually been obtained from measurements or from empirical models (e.g., Bilitza, 2001; Hedin, 1991). However, detailed study of the thermosphere/ionosphere region has historically been difficult because of its relative inaccessibility to direct measurement techniques and the complex and highly coupled processes which occur there. Thus, simulations play an important role in studying the thermosphere and ionosphere.

For many years there has been a growing need to simulate physical and chemical processes occurring in the thermosphere and ionosphere. Prevenient researchers had developed many ionospheric numerical models (e.g., Bailey et al., 1997; Huba et al., 2000; Yue et al., 2008), and a series of global thermospheric numerical models also had been developed (e.g. Fuller-Rowell and Rees, 1980, 1983; Dickinson et al., 1981, 1984). However, these two kinds of numerical models are generally independent of each other. Global empirical models of the ionosphere (e.g., Bilitza, 2001) and global empirical models of the atmosphere (e.g., Hedin, 1991) have generally played important roles in these numerical models. In order to actually examine how the neutrals and ions are coupled together, one needs to turn to more complex numerical models of this coupled system. Global self-consistent models of the thermosphere and ionosphere including electrodynamics have been developed during the last 20 years to describe the complex coupled physical and chemical processes of the upper atmosphere environment as a whole (e.g., Fuller-Rowell et al., 1987; Rees and Fuller-Rowell, 1988, 1990; Roble et al., 1987, 1988; Roble and Ridley, 1994; Namgaladze et al., 1989, 1990, 1991; Richmond et al., 1992; Wang et al., 1999; Ridley et al., 2006).

One of the most important global self-consistent models of the thermosphere and ionosphere is the National Center for

* Corresponding author.
E-mail address: wanw@mail.iggcas.ac.cn (W. Wan).

1364-6826/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jastp.2009.09.015

Atmospheric Research thermosphere–ionosphere general circulation model (NCAR-TIGCM), which was developed from thermosphere general circulation model (TGCM) (Dickinson et al., 1981, 1984). The TIGCM solves for the time-dependent structures of the main thermospheric and ionospheric parameters, including neutral wind vectors; neutral, electron and ion temperature; mass mixing ratios of the neutral major species O_2, N_2, and O and the neutral minor species $N(^2D)$, $N(^4S)$, NO, He and Ar; and ion number densities of O^+ ,O_2^+, N_2^+, NO^+ and N^+. It is a full three-dimensional (3-D) code with 5° latitude by 5° longitude by 0.5 scale height altitude cells. Richmond et al. (1992) added a self-consistent mid- and low-latitude electrodynamics to the TIGCM, resulting in the thermosphere–ionosphere-electrodynamics general circulation model (TIEGCM). Roble and Ridley (1994) extended this model down into the mesosphere and developed the thermosphere–ionosphere–mesosphere-electrodynamics general circulation model (TIMEGCM). The thermosphere–ionosphere nested grid model (TING) uses the TIGCM as a base, but adds a nested grid within the domain to allow for higher resolution in a limited area (Wang, 1998; Wang et al., 1999).

Another important global self-consistent model of the thermosphere and ionosphere is the Coupled Thermosphere–Ionosphere Model (CTIM) (Fuller-Rowell and Rees, 1980, 1983; Fuller-Rowell et al., 1987; Rees and Fuller-Rowell, 1988, 1990). This model extended up into the plasmasphere and is called the Coupled Thermosphere–Ionosphere–Plasmasphere general circulation model (CTIP). Harris et al. (2002) extended this model down into the mesosphere and developed the Coupled Middle Atmosphere and Thermosphere general circulation model (CMAT). These models model the ionosphere along field lines. However, similar to the TIGCM, these models use a pressure-based coordinate system in its thermospheric part, and simulate the time-dependent structure of the wind vectors, temperature and density of the neutral thermosphere with a resolution of 2° latitude by 18° longitude by 1 scale height altitude cells.

The GSM TIP (Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere) was developed at the West Department of IZMIRAN (former Kaliningrad Observatory) and modified later at the Polar Geophysical Institute in Murmansk (Namgaladze et al., 1988, 1990, 1991). It calculates the time-dependent 3-D structure of the neutral temperature, wind velocity vector and number density of O_2, N_2, and O in the height range from 80 to 520 km in a spherical geomagnetic coordinate system. O^+, H^+, and molecular ion number densities, ion and electron temperatures and ion velocities in the ionosphere and plasmasphere from 80 km to 15 Earth radii (R_E) are also calculated. The ionospheric electric potential in GSM TIP model is solved in a program module, which uses the geomagnetic system, including the dynamo action of the thermospheric winds and magnetospheric sources.

The Global Ionosphere–Thermosphere Model (GITM) is the latest 3-D spherical code that models the Earth's thermosphere and ionosphere system using a stretched grid in latitude and altitude (Ridley et al., 2006; Deng and Ridley, 2006). GITM explicitly solves for the time-dependent 3-D structures of the main thermospheric and ionospheric parameters, including neutral and ion velocities; neutral, electron and ion temperature; neutral densities of O, O_2, N_2, $N(^2D)$, $N(^2P)$,$N(^4S)$, NO, H and He; and ion species $O(^4S)^+$, $O(^2D)^+$, $O(^2P)^+$, O_2^+, N_2^+, NO^+, N^+, H^+ and He^+. The major differences between GITM and the other thermosphere models is that GITM does not assume a hydrostatic solution. This allows the model to more realistically capture physics in the high-latitude region, where auroral heating is prevalent. The grid system within GITM is fully parallel and is quite versatile. The code can be run in a one-dimensional (1-D) or 3-D mode.

Chinese researchers had also developed a series of thermospheric numerical models (e.g., Lei et al., 2003a, b; Ji, 2006), ionospheric numerical models (e.g., Zhang and Huang, 1995; Tu et al., 1997; Liu et al., 2000; Lei et al., 2004; Yue et al., 2008), and ionospheric dynamo models (e.g., Yu et al., 2003; Ren et al., 2008). Expressly, a two-dimensional (2-D) ionosphere and thermosphere coupling model has been constructed by Gao and Xiao (1992) and Wang and Xiao (1999, 2000). At the same time, researchers also carried out much work related with these numerical models, such as Zhu et al. (1998), Zhang et al. (2003) and Zhang et al. (2004). The thermosphere and ionosphere are tightly coupled together. Hence, the numerical models for individual thermosphere and ionosphere play important roles in the research of the coupled ionosphere–thermosphere system. Even though, we need more complex coupled models to study many important processes of this system, e.g. the couple between the neutrals and ions, the influence of the mesosphere on this system, the couple between magnetosphere and this coupled system, and the anomaly of the ionospheric and thermospheric spatio-temporal variations. Thus, we develop a coupled model to simulate the ionosphere–thermosphere system as a whole, and try to use this coupled model to study above processes. In this paper, we will present this new global 3-D self-consistent model of the ionosphere and thermosphere including electrodynamics (Global Coupled Ionosphere–Thermosphere-Electrodynamics Model, Institute of Geology and Geophysics, Chinese Academy of Sciences, GCITEM-IGGCAS).

2. Model description

GCITEM-IGGCAS is a new global 3-D self-consistent model of the ionosphere and thermosphere including electrodynamics. It is developed at the Institute of Geology and Geophysics, Chinese Academy of Sciences. This new model self-consistently calculates the time-dependent 3-D structures of the main thermospheric and ionospheric parameters in the height range from 90 to 600 km, including neutral number density of the major species O_2, N_2 and O and the minor species $N(^2D)$, $N(^4S)$, NO, He and Ar; ion number densities of O^+ ,O_2^+, N_2^+, NO^+, N^+ and electron; neutral, electron and ion temperature; and neutral wind vectors. The ionospheric electric fields in the mid- and low-latitude can also be self-consistently calculated. GCITEM-IGGCAS bases on the hydrostatic assumption. It is a full 3-D code with 5° latitude by 7.5° longitude cells in a spherical geographical coordinate system, which bases on an altitude grid. The vertical grid spacing is about 3 km in the lower thermosphere, and about 30 km in the upper thermosphere. This model is solved by a time-stepping finite difference procedure, whose time step is 2–5 min. The horizontal difference procedure uses explicit numerical method. With the effect rapid vertical molecular diffusion, the vertical difference procedure has to use implicit numerical method.

GCITEM-IGGCAS can simulate the complex chemistry, thermodynamics, dynamics and electrodynamics of the coupled ionosphere–thermosphere system. As the mid- and low-latitude ionospheric electric fields can also be self-consistently calculated, GCITEM-IGGCAS can well simulate the couple between the neutrals and ions. The previous most important global Ionosphere–Thermosphere-Electrodynamics Models are TIEGCM and CTIP. Different from CTIP model, the ionospheric module and the electrodynamics module of GCITEM model can both use a realistic geomagnetic field. Thus, similar to the TIEGCM model, GCITEM model can simulate the ionosphere–thermosphere system in a realistic geomagnetic field. This is important in the research of the couple between the neutrals and ions, and the anomaly of the ionospheric and thermospheric spatio-temporal variations (e.g. Zeng et al., 2008). Different from the TIEGCM and CTIPE which use