Final Report

on UAH Contract NAS8-37106

With the Marshall Space Flight Center

"The Imaging Spectrometric Observatory for the ATLAS 1 Mission"

Written by:

Dr. Douglas G. Torr
Principal Investigator
Physics Department and the Center for Space Plasma and Aeronomic Research
Optical Aeronomy Laboratory
Optics Building, Room 300
The University of Alabama in Huntsville
Huntsville, Alabama 35899
205-895-6118

May 8, 1995

1. Historical Summary

The Imaging Spectrometric Observatory (ISO) was started at the University of Michigan in 1976. This array of advanced imaging systems represented a substantial advance in technology above that available at that time and still represents state of the art technology in Aeronomy. The Program was transferred to Utah State University (USU) in 1980 and flown on the Spacelab 1 mission in 1983. In 1985, the Principal Investigator, Dr. Marsha Torr, and Co-Investigator, Dr. Douglas Torr, moved to Huntsville locating respectively at the Marshall Space Flight Center (MSFC) and the University of Huntsville in Alabama (UAH). Associated with the relocation was the transfer of the equipment that currently constitutes the bulk of the inventory currently carried under this contract. The ISO was delivered directly from USU to Cape Kennedy for integration on the Earth Observations Mission 1 (EOM 1), which was subsequently delayed by the Challenger accident in 1986. The ISO was then relocated at McDonald Observatory in Texas for 18 months. During that time the ISO gathered data which was used to design the first facility class spectrometer for the National Science Foundation's national aeronomy initiative CEDAR (Coupled Energetics and Dynamics of the Atmospheric Regions). The ISO data was also used to pioneer the first methods for retrieving the composition and temperature of the thermosphere from ground-based measurements of airglow. During this time the EOM mission was reconstituted as the ATLAS mission, and the investigation was selected for reflight (through three separate selections). In 1988 the ISO was delivered to MSFC for refurbishment to fly on the ATLAS 1 mission, which evolved from the EOM series. UAH was responsible for the refurbishment tasks listed below as well as mission operations and data analysis. These tasks are taken directly from the scope of work given in the ISO contract.

In 1989 Dr. Marsha Torr stepped down as Principal Investigator because her duties as Mission Scientist, Division Chief and other commitments did not allow her the time needed to meet her PI responsibilities on the ISO investigation. Responsibilities for this role were assigned by the Mission Manager, Program Manager and Project Scientist to Dr. Doug Torr.

The ATLAS 1 Mission was flown between March 26 and April 2, 1992. The flight was enormously successful, providing a baseline database on the coupled stratospheric, mesospheric thermospheric and ionospheric regions.

Apart from participation in the data analysis, the primary post-flight responsibility of MSFC, was the delivery of the final post mission dataset which would include a major portion (provided by the Goddard Space Flight Center (GSFC)) that could not be acquired real-time at the POCC. It was arranged that Space Science Lab (SSL) personnel would be responsible for the integration of the

final dataset into a database that was designed by UAH personnel. This database system would provide various functions such as random access based on a large variety of fields, *e.g.* date, universal or local time, height, latitude, longitude, spectrometer parameters *etc.* During 1992 the Marshall and UAH personnel worked on this system collaboratively, with UAH providing the scientific input for the design. Because of delays in the delivery of the Goddard data followed by various technical difficulties that had to be dealt with by both teams, proper configuration of the data in the database took much longer than originally anticipated.

In 1993, cooperation with UAH was phased out by Marshall management, and SSL personnel had to continue the database work without user input or science guidance. As a result, the completion of entry of the data into the database was seriously delayed since problems could only be discovered by user interaction with the data. At one time, all communication of Marshall personnel with UAH personnel was prohibited by SSL management. The delays were negotiated with the ATLAS 1 Project who allowed the contract to be extended without cost from June 30, 1993 to June 30 1994. When it became evident in late 1993 that the data would not be delivered to UAH in time to perform the proper reduction and analysis prior to the expiration of the extended contract, a second no-cost extension was requested. A proposal was written detailing the tasks that would be performed under the second no-cost one year extension, assuming delivery of the data by SSL in the Spring of 1994. In early 1994, the management of the program was transferred from the ATLAS Project Office to SSL. In light of the cessation of all cooperative activities between SSL and UAH on this project, it was anticipated that termination of the project would result, since no response was received at UAH to the proposal for the no-cost extension. Indeed, in due course, Marshall began requesting a final report and return of the ISO equipment by June 30, 1994. The final data was delivered to UAH in July, 1994, after the contract had formally expired. In the mean time the ISO Science Team continued to analyze the data acquired real-time at the POCC and publish good papers in the literature - despite the formidable efforts to stop the project. However, the planned post flight calibration had not yet been permitted.

The above mentioned proposal had also indicated the critical need to calibrate the ISO, and various options were proposed to accomplish this. The proposal also indicated that without the final dataset, UAH was restricted to working on the limited dataset mentioned above that was acquired real-time at the POCC during AOS periods. In addition these data did not have useful pointing information. In collaboration with other ATLAS 1 investigations, UAH undertook the task of determining the causes of the inferior pointing information ($\pm$ 15 km, compared with the needed accuracy of $\leq$ 2 km). Ultimately, the problem was solved after several errors in the pointing data handling procedures were identified.

However, anxious to publish the unique data in a timely manner, and in order not to default on contractual obligations to analyze the data, and in fear of having funds rescinded, UAH continued a program of intensive data analysis using the incomplete real-time data. This also involved developing work-arounds for the lack of a post flight calibration, particularly for the far ultraviolet (FUV) spectrometer (# 4), for which an error had occurred in noting the calibration source brightness settings in the pre-flight calibration process. It was always the intention to use the post flight calibration to correct this problem, since the need to meet the delivery schedule precluded a re-calibration before delivery. Efforts to conduct the re-calibration of the ISO under the existing funding authorized failed. Spectrometer 3 data was therefore used to calibrate Spectrometer 4 by tracing the calibration approximately from the near UV to far UV via theoretical ratios of various spectral features. This was unfortunate, because the FUV data acquired on Module 4 was the best obtained on the mission. It was also important data, because it was to be used in assessing the UVI data analysis software routines, and in addition it provides an excellent means of retrieving the concentrations of thermospheric neutral densities. UAH also received continual requests for this data. Further details on how these various problems were addressed are given in the sections that follow.

In summary the ISO investigation potentially could have been one of the highlights of NASA's shuttle missions, because much of the mesosphere and lower thermosphere were comprehensively explored for the first time. This was potentially a history making mission. However, it proved impossible to realize these goals under the constraints which UAH was placed. Nevertheless, a relatively good job was done with what was available.

2. Summary of Tasks Completed.

a.) Scientific planning and implementation.

b.) Modification of the ISO to change from a Spacelab module configuration to that required for a pallet/igloo mission.

c.) Completed the development, fabrication, assembly, test, calibration, and delivery of the ISO for the ATLAS 1 mission.

d.) Developed a significant amount of the software for control and operation of the ISO

e.) Refurbished the ISO

f.) Supported payload integration, training, pre-launch and post flight activities and mission operations

g.) Performed data reduction and analysis, reported findings at meetings and published the results

h.) Represented the investigation at Investigator Working Group Meetings

3. Further Elaboration on Important Aspects of the Investigation

3.1 The Scientific Goals of the Mission

The main goals of the ATLAS 1 mission were to obtain the first comprehensive database of the upper atmosphere regions from the lower stratosphere to the thermosphere, and to utilize these data in a coordinated manner to:

a.) Provide a reference dataset for the future to detect long term changes in the environment. The philosophy behind this goal was based on the capability of the shuttle to return facility class instrumentation so that laboratory calibration of the instruments could be done both before and after flights, thereby removing the uncertainties of instrumental changes on the results. The ATLAS Mission was intended to provide a means of placing data acquired on other long term missions such as UARS and EOS on an absolute basis.

b.) Study the effects of changes in the energy input to the atmosphere on the physical properties of the atmosphere.

3.2 The Following Scientific Objectives Were Established for the ISO Investigation

a.) Measure the concentration of the hydroxyl radical in the mesosphere.

b.) Conduct studies of the global ionosphere in collaboration with the worldwide network of incoherent radar, ionospheric and airglow stations. Develop a global ionospheric model and compare observations with theory.

c.) Demonstrate that height profiles of thermospheric neutral densities, temperature, and the solar EUV flux can be determined from airglow measurements.

d.) Measure the vibrational distributions of mesospheric metastable oxygen emissions and develop techniques for separating the bands of these systems - specifically separate the Herzberg I and II emissions. Use these data to study the sources of the atomic oxygen green line in the mesosphere.

e.) Establish if the mesospheric emissions can be used to retrieve atomic oxygen in the mesosphere.

f.) Make measurements of the mesospheric hydroxyl emissions in the Meinel bands. Use these to measure mesospheric temperature and to study the spectroscopy of the system.

g.) Search for the theoretically predicted Herzberg III bands.

h.) Attempt to map the distribution of metallic species in the lower thermosphere and mesosphere.

i.) Make high resolution measurements of mesospheric and thermospheric nitric oxide and compare the results with model calculations.

j.) Generate a database of auroral emissions to validate the data processing and analysis techniques that will be used for the Ultraviolet Imager on GGS mission.

k.) Carry out studies of thermospheric Minor Species.

3.3 Resources Developed to Achieve Goals

The following activities were performed and resources developed in support of the mission science:

a.) Calibration of the instrument, and the development of calibration support software, and calibration files.

b.) Data reduction software development including
- Comprehensive spectral analysis calculator (SpeCal)
- Synthetic spectral analysis software
- Global ionospheric/airglow model for data interpretation

3.4 Accomplishments and Problems

3.4.1. Mission Accomplishments

The overall ATLAS 1 mission has been referred to as one of the most successful of NASA's missions. The most comprehensive database to date was acquired successfully on the coupled atmospheric regions: the stratosphere, mesosphere and thermosphere. The ISO acquired an unprecedented database on the lower thermosphere and mesosphere - much of the data represents first time measurements on a global scale. In a sense, the ISO explored the last remnant of the earth's atmosphere that could be regarded as virgin territory, aptly referred to as the ignorosphere by science writers. With the potential loss of the TIMED mission, the ISO database may be the only comprehensive record of the lower thermosphere and mesosphere for the foreseeable future.

3.4.2. Specific ISO Accomplishments

a.) Measurements of the Hydroxyl Radical

The greatest highlight was the measurement of the odd hydrogen species, the hydroxyl radical. This species plays a fundamental role in the catalytic destruction of ozone in both the mesosphere and stratosphere. In the stratosphere it also moderates the catalytic destruction of ozone by odd chlorine and odd nitrogen. Because the odd hydrogen chemistry dominates the mesosphere, it can be studied in isolation of the other catalytic cycles, allowing the chemistry to be readily quantified. The results can then be applied to the more complex stratosphere. Of fundamental importance is that all the major components of the odd hydrogen family were obtained on ATLAS 1, *i.e.* H, OH and HO_2. This has never been accomplished previously from orbit, and thus provides the opportunity for quantitative studies of the effect of odd hydrogen on the chemistry of the system for the first time.

To date, one paper has been published on the preliminary results (Morgan *et al.*, 1993). Unpublished global maps of the OH density have been produced, but the lower mesospheric portion have still to be corrected for self-absorption. The main problem with completing the project has been delays in getting a complete dataset from SSL. This only became available from Marshall in July, 1994 after the contract was terminated.

b.) Studies of the Global Ionosphere

The most significant accomplishment in this area was the development of a quantitative global model of the ionosphere (The Interhemispheric Field Line

Plasma model or FLIP [See M. Torr *et al.*, 1990]), which generally provides accurate predictions of the behavior of the airglow and the ionosphere. This task was a five year program, in which the code was designed to run on the MSFC Cray XMP. A predictive run was made of the state of the thermosphere prior to the ATLAS 1 mission and compared with the spectral measurements made by the ISO. The results proved to be extraordinary in that the FLIP predicted essentially all the correct emission intensities for the day studied [D. Torr *et al.*, 1993].

Major setbacks to this initial good start included the following:

1.) Measurements of the critical ionospheric O^+ ion could not be accurately retrieved from the ISO data for the following reasons: The calibration of the needed extreme ultraviolet spectrometer module could not be done at MSFC, hence it was planned to have the instrument calibrated at NIST after the mission. A partial pre-flight calibration was accomplished with the equipment at Marshall, which could have provided some interim results. However, the SEPAC electron beam instrument was fired during an early operation of the EUV module, and this seriously affected the subsequent sensitivity of the module. Hence the post flight calibration became critical, and the ATLAS Project Office cooperated fully in an effort to get the instrument calibrated in 1993, but without success. Serious effort was also made by the UAH Administration in 1994 to obtain the instrument from MSFC for a post flight calibration, however, these efforts were also unsuccessful.

2.) Modeling of the global airglow was reaching a peak phase of activity when further UAH access to the Cray computer on which the code was being run was stopped in 1993. All output files and the code were lost to UAH, and the five year effort had to be re-started on the much smaller VAX 4000 computer at the University supporting general ISO data analysis. It required over a year of effort to reconfigure the code. This greatly reduced the global modeling productivity. Modeling was just coming back up to speed in early 1995 with a major flurry of activity to compare the FLIP results with the measurements of the global network of stations when UAH was instructed to return the VAX 4000 to Marshall. Although every effort was made to complete the very time consuming and output intensive global runs, the computer had to be packaged up before this could be accomplished. Although an additional three weeks was *granted on the day* the computer was due at Marshall, all software had been removed from the machine by that time. Thus it will not be possible to publish the full global comparison of the FLIP results with the data. The impact to the international community that supported the mission was significant.

c.) Retrieval of the Concentrations of Neutral Species from the ISO Data

Preliminary studies revealed that the codes generated for this purpose appeared to work satisfactorily as assessed by comparison with the MSIS model values [Fennelly *et al.*, 1993]. Subsequent attempts to derive neutral densities to include in the FLIP model runs were stopped for the reasons given in Point b above.

d.) Studies of Mesospheric Oxygen Emissions

This task was being done by Mr. Jerry Owens of SSL. The ISO data in this spectral region are excellent and Mr. Owens published a good preliminary paper on this topic in 1993 [Owens *et al.*, 1993] He was in the process of developing the synthetic spectral code to separate the Herzberg II from the Herzberg I emissions, which would have constituted a "first" with major scientific potential for understanding the mechanisms producing these important emissions, when it was learned that he was no longer allowed to collaborate with UAH, neither could UAH have access to his data or his software. To our knowledge, nothing further came out of this important work.

e.) Retrieval of Mesospheric O from Oxygen Emissions

This topic is one of importance to the aeronomy community, because measurements of atomic oxygen are notoriously difficult to make in the mesosphere, as there is no direct optical signature from mesospheric O. Significant progress was made in developing techniques for addressing this topic. Preliminary results were reported by Leko *et al.* [1993]. However, final results will not become available because of the exhaustion of available resources and the loss of the computer.

f., g.) Studies of the OH Meinel Bands and the Search for the Herzberg III Bands

Mr. Owens was responsible for these studies at MSFC. Some preliminary work was underway during his collaboration with UAH, but nothing further has been reported to his UAH colleagues since 1993 when he was instructed to discontinue collaboration with UAH.

h.) Search for Metallic Species

The time allocated to this study was greatly reduced by the real-time decision to reallocate the observing slots to the global ionospheric study to ensure adequate coverage of stations. Nothing has been done on this study to date.

i.) Studies of Thermospheric Nitric Oxide

This study was being done by Dr. M. Torr assisted by Ms. Sopo Yung and Mr. David Billips. In 1993, Mr. Billips and Ms. Yung were instructed not to provide further assistance to Dr. M. Torr, who was subsequently denied access to the SSL computers and her own datasets. In addition, attempts by UAH personnel to obtain the data files to pick up the work were stopped, since Ms. Yung explained to Mr. Wesley Swift, a member of the UAH ISO team, that further collaboration with UAH would result in the termination of her position at Boeing. Subsequently, UAH reprocessed the data from scratch resulting in an excellent comprehensive paper on the topic in the *Journal of Geophysical Research.* A preprint is attached.

j.) Auroral Study of Molecular Nitrogen Emissions

An analysis was conducted of the far ultraviolet N_2 Lyman Birge Hopfield bands. Excellent spectra were retrieved of the LBH bands providing a clear spectral signature that can be folded with the filter response function measured for the UVI. However, the preliminary dataset from the POCC was not complete enough to conduct a more comprehensive assessment of the kinds of spectral distributions that may have to be dealt with in processing the UVI data.

One paper was written for the *Journal of Geophysical Research* [M. Torr *et al.*, 1994] which resolves a controversy as to whether the bands are produced by electron impact excitation of the parent state alone, or whether there is a contribution by cascade from higher lying states. Data were found that support both cases.

k.) Studies of Thermospheric Species

Several studies were conducted of Thermospheric Species.

1.) A study of the first negative bands of N_2^+ was carried out which indicated that the excellent data that were acquired on Spacelab 1 (which indicated high vibrational excitation with anomalously high band intensities) could be attributed to a vehicle source, since this phenomenon was not observed on the ATLAS 1 mission [M. Torr *et al.*, 1993]. The paper reports the first spectral images of height profiles of the N_2^+ emission, including the first measurements of the $\Delta v = +1$ progression at 385.4 nm. The first negative system intensities were found to be in good agreement with FLIP model results. However the band ratios could not be accounted for by any adjustment of parameters.

2.) The first dayglow profiles were obtained of the N(^{2}P) emission at 346.6 nm. The first assessment of the sources of the emission was made.

4. Some Problems Encountered

1.) One problem was encountered that requires special mention. The dayglow observations include an underlying scattered light continuum which must be removed. In some configurations of the orbiter, the effect would overwhelm the airglow signals. The removal of the continuum cannot be automated at this time, and requires special operator skills during the data reduction process. For this reason the data should not be used without consulting the UAH Principal Investigator, Dr. Douglas G. Torr. **On no account should raw data of this type be placed in the national archives, as it could lead to gross errors in the scientific interpretation of the results. With appropriate tools and skills it can be removed.**

2.) Calibration: The Extreme Ultraviolet data is essentially useless, and should not be used. The outstanding spectra recorded in the far ultraviolet should also be treated with caution until the instrument is re-calibrated, and even then, the optics may have been contaminated since flight, since no information has been provided to UAH on the current status of the instrument or how it is being stored.

5. Suggestions

1.) Even now the opportunity still exists to calibrate the instrument, since the ISO calibration facility which was being prepared for the calibration of the UVI for the GGS mission is unused, since the UVI is no longer being calibrated at Marshall. It would be to the great advantage of the scientific community if MSFC would approach NASA Headquarters for funds to perform this calibration, with the assistance of the UAH team.

2.) The ISO instrument, despite its age, is still one of, if not the most advanced aeronomical spectrometric facility in existence. It should be working for the scientific community constantly. Funding was received by UAH to use the instrument to support the NSF's national ground-based thrust in aeronomy, the CEDAR initiative. The ISO would provide invaluable data for CEDAR that cannot be acquired by any other means at this time. NASA Headquarters provided written authorization to MSFC to release the instrument to UAH for this purpose. We understand that the instrument has in fact been placed in storage and is not being used for any purpose. Because of its scientific value, it would be more fruitful to use this $10 million instrument, which was funded by tax payer's money, to serve the cause of science. Because of its great cost and, and the current budget climate, there are no longer opportunities to build instruments of this caliber. There can be

no non-scientific or scientific reason that justifies "moth balling" this facility class instrument.

3.) Finally, during the ISO project UAH loaned MSFC equipment purchased on NSF and other grants for use on the ISO investigation. This equipment has not been returned to UAH. Much of the equipment has acquired NASA tags. This equipment is not being used at MSFC and may even have been excessed by now. UAH needs this equipment to continue its support of NSF programs.

4.) In addition to the above, over the years a significant amount of equipment that was purchased under other grants and contracts at the University of Michigan and Utah State was placed on the USU ISO contract which was used as a general contract for monitoring inventory. This equipment was transferred to Marshall. All this equipment, in addition to having NASA tags, should have tags labeled "Government Property" commonly used for labeling NSF equipment. Thus, it should be identifiable.

None of this equipment is being used at Marshall, nor was it ever intended that it should become the property of MSFC. It would be put to good use at UAH or UAH would be pleased to collaborate with Marshall in proposing new programs that would put the equipment to good use.

6.) Publications

"Thermospheric Nitric Oxide from the ATLAS 1 and Spacelab 1 Missions", M. R. Torr, D.G. Torr, T. Chang, P. Richards, W. Swift and N. Li, Preprint, *J. Geophys. Res.*, In Press, January 1995.

"Sensitivity of the 6300 Å Twilight Airglow to Neutral Composition", D.J. Melendez-Alvira, D.G. Torr, P.G. Richards, W.R. Swift, M.R. Torr, T.W. Baldridge and H. Rassoul, *J. Geophys. Res.*, In Press, 1995.

"Middle and Low Latitude Emissions From Energetic Neutral Atom Precipitation Seen From ATLAS 1 Under Quiet Magnetic Conditions", B.A. Tinsley, R.P. Rohrbaugh, W.B. Hanson, M. Ishimoto, M.R. Torr and D.G. Torr, *J. Geophys. Res.*, In Press, 1995.

"Preliminary Results From the Imaging Spectrometric Observatory Flown on ATLAS 1", D.G. Torr, M.R. Torr, M.F. Morgan, T. Chang, J.K. Owens, J.A. Fennelly, P.G. Richards and T.W. Baldridge, American Geophysical Union's *Geophysical Monograph 87* (The Upper Mesosphere and Lower Thermosphere: A Review of Experiment and Theory), 305-322, 1995.

"Achievements in Atmospheric Science from Spacelab: The Mesosphere/Lower Thermosphere", D.G. Torr, *Proceedings of AIAA 32th Aerospace Sciences Meeting*, January 10-13, 1994, AIAA-94-0443, American Institute of Aeronautics and Astronautics, Nevada, January, 1994.

"Global Observations and Modeling of the Ionosphere, Thermosphere and Mesosphere", D.G. Torr, M.R. Torr, M.F. Morgan, J.K. Owens, J.A. Fennelly, P.G. Richards, T. Chang and D.J. Melendez-Alvira, *Adv. Space Res.*, *14*, (9)271-(9)276, 1994.

"Technique to Retrieve Solar EUV Flux and Neutral Thermospheric O, O_2, N_2 and Temperature from Airglow Measurements", J.A. Fennelly, G.A. Germany, D.G. Torr, P.G. Richards and M.R. Torr, *SPIE*, *2266*, 194-205, July 1994.

"The N_2 Lyman Birge Hopfield Dayglow from ATLAS-1", M.R. Torr, D.G. Torr, T. Chang, P.G. Richards and G.A. Germany, *J. Geophys. Res.*, *99*, 21397-21407, November 1994.

"Thermospheric Airglow Emissions: A Comparison of Measurements from ATLAS-1 and Theory", D.G. Torr, M.R. Torr and P.G. Richards, *Geophys. Res. Lett.*, *20*, 519-522, March 1993.

"N(^{2}P) in the Dayglow: Measurement and Theory", M.R. Torr, D.G. Torr and P.G. Richards, *Geophys. Res. Lett.*, *20*, 531-534, March 1993.

"The First Negative Bands of N_2^+ in the Dayglow from the ATLAS 1 Shuttle Mission", M.R. Torr, D.G. Torr, T. Chang, P.G. Richards, T.W. Baldridge, J.K. Owens, H. Dougani, C.W. Fellows, W.R. Swift, S.P. Yung, and K.J. Hladky *Geophys. Res. Lett.*, *20*, 523-526, March 1993.

"Preliminary Measurements of Mesospheric OH $X^2\Pi$ by ISO on ATLAS 1", M.F. Morgan, D.G. Torr and M.R. Torr, *Geophys. Res. Lett.*, *20*, 511-514, March 1993.

"Retrieval of Thermospheric Atomic Oxygen, Nitrogen and Temperature From the 732 nm Emission Measured by the ISO on ATLAS 1", J.A. Fennelly, D.G. Torr, M.R. Torr, P.G. Richards and S.P. Yung, *Geophys. Res. Lett.*, *20*, 527-530, March 1993.

"Mesospheric Nightglow Spectral Survey Taken by the ISO Spectral Imager on ATLAS 1", J.K. Owens, D.G. Torr, M.R. Torr, T. Chang, J.A. Fennelly, P.G. Richards, M.F. Morgan, T.W. Baldridge, C.W. Fellows, H. Dougani, W.R. Swift, A. Tejada, M.A. Orme, G.A. Germany and S.P. Yung, *Geophys. Res. Lett.*, *20*, 515-518, March 1993.

"Re-Evaluation of the $O^+(^2P)$ Reaction Rate Coefficients Derived From Atmosphere Explorer-C Observations", T. Chang, D.G. Torr, P.G. Richards and S.C. Solomon, *J. Geophys. Res.*, *98*, 15589-15597, September 1993.

"Photoionization and Photoabsorption Cross Sections of O, N_2, O_2 and N for Aeronomic Calculations", J.A. Fennelly and D.G. Torr, *Atomic Data and Nuclear Data Tables*, *51*, 321-363, July 1992.

"A Midlatitude Interhemispheric Model of the $O^+(^2P)$ Airglow Emission at 7320 Å", M.R. Torr, D.G. Torr and P.G. Richards, *Geophys. Res. Lett.*, *17*, 65-68, January 1990.

"Ca^+ Emission in the Sunlit Ionosphere", M.R. Torr, D.G. Torr, P.P. Bhatt, W.R. Swift, and H. Dougani, *J. Geophys. Res.*, *95*, 2379-2387, March 1990.

"A Procedure for the Extraction of Airglow Features in the Presence of Strong Background Radiation", W.R. Swift, D.G. Torr, M.R. Torr, C.M. Hamilton, H. Dougani, P.G. Richards and G.G. Sivjee, *J. Geophys. Res.*, *95*, 15227-15241, September 1990.

"Mid- and Low Latitude Model of Thermospheric Emissions: 1. $O^+(^2P)$ 7320 Å and N_2 (2P) 3371 Å", M.R. Torr, D.G. Torr, P.G. Richards and S.P. Yung, *J. Geophys. Res.*, *95*, 21147-21168, December 1990.

"Gas Phase Collisional Excitation of Infrared Emissions in the Vicinity of the Space Shuttle", M.R. Torr and D.G. Torr, *Geophys. Res. Lett.*, *15*, 95-98, January 1988.

"The Imaging Spectrometric Observatory", D. G. Torr and M. R. Torr, AIAA Earth Observing Systems EOS - A Subset of Space Station, AIAA-85-3009, October 1985.

7.) Invited Papers Presented

"Achievements in Atmospheric Science from Spacelab: The Mesosphere/Lower Thermosphere", D.G. Torr, *Proceedings of AIAA 32th Aerospace Sciences Meeting*, January 10-13, 1994, AIAA-94-0443, American Institute of Aeronautics and Astronautics, Presented at Reno, NV, January 10-13, 1994.

"The Photochemistry of the Lower Thermosphere and Mesosphere: What Has Been Achieved and What Remains to be Done", D.G. Torr, Presented as a Keynote Speaker at the 1993 Eight Summer NSF CEDAR Workshop in Boulder, Colorado, June 21-26, 1993.

"Objectives and Preliminary Results From the Imaging Spectrometric Observatory Flown on ATLAS 1", D.G. Torr, M.R. Torr, J.A. Fennelly, J.K. Owens, and P.G. Richards, Presented at the 1992 AGU Chapman Conference in Asilomar, California, November 1992.

8.) Papers Presented

"Ionospheric Global Modeling Results", P.G. Richards and D.G. Torr, Presented at the ATLAS-SUNDIAL Workshop held in McLean, Virginia, November 2-4, 1994.

"An Overview of the ATLAS 1 Mission", D.G. Torr, Presented at the ATLAS-SUNDIAL Workshop held in McLean, Virginia, November 2-4, 1994.

"Retrieval of the Neutral Atmosphere from ATLAS 1 732 and 630 nm Airglow Observations", G.A. Germany, D.G. Torr, P.G. Richards and J.A. Fennelly, Presented at the ATLAS-SUNDIAL Workshop held in McLean, Virginia, November 2-4, 1994.

"Future Directions and Action Items to Finalize Data Analysis and Modeling Activities and Bring the Results to Publication", D.G. Torr, E. Szuszczewicz and the Science Team, Presented at the ATLAS-SUNDIAL Workshop held in McLean, Virginia, November 2-4, 1994.

"Technique to Retrieve Solar EUV Flux and Neutral Thermospheric O, O_2, N_2 and Temperature from Airglow Measurements", J.A. Fennelly, G.A. Germany, D.G. Torr, P.G. Richards, and M.R. Torr, Presented at SPIE's International Symposium on Optics, Imaging and Instrumentation, July 24-29, 1994 in San Diego, California.

"Observations of the Two-Dimensional Distribution of OH in the Mesosphere", M.F. Morgan, D.G. Torr and M.R. Torr, Presented at the 1994 Ninth Summer NSF CEDAR Workshop in Boulder, Colorado, June 20-25, 1994.

"The N_2 Lyman Birge Hopfield Bands as Measured by the Imaging Spectrometric Observatory from ATLAS 1", T. Chang, M.R. Torr, D.G. Torr and P.G. Richards, Presented at the 1994 AGU Spring Meeting in Baltimore, Maryland, May 23-27, 1994, Abstract published in *EOS*, *75*, 251, April 1994.

"Thermospheric and Mesospheric Nitric Oxide Measured by the Imaging Spectrometric Observatory from ATLAS 1 and Spacelab 1", M.R. Torr, T. Chang, D.G. Torr and P.G. Richards, Presented at the 1994 AGU Spring Meeting in Baltimore, Maryland, May 23-27, 1994, Abstract published in *EOS*, *75*, 246, April 1994.

"Sensitivity of the 6300 Å Twilight Airglow to Neutral Composition", D.G.Melendez-Alvira, D.G. Torr, P.G. Richards, W.R. Swift, M.R. Torr, T.W. Baldridge and H. Rassoul, Presented at the 1993 AGU Fall Meeting in San Francisco, California, December 5-12, 1993, Abstract published in *EOS*, *74*, No. 43, Page 472, October 1993.

"Auroral Emissions from Sub-Auroral to Equatorial Latitudes from the ENAP Experiment on ATLAS 1", B.A. Tinsley, M. Ishimoto, G.J. Romick, M.R. Torr and D.G. Torr, Presented at the 1993 AGU Fall Meeting in San Francisco, California, December 5-12, 1993, Abstract published in *EOS*, *74*, No. 43, Page 472, October 1993.

"Implications of Large Variability Observed on ATLAS 1 in Mesospheric Oxygen Airglow for Atomic Oxygen", J. Leko, D.G. Torr, T. Chang, M.R. Torr, M.F. Morgan, P.G. Richards, T.W. Baldridge and H. Rassoul, Presented at the 1993 AGU Fall Meeting in San Francisco, California, December 5-12, 1993, Abstract published in *EOS*, *74*, No. 43, Page 472-473, October 1993.

"Comparison of Photoelectron Fluxes from the FLIP Model with Measured Fluxes and Airglow Emissions", G.A. Germany, P.G. Richards and D.G. Torr, Presented at the 1993 AGU Fall Meeting in San Francisco, California, December 5-12, 1993, Abstract published in *EOS*, *74*, No. 43, Page 465, October 1993.

"Model Comparisons of the Geographic Variation of Thermospheric 6300 Å Airglow Tangent Height Profile As Measured by ISO on ATLAS 1", D.J. Melendez-Alvira, D.G. Torr, M.R. Torr, P.G. Richards, K.J. Hladky and the ISO Team, Presented the ATLAS 1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Modeling of $O(^1S)$ and $O_2(A^3\Sigma)$ Emissions Observed by ISO", D.G. Torr, J. Leko, M.R. Torr, J.K. Owens, T. Chang, J.A. Fennelly, P.G. Richards and the ISO Team, Presented the ATLAS-1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Mesospheric OH Density Profiles Measured During ATLAS 1", M.F. Morgan, D.G. Torr, M.R. Torr and the ISO Team, Presented the ATLAS-1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Improvements in Tangent Height Calculations", M.F. Morgan, D.G. Torr and M.R. Torr, Presented the ATLAS-1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Analysis of the O_2 Herzberg Systems Observed by ISO: Progress in Synthetic Spectral Modeling", J.K. Owens, D.G. Torr, M.R. Torr and the ISO Team, Presented the ATLAS-1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Retrieval of the Neutral Thermosphere During the ATLAS 1 Mission from ISO Airglow Measurements", J.A. Fennelly, D.G. Torr, M.R. Torr, P.G. Richards and the ISO Team, Presented the ATLAS-1 Investigator Working Group Science Review in Huntsville, Alabama, May 11-12, 1993.

"Analysis of Mesospheric O_2 Herzberg Emissions Observed by the Imaging spectrometric Observatory on ATLAS 1 Mission", D.G. Torr, M.R. Torr, T. Chang, J. Leko and H. Rassoul, Presented at the 1993 AGU, MSA, GS Joint Spring Meeting in Baltimore, Maryland, May 24-26, 1993, Abstract published in *EOS*, *74*, No. 16, Page 219, April 1993.

"Model Analysis of Middle and Low Latitude Auroral Spectra from ATLAS 1", M. Ishimoto, B.A. Tinsley, G.R. Romick, R.P. Rohrbaugh, D.G. Torr and M.R. Torr, Presented at the 1993 AGU, MSA, GS Joint Spring Meeting in Baltimore, Maryland, May 24-26, 1993, Abstract published in *EOS*, *74*, No. 16, Page 221, April 1993.

"Results from ISO: An Overview", D.G. Torr and the ISO Team, Presented at the 1993 Eight Summer NSF CEDAR Workshop in Boulder, Colorado, June 21-26, 1993.

"Results from ISO: Retrieval of Thermospheric Composition and Temperature", J.A. Fennelly and the ISO Team, Presented at the 1993 Eight Summer NSF CEDAR Workshop in Boulder, Colorado, June 21-26, 1993.

"Results from ISO: Retrieval of Mesospheric $OH(X^2\Pi)$ Concentrations", M.F. Morgan and the ISO Team, Presented at the 1993 Eight Summer NSF CEDAR Workshop in Boulder, Colorado, June 21-26, 1993.

"Overview of the ATLAS-CEDAR Campaign", D.G. Torr and D.J. Melendez-Alvira and the ISO Team, Presented at the 1993 Eight Summer NSF CEDAR Workshop in Boulder, Colorado, June 21-26, 1993.

"Determination of Mesospheric Temperatures from ATLAS 1 Nightglow Measurements", J.K. Owens, M.R. Torr, T.W. Baldridge, D.G. Torr, J.A. Fennelly and M.F. Morgan, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992, Abstract Published in *EOS*, *73*, No. 43, 417, October 27, 1992.

"Objectives and Preliminary Results From the Imaging Spectrometric Observatory Flown on ATLAS 1", D.G. Torr, M.R. Torr, J.A. Fennelly, J.K. Owens, and P.G. Richards, Presented at the 1992 AGU Chapman Conference in Asilomar, California, November 1992, Paper to be published in Geophysical Monograph.

"$N(^2P)$ in the Dayglow: Measurement and Theory", M.R. Torr and D.G. Torr, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992. Abstract Published in *EOS*, *73*, No. 43, 428, October 27, 1992.

"Thermospheric and Ionospheric Remote Sensing from ATLAS 1 using the Imaging Spectrometric Observatory", D.J. Melendez-Alivra, D.G. Torr, M.R. Torr, J.A. Fennelly, M.F. Morgan and J.K. Owens, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992, Abstract Published in *EOS*, *73*, No. 43, 428, October 27, 1992.

"Thermospheric O, N_2, and T_n from 732 nm Measurements made by ISO on ATLAS 1", J.A. Fennelly, D.G. Torr, M.R. Torr and G.A. Germany, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992, Abstract Published in *EOS*, *73*, No. 43, 428, October 27, 1992.

"Measurements of Mesospheric OH $X^2\Pi$ by ISO on ATLAS 1", M.F. Morgan, D.G. Torr and M.R. Torr, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992, Abstract Published in *EOS*, *73*, No. 43, 418, October 27, 1992.

"A Progress Report and Overview of Results from the Imaging Spectrometric Observatory on ATLAS 1", D.G. Torr, Presented at the Fall Meeting of the American Geophysical Union in San Francisco, California, December 1992, Abstract Published in *EOS*, *73*, No. 43, 428, October 27, 1992.

"Global Observation and Modeling of the Ionosphere, Thermosphere and Mesosphere", D.G. Torr, M.R. Torr, M.F. Morgan, J.K. Owens, J.A. Fennelly and D.J. Melendez-Alvira, Presented at the 1992 STEP Symposium-COSPAR Colloquium No. 5 in Washington D. C., September, 1992.

"Global Modeling of Thermospheric N_2^+ First Negative Emissions and Comparison with Measurements from the Space Shuttle", Presented at the 1992 American Geophysical Union Spring Meeting, Montreal, Canada, May 11-16, 1992, Abstract Published in *EOS*, *73*, No. 14, 231, April 7, 1992.

"An Overview of Preliminary Results from the ISO on ATLAS 1", D.G. Torr, M.R. Torr, J.K. Owens, J.A. Fennelly, P.G. Richards, M.F. Morgan, C.W. Fellows, H. Dougani, T.W. Baldridge, W.R. Swift, A. Tejada, M.A. Orme, G.A. Germany and S.P. Yung, Presented at the 1992 Seventh Summer NSF CEDAR Workshop in Boulder, Colorado, June 24-27, 1992.

"Global Observations of 6300 Å Emission from the ISO on ATLAS 1", D.J. Melendez-Alvira, M.R. Torr, D.G. Torr, M.F. Morgan, J.K. Owens and S.P. Yung, Presented at the 1992 Seventh Summer NSF CEDAR Workshop in Boulder, Colorado, June 24-27, 1992.

"Overview of the ATLAS 1 Mission", D.G. Torr, Presented at the 1992 Seventh Summer NSF CEDAR Workshop in Boulder, Colorado, June 24-27, 1992.

"Preview of Results from the ISO Spectral Imager on ATLAS 1", D.G. Torr, M.R. Torr, J.K. Owens, J.A. Fennelly, T.W. Baldridge, H. Dougani, M.F. Morgan, C.W. Fellows, W.R. Swift, R.D. Campbell, A.G. Loughead, A. Tejada, M.A. Orme, V.D. Hyatt, D.J. Melendez-Alvira and S.P. Yung, Poster presented at the 1992 American Geophysical Union Spring Meeting, Montreal, Canada, May 11-15, 1992.

"Preliminary Modeling of the OI 630 nm Emission Observed by the Imaging Spectrometric Observatory in the ATLAS 1 Mission", D.G. Torr, M.R. Torr, P.G. Richards, S.P. Yung and K.J. Hladky, Poster presented at the 1992 American Geophysical Union Spring Meeting, Montreal, Canada, May 11-15, 1992.