AD-A170 143 MEASUREMENT OF ATMOSPHERIC EMISSION SPECTRA AT HIGH ALTITUDES(U) DENVER UNIV COLO DEPT OF PHYSICS F H MURCRAY ET AL. 22 NOV 85 AFGL-TR-86-0061 1/1

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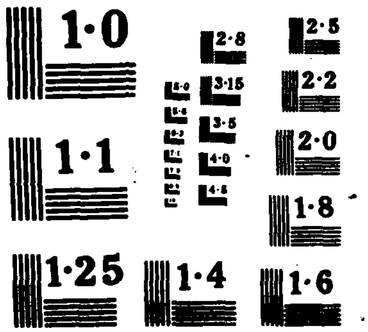
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AFGL-TR-86-0061

Measurement of Atmospheric Emission Spectra at High Altitudes

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November 1985

Final Report
8 November 1982 - 8 November 1985

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE
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"This technical report has been reviewed and is approved for publication"

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REPORT DOCUMENTATION PAGE

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1. REPORT NUMBER: AFGL-TR-86-0061	2. GOVT ACCESSION NO.: AD-A170143
3. RECIPIENT'S CATALOG NUMBER	
4. TITLE (and Subtitle): Measurement of Atmospheric Emission Spectra at High Altitudes.	5. TYPE OF REPORT & PERIOD COVERED: Final Report 11-08-82 - 11-08-85
	6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s): F. H. Murcray, F. J. Murcray, D. G. Murcray and A. Goldman	8. CONTRACT OR GRANT NUMBER(s): F19628-83-K-0006
9. PERFORMING ORGANIZATION NAME AND ADDRESS: Department of Physics, University of Denver, Denver, CO 80208	10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS: 61102F 2310G1BA
11. CONTROLLING OFFICE NAME AND ADDRESS: Laurence Rothman/OPI/Contract Manager, Air Force Geophysics Laboratory, Hanscom AFB, MA 01731	12. REPORT DATE: 22 November, 1985
	13. NUMBER OF PAGES: 13
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)	15. SECURITY CLASS. (of this report): Unclassified
	15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Atmospheric Emission
Interferometer (SCRIBE)
Spectra

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

A balloon-borne interferometer system (SCRIBE) was flown three times on this contract. These flights, their associated problems and final results, are given in this report. Analysis of the data obtained on these flights is also discussed.

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1. Introduction

The objective of this contract has been to obtain high spectral resolution atmospheric emission data at altitudes up to 40 km. In order to accomplish this a cryogenically cooled moving mirror Michelson interferometer system was constructed that is capable of operating independently while being carried aloft by a large balloon. The interferometer and cryostat were constructed by Idealab. The modifications required for balloon operation were performed by personnel at the University of Denver. The system has been flown as part of the work performed on a previous contract F19628-81-K-0018. The unit was flown three times under this contract.

Interpretation of the atmospheric emission spectra obtained under this contract requires a computer program that can calculate theoretical atmospheric emission spectra on a line-by-line basis. All such programs rely on an accurate list of line parameters of molecules of atmospheric interest, such as the one compiled by personnel at AFGL. Part of the work performed on this contract was to improve the data present in this compilation. The results of these programs are discussed in detail below.

2. *Work Performed Under This Contract*

2.1 Balloon Flight Program

As noted the balloon borne interferometer system, Stratospheric Cryogenic Infrared Balloon Experiment (acronym SCRIBE), had been flown on the preceding contract. The major problem encountered during these flights had been obtaining sufficient laser fringe amplitude to get reliable interferogram sampling during the balloon flight. A number of modifications were performed which made the amplitude of the fringes much less sensitive to the balloon environment. As will be noted below these modifications proved successful and the instrument has become a reliable balloon borne system. Details of the three flights and discussion of the results are given below.

2.1.1 Balloon Flight of 23 October 1983.

The SCRIBE payload was launched at 0610 MDT on 23 October 1983. The balloon ascended at a nominal ascent rate of 1000 feet per minute. It reached float altitude (~30 km) at 0750 MDT. After it had been at float approximately 30 minutes the balloon started to descend and it became apparent that it was leaking. In view of this, once a sequence of look angles and calibration were completed, the nadir viewing mirror was moved into position and data were taken with the instrument viewing the nadir for the rest of the flight. The descent rate was controlled as far as possible by dropping ballast and data taking continued until 1030 MDT. At that time the balloon had descended to 18 km. This is a mandatory termination altitude so the flight was terminated at that time. The instrument was recovered in good condition. After the instrument was returned to Denver the dewar was opened and the interferometer examined. This examination revealed a hairline fracture in the beamsplitter.

2.1.2 Balloon Flight of 5 July 1984

For this flight an optical filter which altered the low wavenumber response of the instrument was incorporated in the detector optical system. This reduced the source noise due to the 15 μm CO_2 band, improving the instrument capability to obtain data in the higher wavenumber region. The flight was launched on 5 July 1984. At that time of year the stratospheric winds are fairly strong and carry the balloon from east to west. In view of this the launch was performed from Roswell, NM with telemetry and balloon control operated from Holloman. The flight went very well with no problems either from a balloon or instrument standpoint. The stratospheric winds were high and as a result the time the balloon was within telemetry range was short, however 1 1/2 hours of data were obtained from float altitude. Again recovery was accomplished without incident.

2.1.3 Balloon Flight of 21 June 1985

The original objective of this contract, i.e. the acquisition of high quality high resolution atmospheric emission data at observation angles from above the horizon to nadir, was well satisfied by the preceding flights. With these objectives met it was possible to focus on specific problems in stratospheric photochemistry where emission techniques are uniquely applicable. For such flights instrument parameters and flight times are chosen to address a specific problem. One such problem is the question of the presence of N_2O_5 in the stratosphere. N_2O_5 is predicted to be present in the stratosphere as the result of interactions between NO_2

and ozone. The compound photodisassociates fairly rapidly and it therefore is predicted to exhibit very rapid diurinal changes. The peak concentration of the compound should be reached before sunrise at stratospheric altitudes with a rapid fall off after sunrise. In view of this the instrument was set up to provide good sensitivity in the 1250 cm^{-1} region where N_2O_5 has one of its major bands. Launch times were chosen so data would be taken at float altitude (30 km) an hour before sunrise on the balloon. It was anticipated that data taking would continue to well after sunrise to monitor the decay of the compound.

The flight was originally scheduled for early May in order to take advantage of the light stratospheric winds expected at that time. During preflight checkout of the interferometer a problem developed with the drive system which required the instrument be warmed up and the dewar opened. This required a delay in the scheduled launch date of at least ten days. This impacted other flight schedules so the launch was rescheduled for mid June. Repairs were completed and the instrumentation was ready for launch by that time. Scheduling conflicts and weather problems delayed the flight until June 21. The weather delays were due to high winds in the 300-600 ft level. These winds were not present on June 21 and launch preparations went forward as scheduled. Surface winds started to increase and also change direction after the balloon was inflated. This presented a difficult launch situation and although launch was accomplished the gondola hit the ground during the process. The impact resulted in a complete loss of command capability and balloon control telemetry. The SCRIBE telemetry link was still functional and it was possible to monitor the interferometer performance throughout the flight, however loss of command capability precluded changing the elevation viewing angle and detector bias so the data were degraded. The balloon also appeared to have a hole since the balloon floated at 25 km rather than 30 km (its theoretical float altitude). The lack of command and control capability meant that the balloon flight could not be terminated and recovery of the payload depended on the balloon losing sufficient helium for it to descend. This finally occurred on the morning of June 23 and the balloon impacted in a mountainous area northeast of Tucson. Fortunately the balloon and parachute became entangled in trees after the gondola had been dragged a short distance. The gondola sustained major damage due to the dragging, however it protected the interferometer and associated instrumentation very well and damage to the instrument was minor except in loss of vacuum in the cryostat. The thermal shock associated with the loss of vacuum cracked the beamsplitter.

3. Data Reduction

The data from the SCRIBE system consists of interferograms. Converting these into absolutely calibrated emission spectra requires a great deal of numerical calculations. Each group working with field interferometers has generally developed their own computer programs for performing the transforms required to convert the interferograms into spectra. These programs often differ in the methods of performing phase corrections, apodization etc. In view of this, this contract was set up so the data telemetered from the balloon was recorded by personnel from AFGL, with the University of Denver also recording the data as a back-up and monitor of the instrument performance during flight. Both groups were to reduce their data to spectra and compare the results. In practice some difficulty has been encountered at AFGL in reading the telemetry tapes. As a result most of the data obtained during the balloon flights have been reduced using University of Denver programs. Calibration of the system has been based on scans made during the flight of a black body reference source. This source is allowed to run at ambient temperatures. Samples of the spectra obtained during the July 5, 1984 flight are given in Figure 1. This figure shows the emission of the atmosphere close to the earth's limb. The complexity of the spectrum is evident particularly in the region of ozone emission (1000-1100 cm^{-1}). These spectra are being used for comparison with theoretical spectra calculated using the AFGL molecular line parameters tape. Discussions of this comparison is given in the next section.

4. Analysis

As noted above major emphasis on this contract has been placed on obtaining atmospheric emission spectra from high altitude. A small effort has been devoted to analysis of atmospheric spectra. This effort has been largely devoted to two main areas. The first of these has been concerned with generating spectral line parameters for inclusion on the AFGL tape.

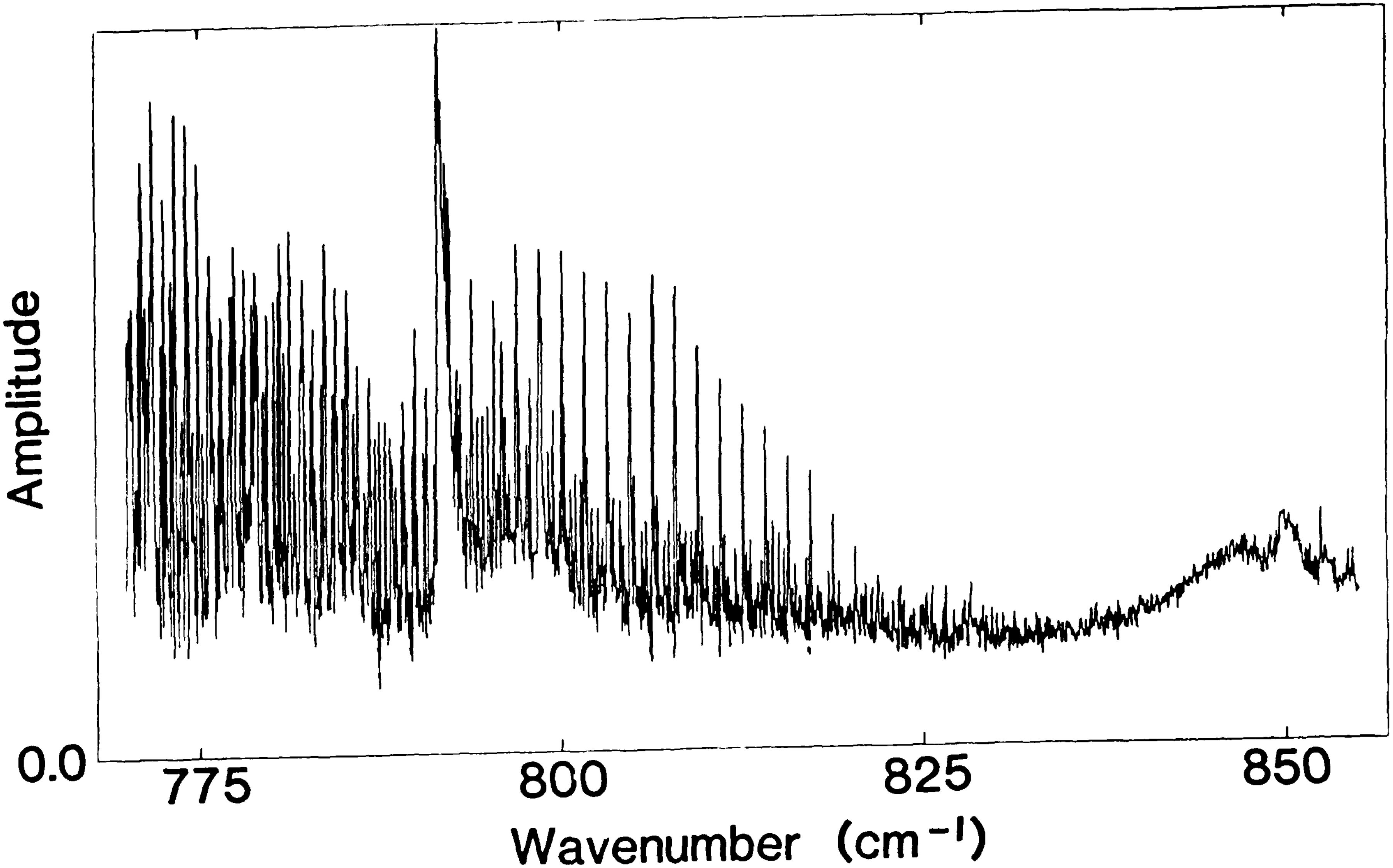

Figure 1 (a). Atmospheric emission spectrum obtained from an altitude of 30 km, viewing angle -3.2°.

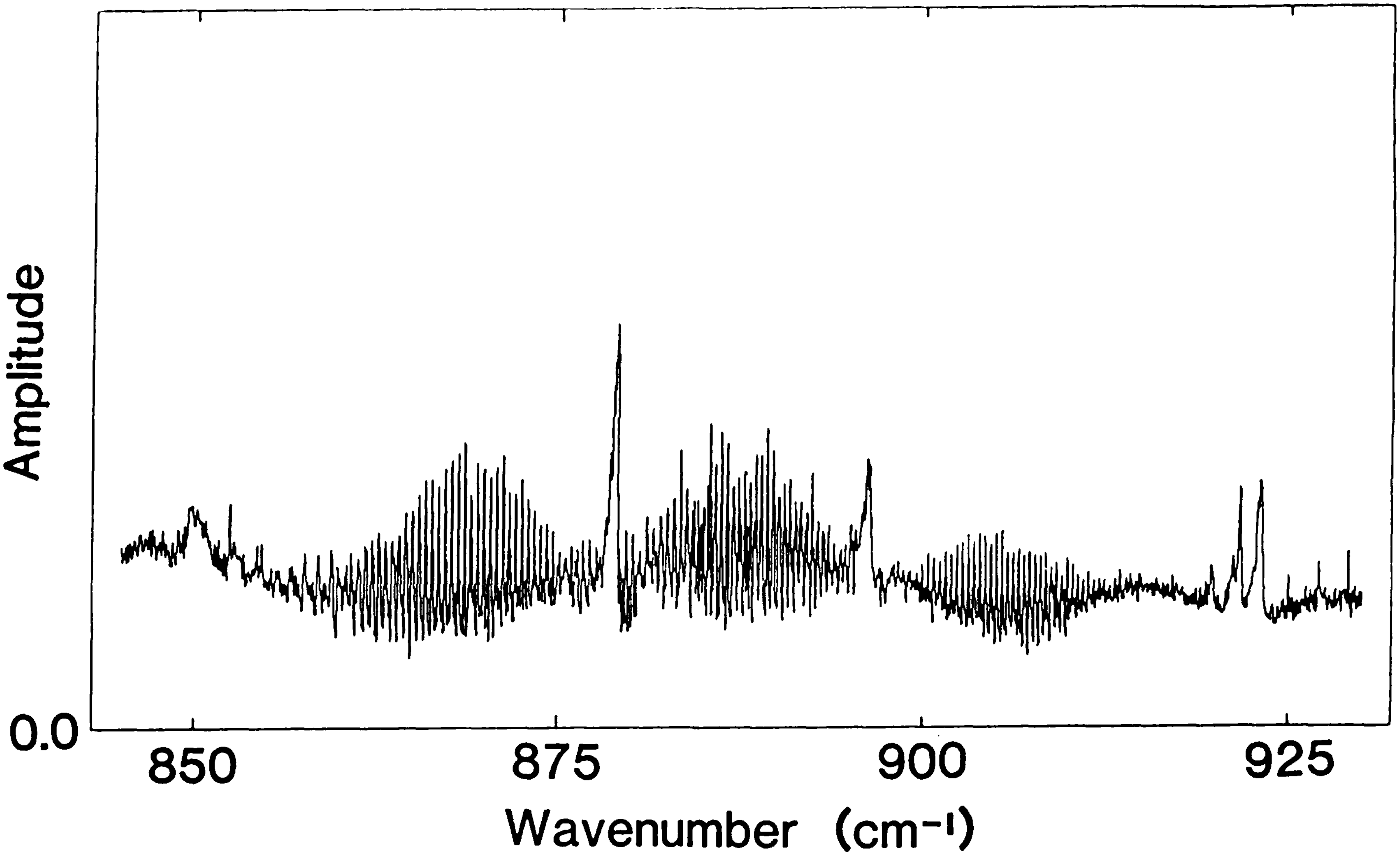

Figure 1 (b). Atmospheric emission spectrum obtained from an altitude of 30 km, viewing angle -3.2°.

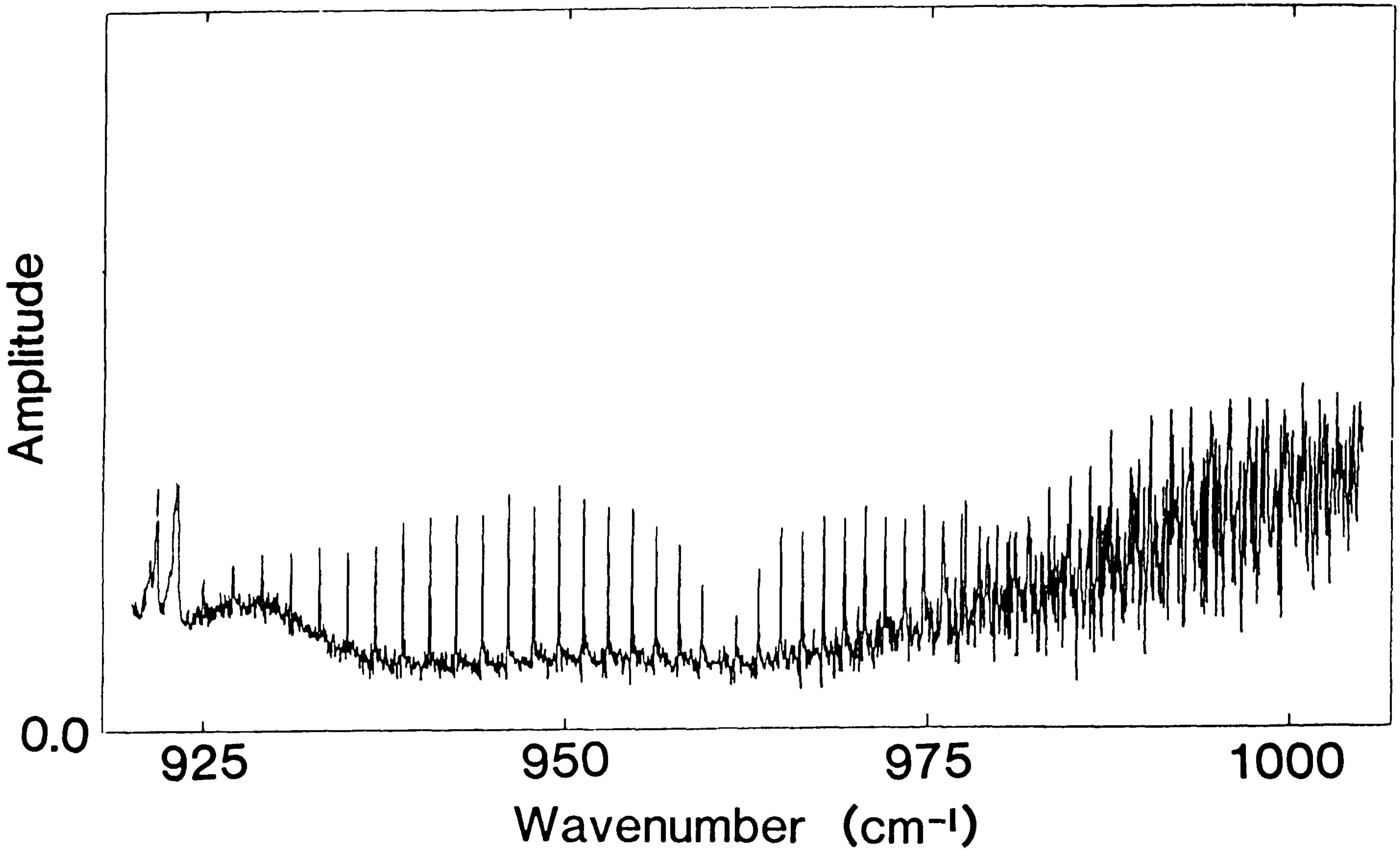

Figure 1 (c). Atmospheric emission spectrum obtained from an altitude of 30 km, viewing angle -3.2°.

The second has been analysis of the SCRIBE data, particularly that obtained during the July 5, 1984 flight.

Work performed on the first task included using our experimental data obtained on other programs, e.g. our stratospheric solar spectra and our laboratory spectra to derive new parameters for several bands. These include the pure rotation solar OH bands, the H_2S ν_2 band, the HCOOH ν_6 band, the HNO_3 11μ bands ($2\nu_9,\nu_5$, $3\nu_9-\nu_9,\nu_5+\nu_9$) and the ozone $\nu_1+\nu_2+\nu_3-\nu_2$ band.

Updates of line parameters have been generated for the H_2O_2 ν_6 band, the O_3 $\nu_1+\nu_2+\nu_3$ band and the solar CO ν=1, 2 bands.

Empirical line parameters have been generated for the $ClONO_2$ ν_4 band and spectral cross sections in selected regions were generated for F12, F11, $ClONO_2$, N_2O_5, CCl_4, CF_4, F_2, F113, F114 and HNO_3.

All of the above sets have been submitted to the AFGL for inclusion on the AFGL line parameters tape and many of them have been used for the analysis of atmospheric spectra (such as for the 870 cm^{-1} region of HNO_3).

The SCRIBE analysis has included processing and calibrating 4 sets of data obtained during the July 5, 1984 flight. These sets were taken at zenith angles of 88.1, 93.2, 93.7 and 180°. Comparison of line-by-line calculations have been carried out for selected spectral regions from all four data sets. Such a comparison is shown in Figure 2 for the 180° case.

5. Publications Resulting From Work On This Contract

The major effort of this contract has been directed toward obtaining atmospheric emission spectra at high altitudes. These data are now becoming available for analysis and it is expected that a number of publications will result from these analysis. The analyses that have been performed to date have been concerned with verifying the accuracy of the data in regions where it is felt that the theoritical calculations are valid. Publications on the SCRIBE instrumentation and the SCRIBE data are included in the following publications list. A number of publications have resulted from the analysis of other data performed on this contract.

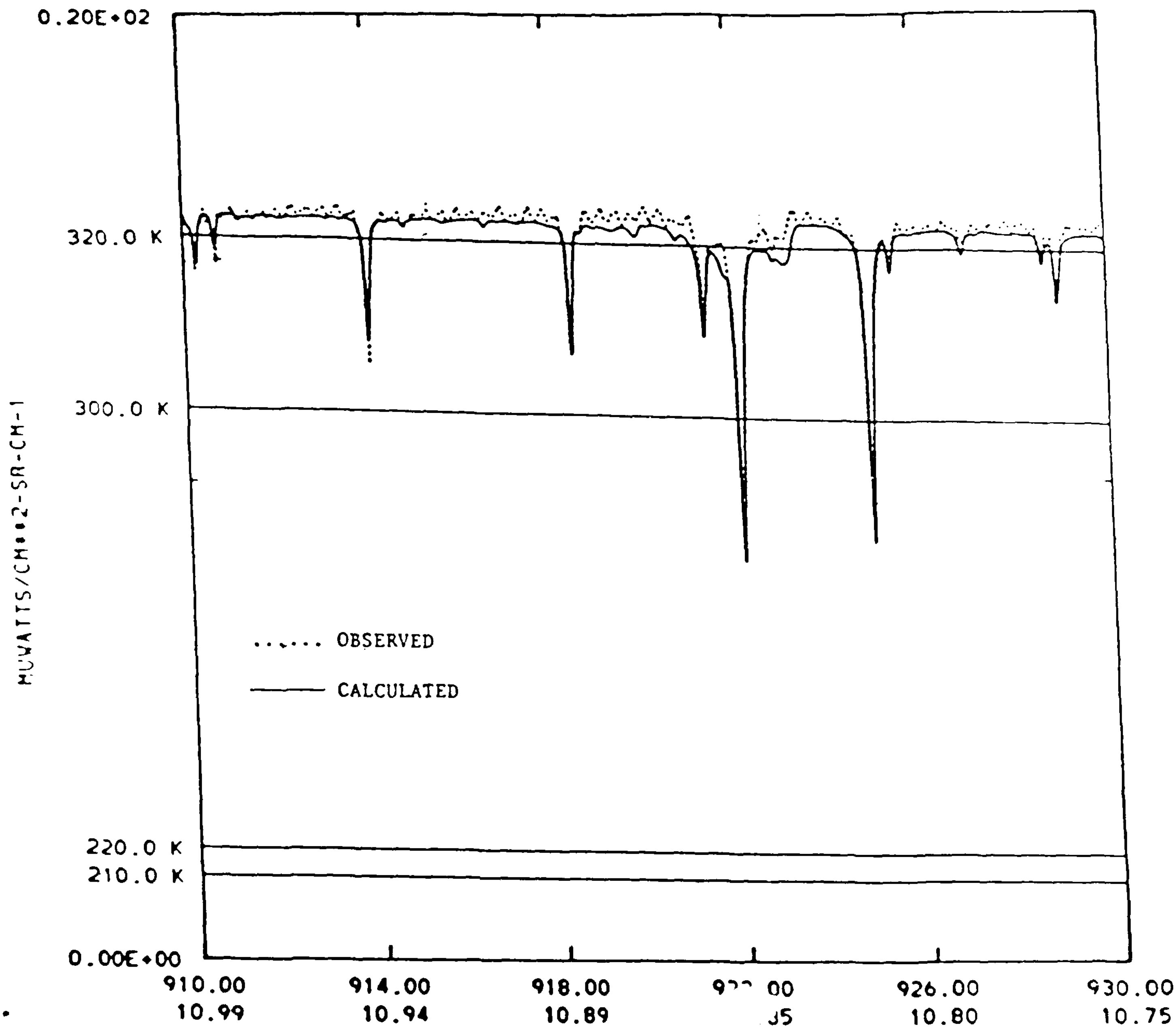

Figure 2. Portion of a spectrum of the earth's surface as observed from 30 km by the SCRIBE system. The spectrum is compared with a spectrum calculated using a line by line radiative transfer program.

6. Personnel

In addition to the authors, the following personnel have made significant contributions to this program:

John Van Allen, John Kosters, John Williams, Warren Cochran and Troy Dow.

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