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DEPARTMENT OF MECHANICAL ENGINEERING AND MECHANICS
SCHOOL OF ENGINEERING
OLD DOMINION UNIVERSITY
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COMPUTERIZED DATA REDUCTION TECHNIQUES FOR
NADIR VIEWING REMOTE SENSORS

By

Barbara B. Gormsen

Principal Investigator: S. N. Tiwari

Final Report
For the period February 15, 1984 - April 1, 1985

Prepared for the
National Aeronautics and Space Administration
Langley Research Center
Hampton, Virginia 23665

Under
Research Grant NAG-1-456
H. Andrew Wallio, Technical Monitor
ASD-Chemistry and Dynamics Branch

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Submitted by the
Old Dominion University Research Foundation
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FOREWORD

This report describes the work completed on the research project "Experimental Studies of Computerized Data Reduction Techniques for Nadir Viewing Remote Sensors." The work was supported by the NASA Langley Research Center (Atmospheric Sciences Division - Chemistry and Dynamics Branch) through research grant NAG-1-456. This grant was monitored by Mr. H. Andrew Wallio, of the Atmospheric Sciences Division, Mail Stop 401A, Phone: (804) 865-2576.

TABLE OF CONTENTS

	<u>Page</u>
FOREWORD.....	ii
SUMMARY.....	1
1. INTRODUCTION.....	2
2. OSTA-1 DATA ANALYSIS.....	2
2.1 Instrument Characterization.....	3
2.2 Atmospheric Modeling.....	4
2.3 Coefficient Generation.....	4
2.4 Data Inversion.....	5
2.5 Cloud Filtering.....	5
2.6 Data Display.....	6
3. CORRELATIVE MEASUREMENTS PROGRAM.....	6
4. OSTA-3 DATA.....	8
5. ERROR STUDIES.....	8
6. CONCLUSIONS.....	9

COMPUTERIZED DATA REDUCTION TECHNIQUES
FOR NADIR VIEWING REMOTE SENSORS

By

Barbara B. Gormsen^{*}

Principal Investigator: S. N. Tiwari^{**}

SUMMARY

Computer resources have been developed for the analysis and reduction of MAPS experimental data from the OSTA-1 payload. Extensive effort was also expended in support of the MAPS/OSTA-3 shuttle flight. Specific capabilities and resources developed are discussed.

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1. INTRODUCTION

The MAPS Research Project is concerned with the measurement of the global distribution of mid-tropospheric carbon monoxide. The measurement technique for the MAPS instrument is based on non-dispersive gas filter radiometer operating in the nadir viewing mode. The MAPS experiment has two passive remote sensing instruments, the prototype instrument which is used to measure tropospheric air pollution from aircraft platforms and the third generation (OSTA) instrument which is used to measure carbon monoxide in the mid and upper troposphere from space platforms.

The major objectives of this study were as follows:

- I. To provide programming analysis for the reduction and analysis of the data obtained from the OSTA-1 shuttle flight. To develop a color display software for the OSTA-1 reduced data.
- II. To assemble, integrate develop and adapt a new LSI 11/23 computer system for the MAPS correlative measurement program.
- III. To provide programming analysis for the OSTA-3 spacecraft and correlative measurements data.
- IV. To provide an error analysis of the carbon monoxide retrieval procedure.

The works completed on these objectives are presented separately in the following sections.

2. OSTA-1 DATA ANALYSIS

The MAPS experiment flew as part of the OSTA-1 payload aboard the second flight of the Space Shuttle (STS-2) during November 1981.

This experiment was the first attempt to measure a pollutant gas in the troposphere from an orbiting platform. A nearly circular orbit of 139 N.M. altitude and 38.1° inclination was achieved. During the 56 hour mission, the MAPS experiment operated approximately 42 hours. The experiment acquired approximately 32 hours of nadir viewing data, with the remaining 10 hours of time devoted to periods of instrument warm-up and calibration or to periods when the spacecraft was not in Earth viewing altitude. The 32 hours of nadir viewing data provided coverage of the troposphere between 38°N and 35°S latitude. This represents approximately 1 million kilometers of data along the flight track. The reduction and analysis of this data was a major accomplishment and accounts for approximately 80% of the study work effort.

The data reduction and analysis process was comprised of six major steps:

- (1) Instrument characterization
- (2) Atmospheric modeling
- (3) Coefficient generation
- (4) Data inversion
- (5) Cloud filtering
- (6) Data display

These are discussed briefly in the following subsections.

2.1 Instrument Characterization

The equations to convert instrument voltage signals into radiance measurements and instrument temperatures were obtained from personnel responsible for instrument characterization studies. These equations were incorporated into the program used to compute CO mixing ratios.

Because of various problems associated with instrument thermal instability, it was necessary to modify these equations numerous times and then reprocess the OSTA-1 data for new CO mixing ratios.

2.2 Atmospheric Modeling

To define the meteorological conditions from 45° south to 45° north, six latitudinal averaged models were developed. These models were processed by the MAPS radiative transfer program to compute the predicted atmospheric radiation for the three channels as a function of solar zenith angles for night and day and surface emissivities for land and water.

Additional analysis led to the development of nine atmospheric models based on constant lapse rates and on varying tropopause heights and surface temperatures. These nine models were also processed with two solar zenith angles and two surface emissivities and were used in the final data analysis.

Additional atmospheric models were developed for error studies. A total of 74 atmospheric models were processed with the MAPS radiative transfer program.

2.3 Coefficient Generation

The predicted atmospheric radiation from the atmospheric models was then used in a regression analysis technique to generate the coefficient sets for the data inversion program. The data inversion program selects the coefficient set to be used in the calculation of CO on the basis of signal function weighted temperature, terrain type and a day or night condition.

A coefficient study was conducted to improve the accuracy of the CO retrieval technique. In this error study, those radiance values for CO

concentrations outside the solution set were excluded in the regression technique. Four combinations were considered in the study and 118 coefficient sets were generated.

The coefficient sets based on six CO concentrations ranging from 22 to 137.5 ppbv gave an accuracy improvement in CO retrieval of two to four percent and were used for the final data inversion.

2.4 Data Inversion

The program used to compute inferred CO was modified several times because of changes in radiance equations, coefficient selection methods, temperature equations, terrain type selection, and etc. The OSTA-1 data was processed for radiance values and inferred CO numerous times. These results were then plotted, compared and analyzed.

2.5 Cloud Filtering

An interactive cloud filtering program was developed to generate a data set with the cloud contaminated data removed. The data was processed in time blocks ranging from one second of data up to 30 minutes of data. The data was filtered by a maximum and/or minimum range and/or a statistical filtering method. With the statistical filter, each data point was differenced to the mean of the η preceding data points. If the difference was less than σ times the standard variance of the preceding η points the data was considered cloud free and retained in the data set. The time interval, maximum value, minimum value, η and σ were specified interactively.

The filtered data was then graphically displayed and the decision was made to either refilter with different criteria or accept as cloud free data.

This filtering process was applied to the OSTA-1 data and the results plotted for comparison to the MAPS photography. After this comparison, the data was refiltered to remove additional cloud contaminated data.

2.6 Data Display

Several graphics programs were developed to display the OSTA-1 data during the analysis phase. Numerous plots of CO mixing ratios, voltages, radiance values, blackbody temperatures, etc. were generated for MAPS scientist and engineers.

A system of color graphics programs were developed to display the OSTA-1 reduced data. A file containing the data as 30 second averages and a file of the data summed as 5° x 5° latitude/longitude boxes were generated for graphic display on the color graphics system.

3. CORRELATIVE MEASUREMENTS PROGRAM

The MAPS OSTA instrument was also an experiment on the OSTA-3 payload which flew on the Space Shuttle (Mission 41-G) in October 1984. In support of this flight, grant personnel participated in conducting a correlative measurements program using the prototype instrument on an aircraft platform.

The existing data system for the prototype instrument was a PCM system which wrote the data to a 7-track tape. In June 1984, the MAPS project purchased a LSI 11/23 computer system with a 9-track tape recorder as a replacement for the PCM system.

The first phase in the development of the new inflight data system was the generation of the RSX 11M 4.1 operating system and the modification of the system to meet the special needs of the MAPS instrumentation. The next

phase was the installation of an RSX-LIB software package which was used to interface the computer with the A/D boards. After correcting the errors found in the software package, it was modified to meet the specific needs of the MAPS data system. The next phase consisted of the development of computer software for data collection, storage and display. Extensive diagnostics were performed for system verification. Data comparisons were also made between the PCM system and LSI 11/23 system. Additional computer programs were developed for the post-flight display and verification of inflight data.

Both the PCM and the LSI 11/23 data systems, working independently, were used in the correlative measurements program, with the PCM system being designated as the primary data system. The staging point for the correlative measurements program was Homestead Air Force Base in Florida. Two computer facilities with 7-track tape drives, Cape Canaveral Computer Center at KSC and the NOAA Hurricane Tracking Center in Miami, were contacted and arrangements were made for the post-processing of the PCM data tapes. Software used at the LaRC computer center was modified for use at the KSC complex. By working directly with NOAA personnel, new software was developed to post-process the PCM data on an HP 2117F computer at their facility.

Responsibilities as an active participant in the correlative measurements program included functioning as flight coordinator and crew member in aircraft under flights, traveling to KSC and NOAA to post-process the PCM inflight data tapes, post-processing the LSI 11/23 inflight data tapes, and verifying that the data collected on the two systems was in agreement with inflight panel readings.

4. OSTA-3 DATA

As previously stated, the MAPS experiment flew on the Space Shuttle in October 1984. Based on information gained from the OSTA-1 flight, several electronic modifications were made to the spacecraft instrument. Because of these instrument changes, software modifications were required in the tape decoding program and in the graphics stripchart program.

After the spacecraft, the OSTA-3 data tape was processed to generate computer listings of calibration data and NOS compatible data tapes. The NOS compatible data tapes were then processed to produce a stripchart of ten instrument variables.

The aircraft PCM flight data tapes were processed to generate computer listings of the data, NOS compatible data tapes and stripcharts of the data. The LSI 11/23 data tapes were processed to generate complete computer listings of the data.

5. ERROR STUDIES

Studies were conducted to determine the sources of error in the procedure used to infer carbon monoxide mixing ratios. These studies include an analysis of errors due to instrument noise, errors from instrument characterization equations, atmospheric modelling errors from the equations used to compute theoretical radiance values, regression errors in the inversion method, and errors in the assumptions used in the retrieval process. The results of these studies are discussed in a paper that is to be submitted for journal publication.

6. CONCLUSIONS

The following specific tasks were completed during the present study:

1. Development of software systems for the reduction and analyses of OSTA-1 spacecraft data,
2. development of colorgraphic systems for the display of OSTA-1 reduced data sets,
3. development of a new LSI 11/23 computer system for the MAPS correlative measurement program,
4. participation in the MAPS aircraft correlative measurements program in support of the OSTA-3 shuttle flight, and
5. preliminary examination of the OSTA-3 spacecraft and correlative measurements data.

Further work, however, is needed to review other available software systems, make essential modifications, and develop new methods for the reduction and analysis of MAPS data.