View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by NASA Technical Reports Server

NASA CR 194689

32 CIT.

195938

16 P

THE UNIVERSITY OF MICHIGAN, DEPARTMENT OF ATMOSPHERIC, OCEANIC AND SPACE SCIENCE,

Space Physics Research Laboratory,
2455 Hayward St.,
Ann Arbor, Michigan 48109-2143.

Contract/Grant No.:	NAG5 - 465
Project Name:	Dynamics Explorer-2 - continued FPI and NACS instrument data analysis and associated scientific activity at the University of Michigan.
Report Author(s):	Alan Burns.
Author(s) Phone:	(313)-763-6246.
Preparation Date:	December 7, 1993.
Report Type:	Final Report.
Period Covered:	December 1990 - Jan. 31, 1994.
Project Director:	T. L. Killeen.
Principal Investigator(s):	T. L. Killeen.
Program Technical Officer/Address:	Mr. G. D. Bullock, NASA - GSFC Org. 602, Greenbelt, MD 20771.

(NASA-CR-194689) DYNAMICS EXPLORER 2: CONTINUED FPI AND NACS INSTRUMENT DATA ANALYSIS AND ASSOCIATED SCIENTIFIC ACTIVITY AT THE UNIVERSITY OF MICHIGAN Final Report, Dec. 1990 - 31 Jan. 1994 (Michigan Univ.) 16 p

N94-20173

Unclas

G3/18 0195938

FINAL REPORT ON GRANT NAG5-465

1. PREAMBLE.

The grant entitled "Dynamics Explorer-2 - continued FPI and NACS instrument data analysis and associated scientific activity at the University of Michigan" is a continuation of a grant that began with instrument development for the Dynamics Explorer 2 (DE 2) satellite. Over the years, many publications and presentations at scientific meetings have occurred under the aegis of this grant. This present report details the progress that has been made in the final three years of the grant. In these last 4 years of the grant 26 papers have been published or are in press (Appendix 1) and about 10 more are in preparation or have been submitted. A large number of presentations have been made in the same time span: 36 are listed in Appendix 2. Evidence of the high educational utility of this research is indicated by the list of Ph. D. and M. S. theses that have been completed in the last 3 years that have involved work connected with NAG5-465.

The structure of this report is as follows: a brief synopsis of the aims of the grant NAG5-465 is given in the next section; then there is a summary of the scientific accomplishments that have occurred over the grant period; last, we make some brief concluding remarks. Reprints of articles that have recently appeared in refereed journals are appended to the end of this document.

1. INTRODUCTION: TASKS PROPOSED FOR NAG5-465.

In 1988, a proposal was accepted to perform a number of tasks associated with the FPI and NACS instruments that flew on board the DE 2 satellite. As well as the scientific tasks that will be discussed shortly, several tasks associated with routine data processing were proposed. They are outlined here in tabular form:

TABLE 1. ROUTINE DATA PROCESSING TASKS PROPOSED

Proposed Task	Status
The re-analysis of image files on the local VAX, and the submission of these files to NSSDC.	Completed.

Updating the FPIDISP program for use on the VAX. This program was to be updated to allow the processed FPI geophysical data to be ingested into the VAX.	Completed.
Continued updating of science analysis programs. These included the VAX database structure as the development of user friendly graphics interfaces.	Completed.
Data processing in support of data requests.	Completed

In addition to the proposed work listed above, was the requirement to co-ordinate with NSSDC to submit the data into the NSSDC database in a usable form. The FPI data were thoroughly checked and the required image and geophysical data files were submitted to this database. All FPI data can now be obtained through NSSDC

Although it was not listed in the proposal submitted in 1989, an additional major data analysis task was performed. This was the development of an equivalent database using a different database management system (DBMS) on a UNIX computer. The reason for doing this was the need to continue having a usable data system throughout the period of the grant and the gradual decline of the hardware on the aging VAX systems that were running the DBMS that existed at the time the proposal was submitted. No extra costs were associated with this development.

As well as these data analysis tasks, a number of scientific studies were proposed. The scientific results will be listed in detail in the next section, but a brief list of tasks is included in this section.

TABLE 2. SCIENCE TASKS PROPOSED

Proposed Task	Status
Semi-empirical modeling of dynamics, temperatures and composition from DE-2 and NCAR-TGCM measurements and calculations.	A comprehensive semi-empirical model (the time dependent VSH model) has been developed and made available to the scientific community. A paper is being prepared that describes the new model, two more have been published that describe aspects of this work. In addition, Drs. J. P. Thayer and R. G. Raskin have completed Ph. D. theses that involve work with this model.

Ion-neutral coupling. This proposed work involved a number of different studies of various aspects of this problem excluding those involving Joule heating.	A number of papers have been published describing this work.
Ion-neutral frictional heat exchange. This proposed work involved studying Joule heating.	Two papers have been published or are in press that describe this work.
Investigation of the properties of the neutral atmosphere near auroral arc crossings-local effects.	One paper has been published and one is ready to be submitted on this subject.
Global mapping of winds and "conjugate" effects.	Three papers have been published that describe aspects of this work. In addition, it formed a significant proportion of Dr. J. P. Thayer's Ph. D. work.
Lower thermosphere wind systems.	A paper was published on this work in 1992. It formed a major part of Dr. B. Nardi's Ph. D. work.
Non-thermal daytime green line.	Aspects of this work formed part of Dr. B. Nardi's Ph. D. thesis.
Overflights of sounding rockets, radar and ground-based Fabry-Perot sites.	A paper is in press concerning overflights.
Comparison of forcing terms and thermospheric parameters from DE measurements with the predictions of the TGCMs	Mr. S. Lehr completed a M. S. thesis on this topic. It also formed part of Dr. W. Deng's Ph. D. thesis. A number of papers have been published on this topic in the last 4 years.
Further quantification of IMF, geomagnetic activity effects. Comparison of auroral images with DE 2 measurements.	Aspects of this work has been published in several papers.

Airglow studies - direct observations of waves in airglow.	This study formed part of Dr. B. Nardi's Ph. D. thesis and was the basis of Mr. P Purcell's M. S. thesis. Work been published on it in a paper published in 1992.
Thermospheric temperature measurements - comparisons of optical and mass spectrometric measurements.	A study was conducted involving these comparisons. Working in collaboration with Dr. Hedin, an error was found in the FPI analysis program. This error was corrected and the re-analyzed geophysical data files were those submitted to NSSDC.
Ion upwelling caused by thermospheric Joule heating events.	This work formed a major part of Dr. R. Cannata's Ph. D. thesis.
Collaborative investigations.	It can be seen from the accompanying reference list that a large number of collaborative investigations were undertaken.

3. SCIENTIFIC ACCOMPLISHMENTS.

In this project we have addressed all of the general scientific aims of the project that were mentioned above, as indicated in Table 2. The total amount of material covered is thus huge, as indicated in the list of papers published that is given in Appendix 1. Because of this large volume of work it is not feasible to discuss it all here, so instead only a small subset of the work is mentioned. Thus, the following results describe a few of our main achievements during the three year grant period.

IMF-Neutral Wind Morphology Study.

The development of a spectral representation capability for the output of the TGCM (VSH model) has enabled us to perform additional calculations that are not readily available from the TGCM itself. One such capability is the opportunity to derive the non-divergent

and irrotational parts of the neutral easily. The VSH model also permits the ingestion of DE data to perform the same analysis for the data itself. Thayer (1990), Thayer and Killeen (1991) and Thayer and Killeen (1993) performed such an analysis.

The advantage of separating the neutral flow into its non-divergent and irrotational components is that it is much easier to separate the influence of momentum transfer that results from the Lorentz force from the influence of the pressure gradient force due to solar heating and Joule heating. The above-mentioned work investigated these influences and found that, surprisingly, irrotational flow due to pressure gradient forces increases more with increased geomagnetic activity than the non-divergent flow due to ion-neutral does.

Lower Thermospheric Winds.

Until recently, no studies of the green line winds from the Fabry-Perot Interferometer had been made. The problem was the difficulty in developing the inversions needed to produce realistic neutral winds. However, because these data represent the first global data set of winds in the region between 100 and 150 km a large effort was made to calculate the correct inversions. These inversions were described by Nardi (1990)

In 1992, Killeen et al. published the first green line wind results made using the DE 2 data and these new inversion techniques. They found that the satellite results were in reasonable agreement with the winds predicted by both the UCL and the NCAR-TGCMs, although significant regional discrepancies did exist. The wind speeds were similar in both models and in the data, with maximum equatorward speeds of around 300 m/s being found in the early morning sector.

Geomagnetic Storm Effects.

One challenging area in thermospheric physics at the present time is the study of the effects of geomagnetic storms on the neutral atmosphere. The DE 2 data present a fine opportunity to study various aspects of this problem. Therefore, over the last 4 years we have published a number of papers describing various aspects of the effects of geomagnetic storms.

Burns et al. (1991) published a paper on the causes of the enhancements of the density of the molecular species that is seen in the high latitude upper thermosphere. They and Fuller-Rowell et al. (1991) laid to rest the problem of the lack of agreement between the results of TGCMs and the data, finding good agreement with the model patterns and data-derived patterns such as those of Prölss (1981). In addition, Burns et al. (1991) also found

that the nitrogen rich air seen at altitudes around 350 km was advected rapidly upwards (in 3-4 hours) from altitudes as low as 150 km. At 350 km the strong antisunward neutral winds, that are driven by the ion convection pattern, advect this nitrogen-rich air into the early morning sector, causing the region of enhancement of the molecular species to extend to much lower latitudes in this region.

A purely data study was performed by Burns and Killeen (1992). They averaged DE 2 data to study the changes in the low latitude thermosphere that occur as a function of geomagnetic storm time. Some 3 to 6 hours after the start of the storm a wave has propagated from the high latitudes of both hemispheres to the equator. Other, longer term changes occur after about 12 hours. At this time there are major increases in density and temperature in the morning sector, but only relatively minor increases in temperature in the evening sector.

Another feature of geomagnetic storms is the potential tendency for the ion winds to decelerate immediately at the end of magnetospheric forcing, but for the neutral winds to remain "spun-up", potentially driving a neutral-wind dynamo - the fly-wheel effect. Deng et al. (1992, 1993) published papers on this effect, finding that there was evidence that it existed at least locally in the DE 2 data, and that these flywheel effects could be expected to exist some 3 to 6 hours after the end of magnetospheric forcing.

4. Concluding Remarks.

In the last four year period of NAG5-465 we achieved most of the scientific goals that we described in our original proposal. During this time, 26 papers have been published which are connected with this grant. Reprints of two of these articles are included with this report in Appendix IV. In addition, 36 presentations have been made at scientific meetings. Lastly, six Ph. D. and four M. S. degrees, that involved work done under this grant, have been finished in the last four years.

5. REFERENCES

Burns, A. G., T. L. Killeen, and R. G. Roble, A Theoretical Study of Thermosphere Composition Perturbations During an Impulsive Geomagnetic Storm, J. Geophys. Res., 96, No. A8, 14,153-14,167, 1991.

Burns, A. G. and T. L. Killeen, The Equatorial Neutral Thermospheric Response to Geomagnetic Forcing, Geophys., Res. Lett., 19, No. 10, 977, 1992.

Deng, W., T. L. Killeen, A. G. Burns and R. G. Roble, The Flywheel Effect: Ionospheric Currents After a Geomagnetic Storm, Geophys. Res. Lett., 18, 1845-1848, 1991.

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 a Geomagnetic Storm, J. Geophys. Res., 98, A7, 11,549, 1993.

Fuller-Rowell, T. J., D. Rees, H. Rishbeth, A. G. Burns, T. L. Killeen, and R. G. Roble, Modelling of Composition Changes During F-region Storms: A Reassessment, J. Atmos. & Terr. Physics, 53, 541-550, 1991.

Killeen, T. L., B. Nardi, P. N. Purcell, R. G. Roble, T. J. Fuller-Rowell, and D. Rees, Neutral Winds in the Lower Thermosphere from Dynamics Explorer 2, Geophys., Res. Lett., 11, 1093, 1992.

Nardi, B., An inversion technique to recover lower thermospheric winds from space-borne remote measurements of [OI] 5577 Å, Ph. D. thesis, University of Michigan, August 1991.

Prölss, G. W., Latitudinal structure and extension of the polar atmospheric disturbance, J. Geophys. Res., 86, 2385-2396, 1981.

Thayer, J. P., Neutral wind vortices in the high-latitude thermosphere, Ph. D. thesis, University of Michigan, May 1990.

Thayer, J. P. and T. L. Killeen, Vorticity and Divergence in the High-Latitude Upper Thermosphere, Geophys. Res. Lett., 18, 701-704, 1991.

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.

APPENDIX 1.

PUBLICATIONS DURING THE GRANT PERIOD.

1. Burns, A. G., T. L. Killeen, G. Crowley, B. A. Emery, R. G. Roble, On the mechanisms responsible for high-latitude thermospheric composition variations during the recovery phase of a geomagnetic storm, J. Geophys. Res., 94, No. A12, 16,961-16,968, 1989.
2. Marcos, F. A., T. L. Killeen, A. G. Burns and R. G. Roble, Evaluation of new atmospheric drag modelling techniques, Astrodynamics 1989, Vol. 71, Adv. Astronaut. Sci., 763-782, eds. C. L. Thornton, R. L. Proulx, and F. R. Hoots, 1990.
3. McCormac, F. G., T. L. Killeen and J. P. Thayer, The Influence of IMF By on the High-latitude Thermospheric Circulation During Northward IMF, J. Geophys. Res., Vol. 96, No. A1, 115-128, 1991.
4. Fuller-Rowell, T. J., D. Rees, H. Rishbeth, A. G. Burns, T. L. Killeen and R. G. Roble, Modelling of Composition Changes During F-region, Storms: A Reassessment, J. Atom. Terr. Phys., 53, No. 6/7, 541-550, 1991.
5. Prölss, G. W., L. H. Brace, H. G. Mayr, G. R. Carignan, T. L. Killeen, and J. A. Klobuchar, Ionospheric Storm Effects at Subauroral Latitudes: A Case Study, J. Geophys. Res., 96, No. A2, 1275-1288, 1991.
6. Killeen, T. L., F. G. McCormac, A. G. Burns, and R. G. Roble, Thermospheric dynamics, energetics and composition at auroral latitudes, Chapter II-5 in *Auroral Physics,* pp. 67-81, Cambridge University Press, 1991.
7. Siscoe, G. L. and T. L. Killeen, Upper Atmosphere, in "*Physics News in 1990*", Amer. Inst. Phys., pp. 47-48, 1991.
8. Hedin, A. E., M. A. Biondi, R. G. Burnside, G. Hernandez, R. M. Johnson, T. L. Killeen, C. Mazaudier, J. W. Meriwether, J. E. Salah, R. J. Sica, R. W. Smith, N. W. Spencer, V. B. Wickwar and T. S. Virdi, Revised Global Model of Thermosphere Winds Using Satellite and Ground-Based Observations, J. Geophys. Res. , 96, No. A5, 7657-7688, 1991.
9. Killeen, T. L., F. G. McCormac, A. G. Burns, J. P. Thayer, R. M. Johnson and R. J. Niciejewski, On the Dynamics and Composition of the High-Latitude Thermosphere, J. Atmos. Terr. Phys., 53, No. 9, 797-815, 1991.
10. Thayer, J. P. and T. L. Killeen, Vorticity and Divergence in the High-Latitude Upper Thermosphere, Geophys. Res. Lett., 18, 701-704, 1991.
11. Fuller-Rowell, T. J., D. Rees, H. Rishbeth, A. G. Burns, T. L. Killeen, and R. G. Roble, Modelling of Composition Changes During F-region Storms: A Reassessment, J. Atmos. & Terr. Physics, 53, 541-550, 1991.

12. Burns, A. G., T. L. Killeen, and R. G. Roble, A Theoretical Study of Thermosphere Composition Perturbations During an Impulsive Geomagnetic Storm, J. Geophys. Res., 96, No. A8, 14,153-14,167, 1991.

13. Deng, W, T. L. Killeen, A. G. Burns, and R. G. Roble, The Flywheel Effect: Ionospheric Current After a Geomagnetic Storm, Geophys., Res. Lett., 18, No. 10, 1845-1848, 1991.

14. McCormac, F. G., T. L. Killeen, A. G. Burns, F. A. Marcos, and R. G. Roble, The effect of solar cycle variations on the Thermosphere, Adv. Astronaut. Sci., 76, 2507, 1992.

15. Burns, A. G. and T. L. Killeen, Changes of Neutral Composition in the Thermosphere, Adv. Astronaut. Sci., 76, 2295, 1992.

16. Eastes, R. W., T. L. Killeen, Q. Wu, J. D. Winningham, W. R. Hoegy, L. E. Wharton, and G. R. Carignan, An Experimental Investigation of Thermospheric Structure Near an Auroral Arc, J. Geophys. Res., 97, A7, 10,539, 1992.

17. Marcos, F. A., R. G. Roble and T. L. Killeen, Thermosphere and Ionosphere Dynamics During 20-30 March 1979 Time Period: Comparison of TIGCM Calculated Densities with Observations, Adv. Space Res., 12, No. 6, (6)93-(6)96, 1992.

18. Burns, A. G. and T. L. Killeen, The Equatorial Neutral Thermospheric Response to Geomagnetic Forcing, Geophys., Res. Lett., 19, No. 10, 977, 1992.

19. Burns, A. G., T. L. Killeen, and R. Roble, Thermospheric Composition Changes Seen During a Geomagnetic Storms, Adv. Space Res., 12, No. 10, (10)253, 1992.

20. Carr, S. and T. L. Killeen, Remote-Sensing Observations of F-region Ion-drift Velocities Using Dynamics Explorer-2 Doppler Measurements of the $[O^+]$ (^2P) λ732.0 nm Emission, Geophys., Res. Lett., 19, No. 14, 1455, 1992.

21. Killeen, T. L., B. Nardi, P. N. Purcell, R. G. Roble, T. J. Fuller-Rowell, and D. Rees, Neutral Winds in the Lower Thermosphere from Dynamics Explorer 2, Geophys., Res. Lett., 11, 1093, 1992.

22. Burns, A. G., T. L. Killeen and R. G. Roble, Thermospheric Heating Away From the Auroral Oval During Geomagnetic Storms, Can. J. Phys., 70, 554, 1992.

23. Deng, W., T. L. Killeen, A. G. Burns, R. G. Roble, J. Slavin, L. E. Wharton and R. Heelis, The effects of Neutral Inertia on Ionospheric Currents in the High Latitude Thermosphere Following Geomagnetic Storm, J. Geophys., Res., 98, A5, 7775, 1992.

24. 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.

25. Killeen, T. L., A. G. Burns, R. M. Johnson and F. A. Marcos, Modelling and Prediction of Density Changes and Winds Affecting Satellite Trajectories, *AGU Monograph on the "Environmental Effects on Spacecraft Trajectories and*

Positioning", Proceedings of the IUGG Union Symposium No. 15, Vienna, 1991, in press, 1993.

26. Killeen, T. L., A. G. Burns, and R. M. Johnson, Thermospheric/Ionospheric Variability and Satellite Orbit Perturbations, Proceedings of the STEP Workshop, Ottawa, CAN, in press, 1993.

APPENDIX 2.

PRESENTATIONS GIVEN DURING THE GRANT PERIOD.

1. "Composition changes at middle latitudes during a geomagnetic storm", A. G. Burns, T. L. Killeen and R. G. Roble, Spring AGU, Baltimore, 1990.

2. "Scientific Rationale and Strawman Program for Future NASA Missions in Ionosphere-Thermosphere-Mesosphere Physics", T. L. Killeen, American Geophysical Union, Spring Meeting, Baltimore, May, 1990.

3. "Simulation of causes of composition changes during a geomagnetic storm", A. G. Burns, T. L. Killeen and R. G. Roble, COSPAR, The Hague, Netherlands, July 1990.

4. "VSH representation of TIGCM results utilizing objective analysis of thermospheric neutral density measurements", R. M. Johnson, R. Raskin, T. L. Killeen, A. G. Burns and R. G. Roble, COSPAR, The Hague, Netherlands, July 1990.

5. "Ionosphere-Thermosphere Coupling as Observed from Dynamics Explorer-2 and from Ground-Based Measurements", T. L. Killeen, Invited paper, XXVIII COSPAR Plenary Meeting, The Hague, The Netherlands, June-July, 1990.

6. "Thermospheric Modelling Based on Satellite and Ground-Based Observations and Numerical Simulations", T. L. Killeen, XXVIII COSPAR Plenary Meeting, The Hague, The Netherlands, June-July, 1990.

7. "Thermospheric heating during geomagnetic storms", A. G. Burns, T. L. Killeen and R. G. Roble, Fall AGU, San Francisco, December 1990.

8. "A semi-empirical model of the neutral thermosphere", R. Raskin, T. L. Killeen, R. M. Johnson and A. G. Burns, Fall AGU, San Francisco, December 1990.

9. "Contribution of the Thermospheric Neutral Wind to the Magnetospheric Poynting Flux", J. P. Thayer, J. F. Vickrey, T. L. Killeen, R. A. Heelis, and J. Slavin, American Geophysical Union, Fall Meeting, San Francisco, December, 1990.

10. "Post-storm recovery: a case study", A. G. Burns, T. L. Killeen and R. G. Roble, Spring AGU, Baltimore, 1991.

11. "The effects of inertia on ionospheric currents in the high latitude neutral thermosphere", W. Deng, T. L. Killeen, A. G. Burns, F. G. McCormac and R. G. Roble, Spring AGU, Baltimore, 1991.

12. "Neutral density structures in the high latitude thermosphere", J. Schoendorf, G. Crowley, R. G. Roble, A. G. Burns and T. L. Killeen, Spring AGU, Baltimore, 1991.

13. "Dynamics Explorer-2 Observations of the Equatorial Thermosphere", Q. Wu and T. L. Killeen, American Geophysical Union, Spring Meeting, Baltimore, 1991.

14. "Dynamics Explorer-2 Observations of 7320Å $O^+(^2P)$ Emissions", S. Carr and T. L. Killeen, American Geophysical Union, Spring Meeting, Baltimore, 1991.

15. "A Technique to Recover Lower Thermospheric Winds from Space-Borne Remote Measurements of OI (5577Å)", B. Nardi, T. L. Killeen and V. J. Abreu, American Geophysical Union, Spring Meeting, Baltimore, 1991.

16. "Thermospheric heating during geomagnetic storms", A. G. Burns, T. L. Killeen and R. G. Roble, IAGA, IUGG, Vienna, Austria, August 1991.

17. "Contribution of the thermospheric neutral wind to high-latitude electrodynamics", J. P. Thayer, J. F. Vickery, T. L. Killeen, W. Deng, A. G. Burns and R. A. Heelis, IAGA, IUGG, Vienna, Austria, August 1991.

18. "The Michigan vector spherical harmonic model: progress in development of a hybrid empirical and theoretical model of the thermosphere", R. M. Johnson, T. L. Killeen, R. Raskin, A. G. Burns, R. G. Roble and F. A. Marcos, IAGA, IUGG, Vienna, Austria, August 1991.

19. "The Michigan Vector Spherical Harmonic model: progress in development of a hybrid empirical and theoretical model of the thermosphere", R. M. Johnson, T. L. Killeen, R. Raskin, A. G. Burns, R. G. Roble and F. A. Marcos, IAGA, IUGG, Vienna, Austria, August 1991.

20. "Modelling and Prediction of Density Changes and Winds Affecting Spacecraft Trajectories", T. L. Killeen and F. A. Marcos, Invited Paper, IUGG General Assembly, Vienna, 1991.

21. "Thermosphere-Ionosphere-Magnetosphere Coupling at High Latitudes: Ground-Based and Satellite Observations and Theoretical Interpretations", T. L. Killeen, American Geophysical Union Fall Meeting, San Francisco, 1991.

22. "Positive storm effects and the diurnal tide", A. G. Burns, T. L. Killeen and R. G. Roble, Fall AGU, San Francisco, December 1991.

23. "Simultaneous Observations of Cusp Optical Emissions, Neutral Wind, and Particle Precipitation Rates by Dynamics Explorer-2", Q. Wu T. L. Killeen and J. D. Winningham, American Geophysical Union Fall Meeting, San Francisco, 1991.

24. "Modifications to the Temperature and Composition Pattern Associated with the Winter Mid-latitude Diurnal Tide during Geomagnetic Storms", A. G. Burns, T. L. Killeen and R. G. Roble, Spring AGU, Montreal, 1992.

25. "Poynting flux in the polar thermosphere as derived from the Dynamics Explorer 2 satellite", W. Deng, T. L. Killeen, A. G. Burns and J. Slavin, Spring AGU, Montreal, 1992.

26. "Statistical studies of thermosphere-ionosphere coupling in the vicinity of auroral arcs", Q. Wu and T. L. Killeen, American Geophysical Union Spring Meeting, Montreal, CAN., May 1992.

27. "Doppler Imaging of High-Latitude Ionospheric Convection from Space: Results of a Simulation and Flight Demonstration Study", T. L. Killeen and S. S. Carr, American Geophysical Union, Spring Meeting, Montreal CAN., May 1992.

28. "Thermospheric/Ionospheric Variability and Satellite Orbit Perturbations: Development of the VSH Operational Model", T. L. Killeen, A. G. Burns, and R. M. Johnson, Solar Terrestrial predictions workshop, Ottawa, May 1992.

29. "Upper Atmospheric Physics", NASA Space Physics Workshop for High School Science Teachers, University of Iowa, July 1992.

29. "Daytime middle-latitude storm effects in the winter ionosphere and changes in the neutral thermosphere", XXIX COSPAR Plenary meeting, Washington, D. C., A. G. Burns, T. L. Killeen and R. G. Roble.

30. "Spectral energetics of the lower thermosphere using the NCAR-TIGCM", R. Raskin, T. L. Killeen, A. G. Burns, R. M. Johnson, AGU Chapman Conference, Asilomar, CA, November, 1992.

31. "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.

32. Analysis Support Package for AE and DE Data (with A. G. Burns), Community-Wide Workshop on NASA's Space Physics Data System, Rice University, Houston, TX, June, 1993.

APPENDIX III.

PH. D. AND MASTERS DEGREES GRANTED IN THE LAST 4 YEARS OF THE GRANT PERIOD.

Ph. D.

Dr. J. P. Thayer	1990
Dr. R. J. Cannata	1990
Dr. B. Nardi	1991
Dr. R. Raskin	1992
Dr. S. Carr	1992
Dr. W. Deng	1993

M. S.

Y. -M. Cheng	1990
S. Lehr	1990
J. Davis	1991
P. N. Purcell	1992

APPENDIX IV

TWO SELECTED REPRINTS FROM THE LAST 4 YEARS.