

THERMOSPHERE-IONOSPHERE-MESOSPHERE MODELING USING THE TIME-GCM

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LONG-TERM GOAL

A major goal of the research is to understand how elements in the coupled upper atmosphere/ionosphere system interact with one another and to determine how this coupled system responds to the variable energy input from the sun and the variable input from the lower atmosphere and ocean. The research focuses on the sources and characteristics of global-scale ionospheric, thermospheric, and mesospheric structure and variability and the coupling of those atmospheric regions to the lower atmosphere and to the magnetosphere and solar wind.

SCIENTIFIC OBJECTIVES

I wish to understand the nature of the sources of variability in the upper atmosphere/ionosphere system and how they are related to solar radiative and auroral particle and electric field forcings. I am also interested in understanding how disturbances from the lower atmosphere and ocean affect the upper atmosphere and how this variability interacts with the variability generated by solar and auroral sources. We accomplish this task by developing large-scale numerical models of the upper atmosphere and ionosphere and using these models to analyze data obtained by satellites and ground-based observatories as well as using these models for numerical simulations to understand how upper atmosphere/ionosphere physics and chemistry interact.

APPROACH

A hierarchy of numerical models has been developed that describes the upper atmosphere and ionosphere and these models have been used to study atmosphere/ionosphere interactions and their response to solar and auroral variability for nearly 20 years. The current version of models include: the TIE-GCM, TIME-GCM, and flux-coupled TIME-GCM/ CCM3, where the I, M, and E represent “ionosphere,” “mesosphere,” and “electrodynamics,” respectively. The CCM3 is the NCAR Community Climate Model, Version 3, a GCM of the troposphere and stratosphere. All models include self-consistent ionospheric electrodynamics, that is, a calculation of the electric fields and currents generated by the ionospheric dynamo, and consideration of their effects on the neutral dynamics. The TIE-GCM is used for studies that focus on the thermosphere and its coupling with the ionosphere and magnetosphere. The TIME-GCM, the most elaborate of the upper-atmospheric TGCM, solves for global distributions of neutral and plasma temperatures, velocities, and compositions, including all of the species that are photochemically important in the mesosphere, thermosphere, and ionosphere. The flux-coupled TIME-GCM/CCM3 is a climate model that extends from the ground, including oceans, to 500 km altitude to study global atmospheric variability and solar-terrestrial couplings.

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WORK COMPLETED

Works include:

1. During the past year considerable effort was made to validate the TGCM's predictions of the mean thermospheric and ionospheric structure and dynamics. We have participated in numerous satellite projects and community campaign studies to evaluate model performance, identify missing aeronomical processes, and develop an understanding of how the coupled system responds to solar and auroral variability;
2. The upper boundary in the TIE-GCM has been raised to 800 km altitude to better represent the electron density distribution in the topside ionosphere. This modification gives a much better representation of total electron content, but there is more work required to include plasmasphere/ionosphere plasma and energy exchange processes at the upper boundary of the model;
3. Several different subgrid scale gravity wave schemes were tested the TIME-GCM by requiring that the calculated upper atmosphere wind, temperature and compositional distributions were consistent with UARS and ground-based observational data and climatology;
4. Major improvements were made to the aeronomical scheme in both the TIE-GCM and the TIME-GCM. The chemical rate coefficients are now from the JPL-94 compilation and many branching rates and quenching coefficients are consistent with the latest laboratory investigations; and
5. Several new post model processors have been developed for easy comparison of model output with observational data and empirical data bases. Model output can be obtained over a given observing station, along a satellite track, or as viewed by a remote sensing instrument onboard an orbiting satellite.

RESULTS

The results from some of the studies conducted during the past year include the following:

1. The TIE-GCM was used to study the ionospheric response to the major geomagnetic storm of October 18-19, 1995. TIE-GCM simulations were compared with global ionospheric maps (GIM) of total electron content (TEC) observations from the Global Positioning System (GPS) worldwide network. The TIE-GCM results, which utilize the realistic time-dependent ionospheric convection and auroral precipitation derived from the assimilative mapping of ionospheric electrodynamics (AMIE) procedure as the inputs at the upper boundary, shows good agreement with the GPS-GIM in terms of simulating storm-time TEC disturbances over the polar regions. The model simulation indicates that the increase of electron density, especially in the high-latitude E and lower F regions below 200 km, is directly related to the magnetospheric energy input through auroral precipitation to the ionosphere;
2. The TIE-GCM was also used to examine optically derived upper thermosphere wind and temperature data collected at Antarctic stations at South Pole, Mawson and Halley. The simulation provided a global background context upon which the widely-separated optical observations can be placed. The simulation showed three large-scale structures in the polar wind field: the morning vortex, the evening vortex and the cross-polar wind jet;

3. The High Resolution Doppler Imager (HRDI) and the Wind Imaging Interferometer (WINDII) onboard the Upper Atmosphere Research Satellite (UARS) obtained for the first time a comprehensive data set of the wind structure of the mesosphere and lower thermosphere between 50 and 200 km altitude. Average wind structure for March/April 1992/1993 equinox and December/January 1992/1993 solstice conditions were obtained. In addition, wind structure as a function of local time at various altitudes were also obtained along with airglow measurements of the atomic oxygen green line, the O₂ Atmospheric Band and the OH airglow emissions. This data set was used to tune the TIME-GCM for equinox and solstice conditions for solar F10.7 values of 150 and geomagnetic quiet conditions. Excellent agreement was obtained between the TIME-GCM predicted wind structure and the UARS measurements for equinox conditions assuming weak gravity wave forcing throughout the mesosphere with rapid dissipation in the lower thermosphere above 100 km. For solstice conditions much stronger gravity wave forcing was required to reproduce the observations suggesting a seasonal variation in the strength of gravity wave forcing at 30 km; and
4. The flux coupled TIME-GCM/CCM3 has been run for nearly a year, from January through October and the results indicate considerable couplings between the lower and upper atmospheres. These couplings are most likely the source of the day-to-day variability that has been observed in the upper atmosphere for years but has not been adequately described by upper atmosphere models. The source of this variability is weather systems and other disturbances generated in the troposphere that propagate upward into the upper mesosphere and lower thermosphere and produce considerable variability on horizontal scale-sizes of thousands of kilometers. These structures are similar to those observed by the WINDII and HRDI instruments onboard the UARS satellite.

IMPACT/APPLICATION

The models we have developed are community models and they have been used by over 100 scientists and students over the past few years. Thus, the models are constantly being evaluated, upgraded and improved by the community feedback. We participate in PRIMER campaign studies, NSF Coupling and Energetics of Atmospheric Regions (CEDAR), Geospace Environmental Modeling (GEM), and Space Weather Initiative (SWI) programs. The models have been used for the NASA Space Physics Theory Program, and various NASA and DOD satellite missions.

TRANSITIONS

There have been no transitions thus far with the contract. The models are being developed for eventual ONR and Space Weather studies.

RELATED PROJECTS

The numerical modeling effort is complemented by a data analysis and interpretation effort. Data from the following satellites have been analyzed and compared with model simulations:

1. NASA UPPPER ATMOSPHERE RESEARCH SATELLITE (UARS);
2. NASA CRISTA AND MAHRSI experiments on board the space shuttle;
3. NASA ISTEP/GGS satellite mission;

4. NSF CEDAR campaigns; and
5. NSF GEM campaigns.

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WEB ADDRESS

<http://www.hao.ucar.edu/public/research/tiso/tgcm/tgcm.html>

PRESENTATIONS IN FY1997

"Observation and Simulation of Antarctic Thermospheric Winds and Temperatures for August 2-10, 1992" (R. W. Smith, R. G. Roble, G. Hernandez, M. Conde, P. L. Dyson, R. Crikmore, and

M. Jarvis). Paper presented at the 1996 Western Pacific AGU meeting, Brisbane, Australia, 1996.

“First Results in Thermosphere Ionosphere Magnetosphere Coupling” (C. Peymirat, A. D. Richmond, B. Emery, D. Fontaines, and R. G. Roble). Paper presented at the fall AGU meeting, San Francisco, CA, 1996.

“Aeronomic Processes in the Upper Atmosphere and Variations Driven by Dynamics and Solar Variability” (R. G. Roble). Invited NICOLET LECTURE presented at the fall AGU meeting, San Francisco, CA, 1996.

“The Application of a Post-Processor for the NCAR-TIGCM to a Study of the Appleton Anomalies” (A. G. Burns, T. L. Killeen, and R. G. Roble). Paper presented at the fall AGU meeting, San Francisco, CA, 1996.

“On the Quantitative Assessment of Global Scale Ionospheric Model Predictions: Issues of Physics and Comparative Accuracies” (E. P. Szuszczewicz, P. Wilkerson, P. Richards, R. G. Roble, B. A. Emery, and others). Paper presented at the fall AGU meeting, San Francisco, CA, 1996.

“Global Low Altitude Coupling” (M. H. Rees, D. Lummerzheim, R. G. Roble, and B. Emery). Paper presented at the spring AGU meeting, Baltimore, MD, 1997.

“Mean Circulation and Tidal Structure of the Mesosphere and Lower Thermosphere for Equinox and Solstice Conditions 1992-1993: Comparison of TIME-GCM Predictions with UARS Observations” (R. G. Roble, G. G. Shepherd, C. A. McLandress, and P. B. Hays). Paper presented at the spring AGU meeting, Baltimore, MD, 1997.