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FINAL REPORT ON GRANT NAGW-3457

1. PREAMBLE.

Three separate tasks were proposed under this award. The first involved extending our continuing study of electrodynamical feedback between the thermosphere/ionosphere and the magnetosphere. The second was a model-experiment comparison study of global dynamics and the third was a "spectral energetics" analysis of tidal dissipation and energy exchange mechanisms.

2. INTRODUCTION

The Earth's mesosphere and lower-thermosphere/ionosphere (MLTI), between ~60 and 180 km altitude, is the most poorly understood region of the Earth's atmosphere, primarily because of its relative inaccessibility. This lack of knowledge has been widely recognized and has provided important scientific rationale for the upcoming NASA TIMED mission [*Killeen et al.*, TIMED Science Definition Team, Volume II, 1991]. While the data gathered during the TIMED era will revolutionize our understanding of the MLTI region, much work can be done prior to the mission, both to develop data-analysis and modeling techniques and to study the more limited relevant experimental data from previous missions. The grant reported on here continues and extends an existing successful program of scientific research into the energetics, dynamics and electrodynamics of the MLTI, using available theoretical and data analysis tools.

Our previous work under this grant (NAGW-1535) focused on two areas. The first was a theoretical study of the bi-directional coupling between the MLTI and the magnetosphere [*Deng et al.*, 1991; 1993]. We have used the NCAR thermosphere-ionosphere general circulation model (TIGCM) to calculate the time-dependent magnitudes of the Hall and field-aligned currents that occur in the recovery phase of geomagnetic storms, driven by the inertia of the neutral gas - the so-called "flywheel effect" [*Lyons et al.*, 1985]. Such currents flow in opposite directions to those more typically associated with the direct magnetospherically-driven system and correspond to electrical energy flowing upwards from the ionosphere. For the first time, our work experimentally demonstrated the existence of a small but significant flywheel effect through comparisons of theoretical calculations and data from DE-2 [*Deng et al.*, 1991; 1993].

Under the grant reported upon here, we proposed a three-year effort to supplement and extend this previous work, focusing on scientific areas of direct relevance to TIMED objectives. Three overlapping studies were proposed, the first two represented extensions of current efforts and the third represented a brand new approach to the study of MLTI energetics. The studies were:

1. An extension of our ongoing theoretical study of the electrodynamical feedback (flywheel) mechanism between the MLTI and the magnetosphere, using specialized post-processors developed by us for use with the NCAR TIEGCM (an updated version of the TIGCM);
2. An experimental study of the global dynamics of the lower thermosphere, using our recently developed wind inversion technique to interpret data from the Fabry-Perot Interferometer (FPI) on Dynamics Explorer-2 (DE-2);
3. A "spectral energetics" analysis of tidal dissipation and energy exchange mechanisms in the MLTI region, using spectral post-processors recently developed for use with the NCAR TIEGCM.

3. Scientific Accomplishments.

The major work on "spectral energetics" analysis was published in 1995. In this work we quantified the spectral energetics of the Earth's lower thermosphere for a quiet, "diurnally-reproducible" case. The energy residing in this region is partitioned into reservoirs by height, energy type and wave mode. These reservoirs are then further analyzed to understand the processes that add energy to the reservoirs, those that dissipate energy and those that redistribute energy between the reservoirs. The results of this study were published in *Raskin et al.* (1995). Our main conclusions were that: in contrast to the lower atmosphere, kinetic energy exceeds the available potential energy; the upwardly propagating diurnal and semi-diurnal tides carry most of the kinetic energy component; and the total potential energy is three orders of magnitude larger than either the available potential energy or the kinetic energy.

We also developed a one-dimensional, hybrid, satellite-track model during the grant period. This has been designed to study the effects of the dissipation of magnetospheric currents in the thermosphere and the way that these can affect the thermal/dynamic regime in the thermosphere. In the paper that was published on this work (*Deng et al.*, 1995), we used this model to study electron densities, ionization rates, particle heating rates, Hall and Pedersen conductivities and the dissipation of magnetospheric currents in the form of Joule heating. In addition, we performed model-data comparisons between a model run made for conditions appropriate to an overflight of the Chatanika radar facility. The principal results of this study are: there is a good first order agreement between DE 2 calculated Poynting fluxes and the height integrated energy conversion rate in the one-dimensional model; generally the dissipation of ionospheric currents is dominated by Joule heating, however over the polar cap the conversion of this electric energy into neutral wind mechanical energy is significant; and the model can reproduce the experimentally determined conductivities and Joule heating rates with reasonable fidelity, but it cannot reproduce all of the details of the radar measurements that were made in the auroral oval.

This satellite-track model is being utilized by Mr. T. Garner, a graduate student. He is looking at the air-glow signature of patches. Other atmospheric parameters below the height of the satellite in his studies are supplied by the satellite track model. A paper is in press on this subject (*Garner et al., 1996*). In this paper we show that patches are seen in the 6300 Å observations made from the Dynamics Explorer 2 satellite. These are the first space-borne observations of patch signatures in airglow. It is also shown in this paper that these emissions appear at altitudes above about 300 km, indicating that the airglow produced by them occurs at a much greater height than the normal background airglow.

We have also done substantial work on the effects of geomagnetic storms on the thermosphere. Two papers have been published that describe changes in the upper thermosphere that occur as a result of geomagnetic storms (*Burns et al.*, 1995 a, b). These papers have established that composition changes on a constant pressure surface have a hitherto unexpected importance in determining positive storm effects in electron densities. Together they also establish a coherent explanation for previously unrelated phenomena that occur at middle and low latitudes during geomagnetic storms. These include: the increase in neutral density in the upper thermosphere; temperature increases in this region; increases in electron density; increases in the height of the F_2 peak; and the small changes in neutral composition that are seen at any particular height.

In an educational institution education is always an important component of research work. In the period of this grant one graduate student has completed his doctorate under its aegis: Mr. W. Deng.

A database system has been developed for our Dynamics Explorer 2 and Atmospheric Explorer satellite data. This can be utilized fully to perform studies of the circulation, composition, thermodynamics and electrodynamics of the Earth's thermosphere if these are funded.

4. CONCLUDING REMARKS.

In the three year period of this grant we achieved the scientific goals that were described in our original proposal. Fourteen papers were published and a similar number of talks were presented during the grant period - an indication of strong scientific achievement. Several brand new concepts have come out of this work: these should be developed more fully in the future. Reprints of some of these articles are included with this report.

5. REFERENCES

Burns, A. G., T. L. Killeen, G. R. Carignan and R. G. Roble, Large enhancements in the O/N_2 ratio in the evening sector of the winter hemisphere during geomagnetic storms, J. Geophys. Res., 100, No. A8, 14,661, 1995.

Burns, A. G., T. L. Killeen, W. Deng, and G. R. Carignan, Geomagnetic storm effects in the Low- to Middle-Latitude Upper Thermosphere, J. Geophys. Res., 100, No. A8, 14,673, 1995.

Deng, W., T. L. Killeen, A. G. Burns, R. G. Roble, J. Slavin, and L. E. Wharton, The effects of Neutral Inertia on Ionospheric Currents in the High Latitude Thermosphere Following Geomagnetic Storm, J. Geophys., Res., 98, A5, 7775, 1993.

Deng, W., T. L. Killeen, A. G. Burns, R. M. Johnson, B. A. Emery, R. G. Roble, J. D. Winningham, and J. B. Gary, A One-Dimensional Hybrid Satellite Track Model for the Dynamics Explorer-2 (DE-2) Satellite, J. Geophys., Res., 100. No. A2, 1611, 1995.

Garner, T. W., T. L. Killeen, A. G. Burns, R. Coley, and D. Winningham, An examination of the oxygen red line signature of a polar cap ionization patch as seen from the Dynamics Explorer 2 satellite, *in press,* Radio Science, 1996.

Lyons, L. R., T. L. Killeen, and R. L. Walterscheid, The neutral "flywheel" as a source of quiet-time, polar cap currents, *Geophys. Res. Lett., 12,* 101-104, 1985.

Killeen, T. L., H. G. Mayr et al., The Final Report of the TIMED Science Definition team, Volumes I, II and III, Space Physics Division, NASA Headquarters, July 1991

Raskin, R., A. G. Burns, T. L. Killeen and R. G. Roble, Energy spectrum of the NCAR-TIGCM lower thermosphere, proceedings of the AGU Chapman Conference, Asilomar, CA, *Geophysical Monograph* 87, 279, 1995.

APPENDIX 1.

PUBLICATIONS DURING THE GRANT PERIOD.

Burns, A. G., T. L. Killeen, G. R. Carignan and R. G. Roble, Large enhancements in the O/N_2 ratio in the evening sector of the winter hemisphere during geomagnetic storms, J. Geophys. Res., 100, No. A8, 14,661, 1995.

Burns, A. G., T. L. Killeen, W. Deng, and G. R. Carignan, Geomagnetic storm effects in the Low- to Middle-Latitude Upper Thermosphere, J. Geophys. Res., 100, No. A8, 14,673, 1995.

Deng, W., T. L. Killeen, A. G. Burns, R. G. Roble, J. Slavin, and L. E. Wharton, The effects of Neutral Inertia on Ionospheric Currents in the High Latitude Thermosphere Following Geomagnetic Storm, J. Geophys., Res., 98, A5, 7775, 1993.

Deng, W., T. L. Killeen, A. G. Burns, R. M. Johnson, B. A. Emery, R. G. Roble, J. D. Winningham, and J. B. Gary, A One-Dimensional Hybrid Satellite Track Model for the Dynamics Explorer-2 (DE-2) Satellite, J. Geophys., Res., 100. No. A2, 1611, 1995.

Garner, T. W., T. L. Killeen, A. G. Burns, R. Coley, and D. Winningham, An examination of the oxygen red line signature of a polar cap ionization patch as seen from the Dynamics Explorer 2 satellite, *in press,* Radio Science, 1996.

Killeen, T. L., Mesosphere-Lower Thermosphere Coupling, EOS Transactions, AGU, 75, No. 18, 1994.

Killeen, T. L., A. G. Burns, R. M. Johnson and F. A. Marcos, Modeling and Prediction of Density Changes and Winds Affecting Satellite Trajectories, *AGU Monograph No. 13, on the "Environmental Effects on Spacecraft Positioning and Trajectories"*, Proceedings of the IUGG Union Symposium No. 15, Vienna, 1991, Vol. 13, 83, 1993.

Killeen, T. L., A. G. Burns, and R. M. Johnson, Thermospheric/Ionospheric Variability and Satellite Orbit Perturbations, *"Solar-Terrestrial Predictions IV Workshop, Ottawa, CAN"*, Proceedings of the STEP Workshop, Vol. 4, 363, 1993.

Killeen, T. L., R. M. Johnson, Upper atmospheric waves, turbulence, and winds: Importance for mesospheric and thermospheric studies, U.S. National Report to the IUGG, Rev. of Geophys., Supplement, 737, 1995.

Killeen, T. L., Y.-I. Won, R. J. Niciejewski, and A. G. Burns, Upper Thermosphere Winds and Temperatures in the Geomagnetic Polar Cap: Solar Cycle, Geomagnetic Activity and IMF Dependencies, J. Geophys., Res., 100, No. A11, 21,327, 1995.

Raskin, R., A. G. Burns, T. L. Killeen and R. G. Roble, Energy spectrum of the NCAR-TIGCM lower thermosphere, proceedings of the AGU Chapman Conference, Asilomar, CA, *Geophysical Monograph* 87, 279, 1995.

Siscoe, G., E. Hildner, T. L. Killeen, L. J. Lanzerotti, and W. Lotko, Developing Service Promises Accurate Space Weather Forecasts in the Future, EOS Transactions, AGU, 75, No. 31, 1994.

Thayer, J. P., and T. L. Killeen, A Kinematic Analysis of the High-Latitude Thermospheric Neutral Circulation Pattern, J. Geophys., Res., 98, A7, 11,549, 1993.

Wu, Qian, T. L. Killeen and N. W. Spencer, Dynamics Explorer-2 Observations of Equatorial Thermospheric Winds and Temperatures: Local Time and Longitudinal Dependences, J. Geophys., Res., 99, A4, 6,277, 1994.

APPENDIX 2.

PRESENTATIONS GIVEN DURING THE GRANT PERIOD.

Analysis Support Package for AE and DE Data, A. G. Burns and T. L. Killeen, Community-Wide Workshop on NASA's Space Physics Data System, Rice University, Houston, TX, June, 1993.

A one-dimensional hybrid satellite track model for the Dynamics Explorer-2 (DE-2) satellite, W. Deng, T. L. Killeen, A. G. Burns, R. M. Johnson, B. A. Emery, R. G. Roble, J. Gary, J. D. Winningham and J. A. Slavin, AGU Baltimore, May 1993.

The solar-cycle-dependent response of the neutral thermosphere to geomagnetic storms, A. G. Burns, T. L. Killeen and R. G. Roble, AGU San Francisco, December 1994.

Dynamics Explorer 2 Fabry-Perot Interferometer observations of $O(^1D)$ red line emissions associated with polar cap ionospheric patches, T. W. Garner, T. L. Killeen, A. G. Burns and W. R. Coley, AGU Baltimore, June 1995.

Changes in the Compositional Structure of the Neutral Upper Thermosphere: Their Nature and Causes, A. G. Burns and T. L. Killeen, invited talk, IUGG XXI General Assembly, July, 1995.

Energy Term Analysis in the Lower Thermosphere, T. L. Killeen, A. G. Burns and R. G. Roble, IUGG XXI General Assembly, July, 1995.

The production and loss of odd nitrogen and the effects of NO cooling on the thermosphere, T. L. Killeen, A. G. Burns and R. G. Roble, AGU San Francisco, December 1995.

A thermosphere/ionosphere nested grid model, W. Wang, T. L. Killeen, A. G. Burns and R. G. Roble, AGU San Francisco, December 1995.

Simultaneous remote and local observations of variations in thermospheric composition with the DE-1 and DE-2 spacecraft, J. D. Craven, T. J. Immel, L. A. Frank, T. L. Killeen and A. G. Burns, AGU San Francisco, December 1995.

O+ variations in the upper thermosphere, A. G. Burns, T. L. Killeen and R. G. Roble, AGU San Francisco, December 1995.