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TECHNICAL REPORT GSTR 87-1

DEVELOPMENT OF DATA PROCESSING, INTERPRETATION AND ANALYSIS SYSTEM FOR THE REMOTE SENSING OF TRACE ATMOSPHERIC GAS SPECIES

By

Joseph C. Casas

and

Mary S. Saylor

Earl C. Kindle, Principal Investigator

Final Report
For the period January 22, 1982 - January 15, 1986

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

Under
Research Grant NCC1-34
Warren D. Hypes, Technical Monitor
Atmospheric Sciences Division

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DEVELOPMENT OF DATA PROCESSING, INTERPRETATION AND ANALYSIS SYSTEM FOR THE REMOTE SENSING OF TRACE ATMOSPHERIC GAS SPECIES

By

Joseph C. Casas,[1] Mary S. Saylor,[2] and Earl C. Kindle[3]

INTRODUCTION

The Cooperative Agreement, NCC1-34, between the NASA/Langley Research Center (LaRC) and Old Dominion University (ODU), entitled "Development of Data Processing, Interpretation and Analysis System for Remote Sensing of Trace Atmospheric Gas Species," represented a major research effort since its award in January 1980. Research done under this Cooperative Agreement was a followup to work performed under NASA grants NSG-1127 and NSG-1395, "Data Reduction Analysis and Application Technique Development for Atmospheric Trace Gas Constituents Derived from Remote Sensors on Satellite or Airborne Platforms." A progress report describing initial accomplishments under this Cooperative Agreement was submitted to the Technical Monitor in June 1982.

The major emphasis of this investigative research was the advancement of remote sensing technology. In particular, the gas filter correlation radiometer (GFCR) technique was applied to the measurement of trace gas species, such as carbon monoxide (CO), from airborne and Earth orbiting platforms. Through a series of low altitude aircraft flights (1 km to 6 km), high altitude aircraft flights (8 km to 12 km), and orbiting space platform flights, data were collected and analyzed, culminating in the first

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global map of carbon monoxide concentration in the middle troposphere and lower stratosphere.

Research personnel had significant responsibility in four major areas of this remote sensing program known as the Measurement of Air Pollution from Satellites (MAPS) experiment. These areas were:

(1) data acquisition

(2) data processing, analysis, and interpretation algorithms

(3) data display techniques, and

(4) information processing.

This report contains an overview of the contributions of the researchers in each of these areas, under this research project.

DATA ACQUISITION

As described in the Progress Report of May 1982, a prototype of the space-borne MAPS instrument was flown in aircraft flight tests. A Cessna 402B carried the MAPS brassboard GFCR in low altitude tests conducted over the St. Petersburg/Clearwater, Florida area in August 1978. As part of the MONsoon Experiment (MONEX) in the summer of 1979, mid-altitude measurements were made from a Convair 990, primarily in the vicinity of the Indian Ocean. Data acquired in these programs, in addition to satisfying the primary objectives of obtaining localized air pollution measurements, formed a basis for comparison with subsequent measurements of the Earth orbiting MAPS sensor.

In November 1981, the space shuttle Columbia carried into earth orbit its first scientific payload. MAPS was one of the five experiments comprising this payload sponsored by NASA's Office of Space and Terrestrial

Applications (OSTA). The MAPS experiment acquired thirty-five hours of nadir viewing data and underwent five in-flight calibrations. The OSTA payload was launched again in October 1984 on board the Space Transportation System (STS) orbiter Challenger. During this 8-day mission, the MAPS flight tape was filled to capacity with 105 hours of measurements, selectively recorded according to spacecraft attitude and underlying Earth targets. Figure 1 shows the data-taking ground tracks of the 41-610STA-3 flight.

ODU researchers were an integral part of the team which supported these two shuttle flights of the MAPS experiment. They participated in pre-flight hardware installation and functional testing, in mission simulations, and in pre-launch and launch support, all at the Kennedy Space Center (KSC). They traveled to the Johnson Space Center (JSC) to participate in both simulated and actual mission activity of the Payload Operations Control Center (POCC). Landing support, including recovery of flight magnetic tape and film and de-integration of hardware, was supported at the Dryden Research Center (DRC) for the OSTA-1 mission and at KSC for OSTA-3.

One aspect of the MAPS experiment data validation program was a series of aircraft underflights of selected STS orbits. Correlative measurements were obtained with a duplicate sensor and in situ instrumentation. For the OSTA-1 mission, aircraft operated over four locations: Farmville, Virginia; Key West, Florida; the Pacific Ocean, 600 miles west of San Francisco; and Melborne, Australia. ODU personnel assisted in the installation and check-out of the experiment hardware on the NASA Learjet which overflew the two eastern United States test sites. Working as experiment crew, ODU researchers operated the hardware and gathered meteorological data and air samples for gas chromatographic analysis.

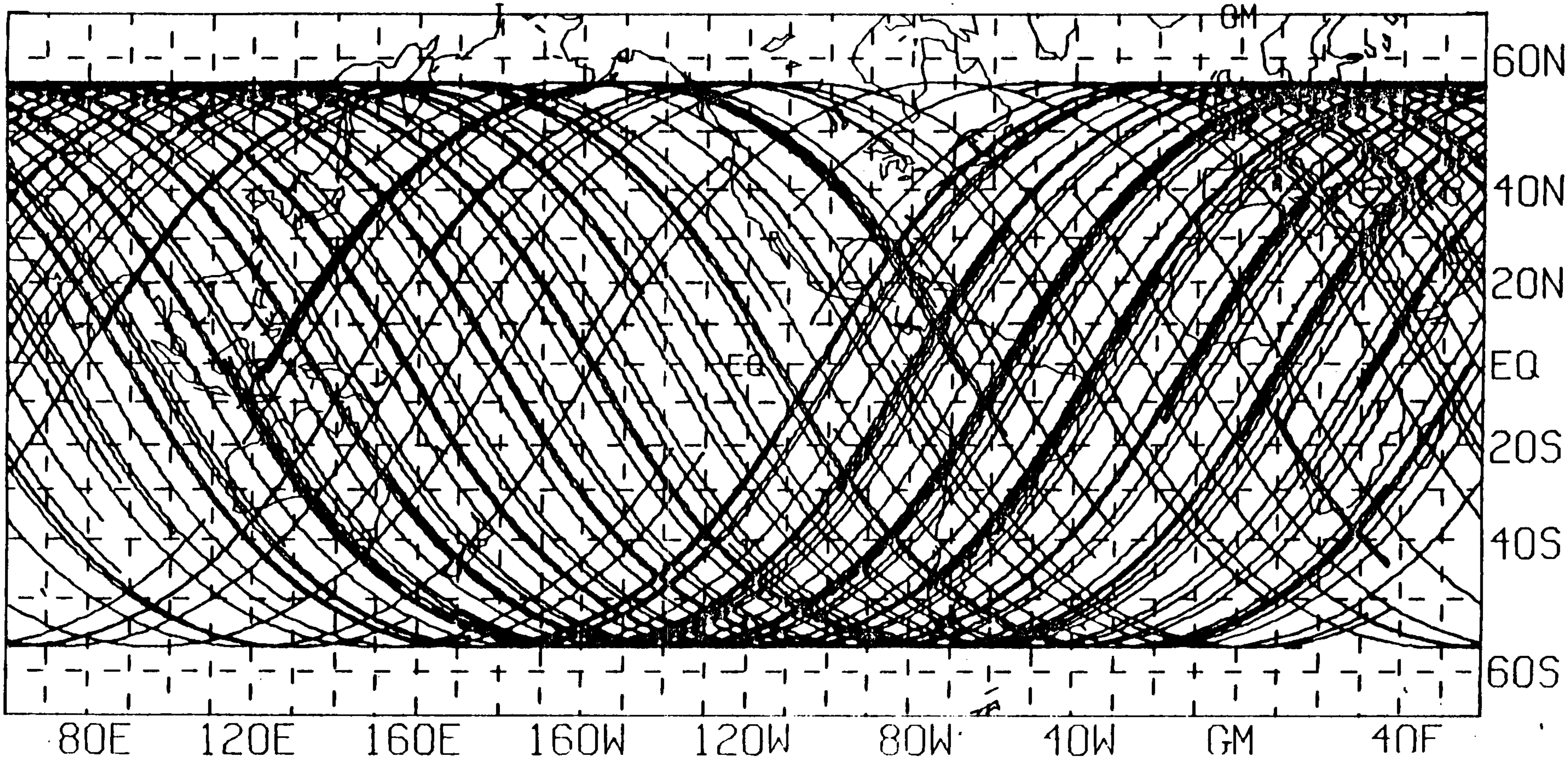


Fig. 1. Data-taking ground tracks of the MAPS experiment during the 41-G/OSTA-3 flight of space shuttle.

For the correlative measurement programs of both shuttle missions, meteorological analysis and weather forecasting services were required to determine the prime locations for the aircraft underflights. A direct tap to the Satellite Field Services Office in Camp Springs, Maryland, was set up in the University's weather center during the OSTA-1 mission. Images from weather satellites were transmitted real-time via this data link. These satellite facsimiles, along with data routinely collected and catalogued by the weather center, enabled the selection of those underflight targets within the fuel range of the aircraft with greatest likelihood of essentially cloud-free skies.

In addition to meteorological parameters, available real-time, upper air analyses of temperature, dewpoint depression, and wind field data were required to construct the atmospheric models needed to reduce the global data sets. These analyses were ordered from the Navy's Fleet Numerical Oceanography Center (FNOC) in Monterey, California, and from NOAA's National Climatic Center (NCC) in Asheville, North Carolina. The computer compatible tapes transmitted were decoded and converted to locally accessible computer files. The polar stereographic and rectangular gridded analyses were validated through intercomparisons and through comparisons to real-time meteorological measurements and climatology.

Other support data were required. JSC supplied the Best Estimated Trajectory (BET) product for the OSTA-1 mission and the on-orbit Postflight Attitude and Trajectory History (PATH) data for the OSTA-3 mission. Worldwide radiosonde launch information was obtained from the NMC. Ohio State University supplied a grid 1° x 1° of mean topographic elevations or bathymetric depths. The primary source of this latter data set was the Defense Mapping Agency Aerospace Center in St. Louis. As was true with the upper air analyses, these data sets were also received on computer compatible tapes, each having a unique storage format which required conversion by ODU personnel for access and use at LaRC.

DATA PROCESSING, ANALYSIS, AND INTERPRETATION ALGORITHMS

Extensive testing of the MAPS instrument was conducted prior to the OSTA-1 launch. A standardized acceptance test procedure was followed before and after every relocation of the instrument to evaluate functional performance. To verify that the MAPS hardware would function properly in the environment of space flight, the instrument underwent a series of compliance tests: vibrational, thermal vacuum, and electromagnetic interface (EMI). After installation of the scientific hardware on the OSTA pallet, integration testing and a final end-to-end check out were conducted in the Vehicle Assembly Building at KSC.

Instrument Calibration

Prior to the STS-2/OSTA-1 flight, the instrument was calibrated in a laboratory at room temperature. Following the flight, it was calibrated in a thermal vacuum chamber at a variety of instrument temperatures. During the actual mission, data were acquired while the instrument was viewing deep space which allowed the determination of the zero position.

Preflight

The MAPS instrument preflight calibration tests were carried out in a laboratory at an ambient temperature of 298 K. These tests determined the magnitude of the output noise, the radiometric responsivity, the degree of linearity of the output signal response, voltage offsets, and the repeatability of the instrument for each of its three channels: V, containing an evacuated cell; ΔV, containing a high pressure (266 torr) CO cell; and ΔV', containing a low pressure (76 torr) CO cell.

The specially designed calibration system controls independently the composition, total pressure, and temperature of the gas mixture contained in a calibration cell of length 0.5 meter. The system also varies the temperature of a high quality calibration blackbody between 238 K and 345 K. The measured temperatures and pressures of the gas mixtures, blackbody target temperatures, instrument output voltages, and other housekeeping signals were recorded during each step of the calibration testing procedure.

The recorded data were used in conjunction with a line-by-line radiative transfer program to compute the instrument radiometric calibration constants. For a given set of test conditions, this computer program calculated the radiance values, L, ΔL, and ΔL', which corresponded to the test conditions for each of the measured signal output voltages of the three instrument channels, V, ΔV, and ΔV'.

The V channel calibration constants, R and β, for each instrument mainframe temperature, which is known to be the same as TBB2, were determined by the least squares solutions to the calibration test data such that

$$V = [R^{V}(TBB2)][L_{target} - L_{BB1}] + \beta(TBB2)$$

where $R^{V}(TBB2)$ is the responsivity (volts/watt cm^{-2} sr^{-1}) and $\beta(TBB2)$ is the offset voltage. The total inband radiances for the target blackbody, L_{target}, and for the internal reference blackbody, L_{BB1}, were calculated using the line-by-line radiative transfer calculations.

The relationship between the output voltage signals for the ΔV and $\Delta V'$ channels and the target radiometric signals ΔL and $\Delta L'$ is given by

$$\Delta V_{target} = [R^{\Delta V}(TBB2)][\Delta L_{target}] + \Delta V_{ref}(V, TBB2)$$

$$\Delta V'_{target} = [R^{\Delta V'}(TBB2)][\Delta L'_{target}] + \Delta V'_{ref}(V, TBB2)$$

where $R^{\Delta V}(TBB2)$ and $R^{\Delta V'}(TBB2)$	are the instrument temperature dependent responsivities,
ΔL_{target} and $\Delta L'_{target}$	are the calculated scene radiances for the ΔV and $\Delta V'$ gas channels, respectively, and
$\Delta V_{ref}[V, TBB2]$ and $\Delta V'_{ref}[V, TBB2]$	are the zero reference offset balance voltages for the ΔV and $\Delta V'$ channels.

The magnitude of the offset voltages is dependent both on the instrument temperature, TBB2, and on the magnitude of the target radiance as indicated by the V channel output signal, V.

Preflight the MAPS instrument was very stable. The repeatability of the calculated constants was better than ± 2 percent for testing performed at approximately the same instrument temperature. The noise level on all three channels remained constant at 1.7×10^{7} watts • cm^{-2} • sr^{-1} for the V channel and 5.7×10^{-9} watts • cm^{-2} • sr^{-1} for the ΔV and $\Delta V'$ channels.

Postflight

The large variation in coolant loop temperature encountered during the space flight necessitated an extensive set of postflight tests and calibrations to characterize the instrument as a function of instrument temperature. The calibrations were carried out in a cryogenically pumped chamber capable of achieving a pressure of 1 x 10^{-7} torr. The instrument was mounted on a heat transfer baseplate and suspended from the upper rail of the chamber. A secondary gas calibration reference cell and secondary standard apparatus replaced the MAPS flight camera. The gas cell was inserted and removed from the space between the optical port of the instrument and the secondary standard blackbody.

The baseplate and secondary standard blackbody were connected to external thermal control units so that their temperatures could be varied independently. Thermistors similar to the internal thermistors of the MAPS experiment were used to measure the temperature of the secondary standard blackbody and the temperature of the 2.12-cm long secondary standard reference gas cell. Test conditions are detailed in Table 1.

The results from the entire set of test conditions were used to determine the calibration constants for the instrument. The output of each channel was an essentially linear function of the input signal. The responsivity, i.e., the slopes of the calibration curves, varied nearly linearly as a function of instrument temperature. However, the zero offsets of the ΔV and $\Delta V'$ channels, in addition to being a function of the instrument temperature, were non-linearly related to the V channel signal.

Inflight

As noted earlier, the MAPS instrument was exposed to very large coolant loop temperature variations during the STS-2 mission. These variations were so large and so rapid that it was not possible, in general, for the instrument to achieve a proper balanced condition during the 22-minute balance

Table 1. Test conditions for postflight instrument characterization tests.

Instrument Temperature (Kelvins)	Secondary Standard Target Temperature (Kelvins)	Secondary Standard Reference Cell Gas Mixtures (Percent CO by Volume)
272.66	273.16*	2.5
276.66	280.16**	3.8
282.16	293.16	10.9
289.16	305.16	
	312.16	
	320.16**	

*Target temperature used in calibration of V channel only.

**Target temperature equivalent to MAPS inflight calibration blackbody temperatures.

cycle. Only during the fourth rebalance attempt, which occurred about 13 hours before the end of the mission, was a good balance achieved.

The instrument temperature was almost the same during the fourth and fifth on-orbit balance/calibrate cycles, and it was nearly constant during the rebalance cycles; however, the instrument temperature varied between 227 K and 285 K during the data acquisition period between these two balance/calibrate cycles. Because the zero reference signal changes as the instrument temperature deviates from the balance temperature, it was necessary to determine the zero reference signal as a function of instrument temperature for the period between the fourth and fifth balance/calibrate cycles. This was accomplished by using data acquired while the instrument was viewing deep space, which is a known and stable source.

STS-41G/OSTA-3 Reflight

In preparation for the reflight of the MAPS experiment as a component of the OSTA-3 payload, the instrument entered the T/V chamber again in February 1984. Appendix I contains the results of this calibration.

The occurrence of the OSTA-1 temperature excursions made the MAPS experiment team aware of the need for additional inflight calibration data. Data takes with the MAPS sensor viewing deep space were added to the 41-G/OSTA-3 integrated payload command plan. These space look calibration points were taken at least twice daily during inertial maneuvers by the shuttle. Analysis of this inflight calibration is in progress. A better characterization of the zero reference signal as a function of instrument temperature will result.

Two other significant changes to the MAPS experiment were made as a result of experience gained during the initial space flight of the MAPS instrument. Electronic modifications were made to decrease the voltages of two signals, the vacuum channel signal and the housekeeping parameter R signal, to fall within the range of the A/D converter. Second, a tape recorder activate and inhibit command capability was implemented to enable selective data sampling.

A transportable IBM-PC system was acquired for use by the OSTA-3 payload operations control team who worked at JSC. The potential exists for this computer system to provide some real-time data analysis. However, the system's primary functions during the OSTA-3 flight of the MAPS experiment were as monitor and recorder. Software modules were written to

- display times and MAPS experiment status
- enter comments into a flight log
- print all or part of the flight log
- simulate actual commands telemetered to the instrument
- record onboard temperatures
- display a directory of potential experiment malfunctions with corrective action(s)
- alert experimenter to test conditions such as rebalance due or approaching end of recording capacity.

Information acquired with this personal computing system has proven useful in the postflight OSTA-3 data reduction, which is now in progress.

Data Reduction

Major steps in the procedure whereby CO mixing ratios were inferred from the OSTA-1 MAPS experiment data are shown in Fig. 2. ODU researchers contributed in varying degrees to the successful completion of each branch of this data reduction method. In addition to work with the instrument

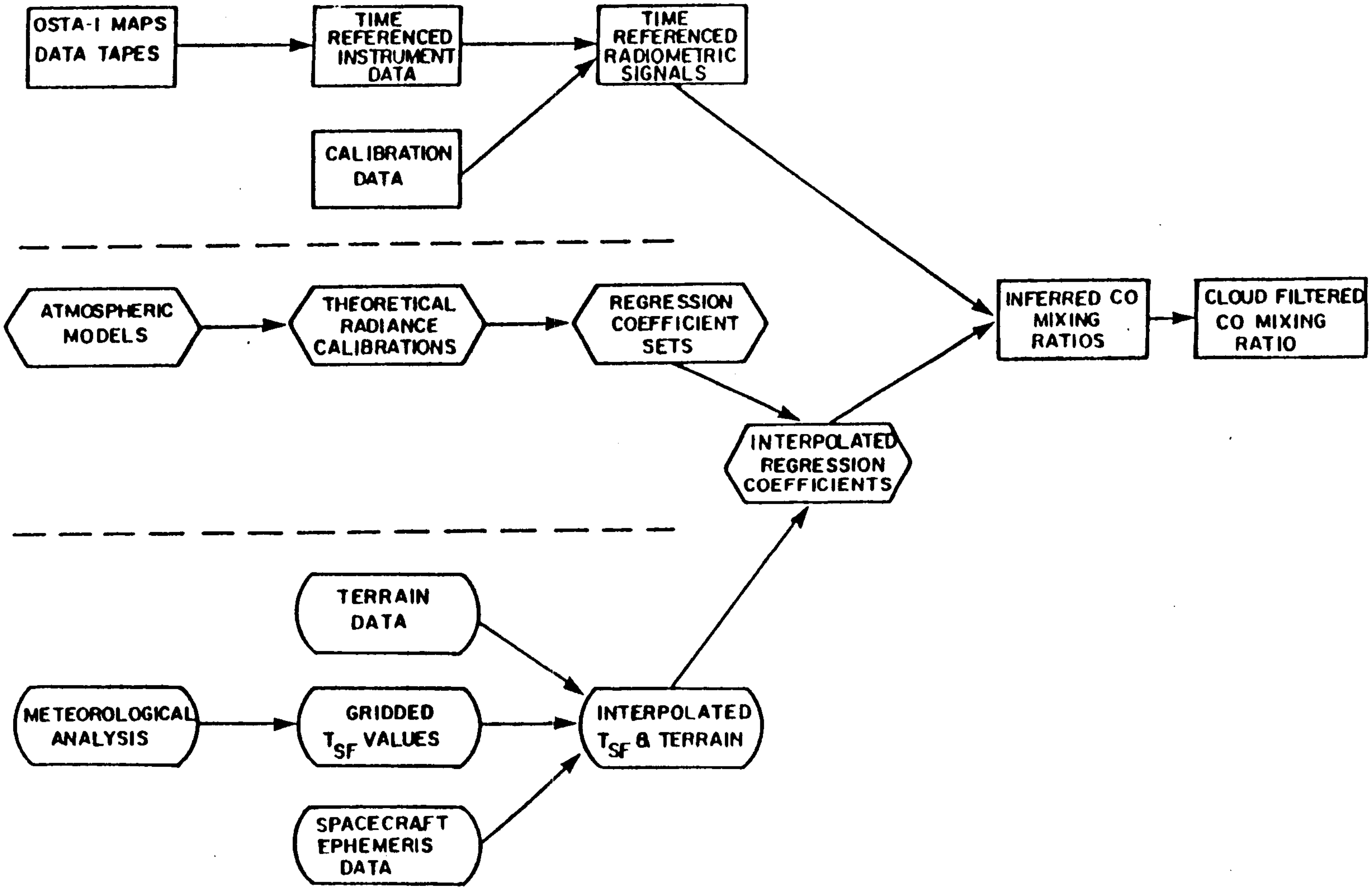


Fig. 2. Procedure for the inferral of carbon monoxide mixing ratios.

calibration as previously discussed, ODU personnel had primary responsibility for the lower branch of the flow chart.

The MAPS experiment did not measure atmospheric temperature, so this data was obtained from the FNOC in the form of gridded meteorological northern and southern hemispheric analyses for 0 Z and 12 Z of the mission period. To incorporate atmospheric temperature into the regression method, the temperature profile was described as a single parameter, T_{SF}, defined as

$$T_{SF} = \frac{\int_{P=1000_{mb}}^{P=0_{mb}} \overline{T}(P) \cdot SF(P)dP}{\int_{P=1000_{mb}}^{P=0} SF(P)dP}$$

where P = the pressure of the standard FNOC pressure levels

$\overline{T}$ = the mean temperature between levels, and

SF = the value of the signal function for each of the layers.

The signal by the instrument received has the inherent property of being integrated over altitude. In a similar manner, the T_{SF} is an average temperature, vertically weighted (by the signal function) over the depth of the atmosphere. Gridded T_{SF} values were computed for each gas cell channel and for each analysis. Through spatial and temporal linear interpolation, the gridded T_{SF} fields, in combination with the spacecraft ephemeris data, were used to produce values of T_{SF} corresponding to the latitude, longitude, and time of each location where CO data were acquired.

The character of the underlying surface and the measure of the solar zenith angle are two other parameters provided as part of the met file. The terrain data were selected from a Defense Mapping Agency terrain analysis of

1° x 1° resolution. Solar zenith angles at each subsatellite point were calculated as a function of latitude, longitude, and time.

DATA DISPLAY TECHNIQUES

Computer generated graphics were used extensively as a method of summarizing, analyzing, and presenting data. Offsite, the hardware used for plotting was the Tektronix 4052 desktop graphics system. Onsite at LaRC, plot vector files were generated by a network of CDC Cyber mainframes, and images were postprocessed to drive the Varian, Versatec, and CalComp plotters. Both black on white and multicolored plots were produced.

Mathematical and statistical software marketed by Tektronix was executed to generate hundreds of working plots like the preflight calibration curve shown in Fig. 3. These graphs provided quick looks at the linearity of data sets. The software allowed for data entry from keyboard, disk, or tape, and computed goodness of fit measures including R-square, residual error, and maximum absolute error. Both simple and polynomial regression curve fitting was available, and regression coefficients could be calculated and displayed.

A general utility plotting program was coded in-house and executed extensively on the Tektronix system. The program displayed one or more sets of coordinate pairs on either linear or logarithmic axes. The user controlled scale factors, titles, symbols, and optional least squares fits to the data. Temperature profiles plotted with this utility are shown in Fig. 4. The temperature values, taken from FNOC gridded analyses, were averaged within five latitudinal bands over the time period of the OSTA-1 flight. Such profiles were needed for the construction of the atmospheric models required in the data reduction process.

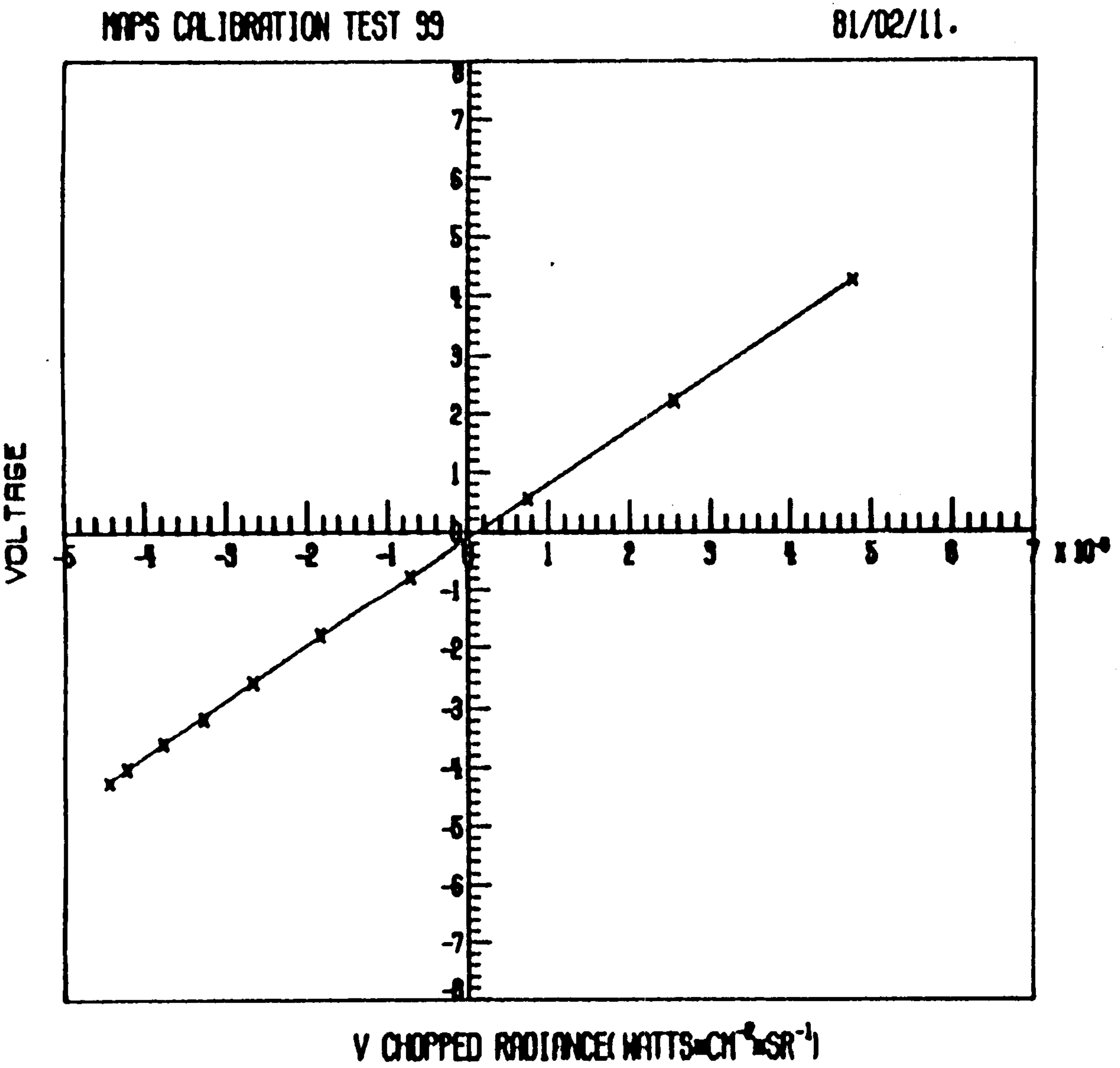


Fig. 3. Preflight calibration curve.

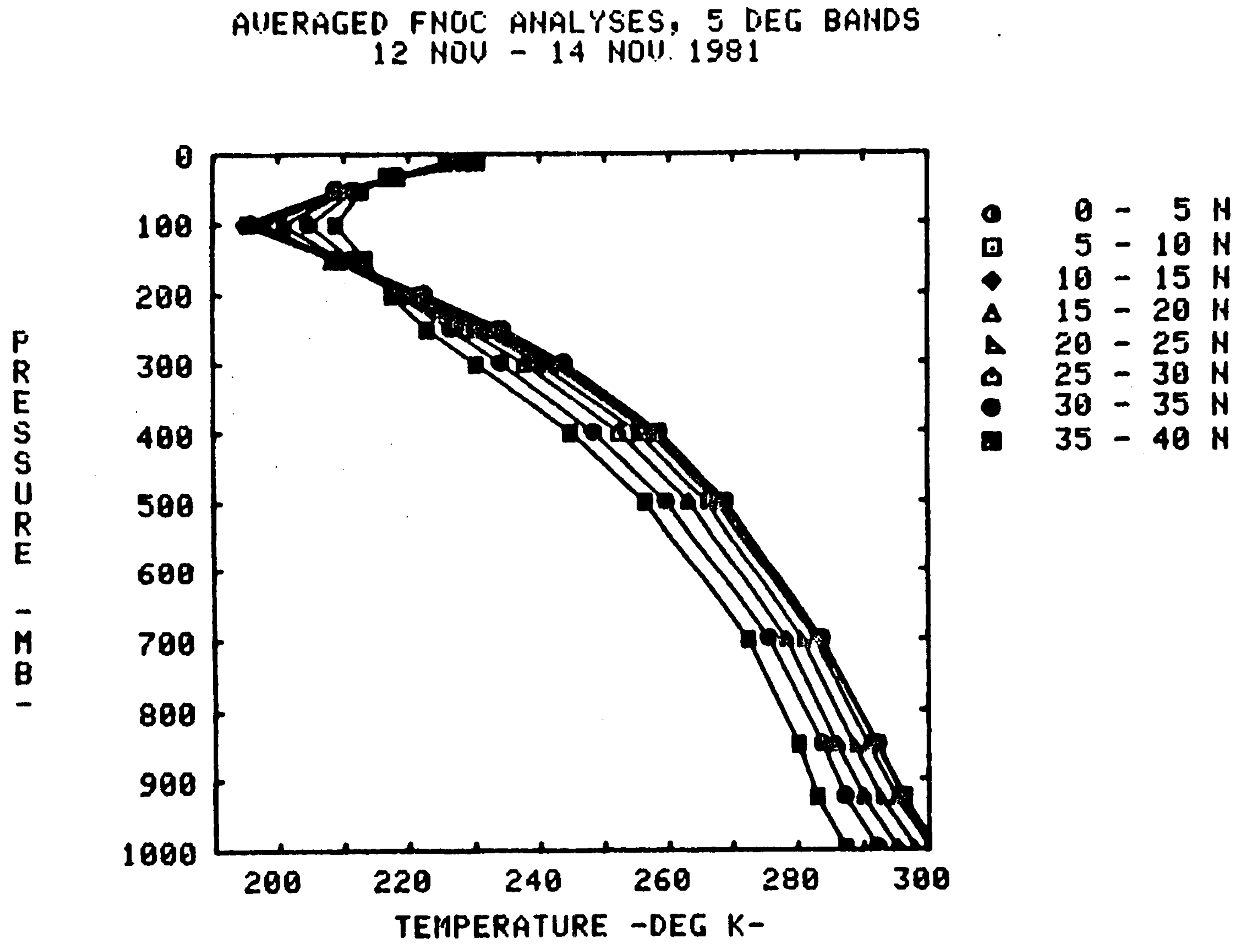


Fig. 4. Latitudinally averaged temperature profiles.

A graphics package originally developed at the National Center for Atmospheric Research (NCAR) has been implemented at the LaRC central computing complex. Among other capabilities, this package generates contour plots of equally spaced data and geographic outlines in nine different projections. This software was used to produce Fig. 5. It shows 50 mb temperature fields taken from an NMC analysis and drawn on top of a polar stereographic projection of the northern hemisphere. Contour plots of this type were used to compare meteorological analyses to actual measurements of atmospheric parameters.

Figure 6 combines the NCAR graphics capabilities with the standard LaRC graphics library programs. It enables a rapid association of inferred CO values with the locations where the data were acquired.

Another use of computer generated graphics as a data analysis tool is illustrated in Fig. 7. The cyclic variations with time of the V channel signal and of the internal reference blackbody (BB1) temperature are evident. This and similar plots revealed the two second time delay in the V channel response to a change in the temperature of BB1.

INFORMATION PROCESSING

In parallel with the development of the MAPS experiment itself, the experiment team interfaced with other persons and organizations involved with the entire OSTA payload and the Space Transportation System. Through working group sessions, telecons, documentation, and memos, operational procedures were agreed upon which maximized the achievement of objectives by all experimenters and complied with shuttle operational and safety requirements. ODU researchers participated in meetings such as the Payload Operations Working Group (POWG) at JSC and the Payload Ground Operations Working

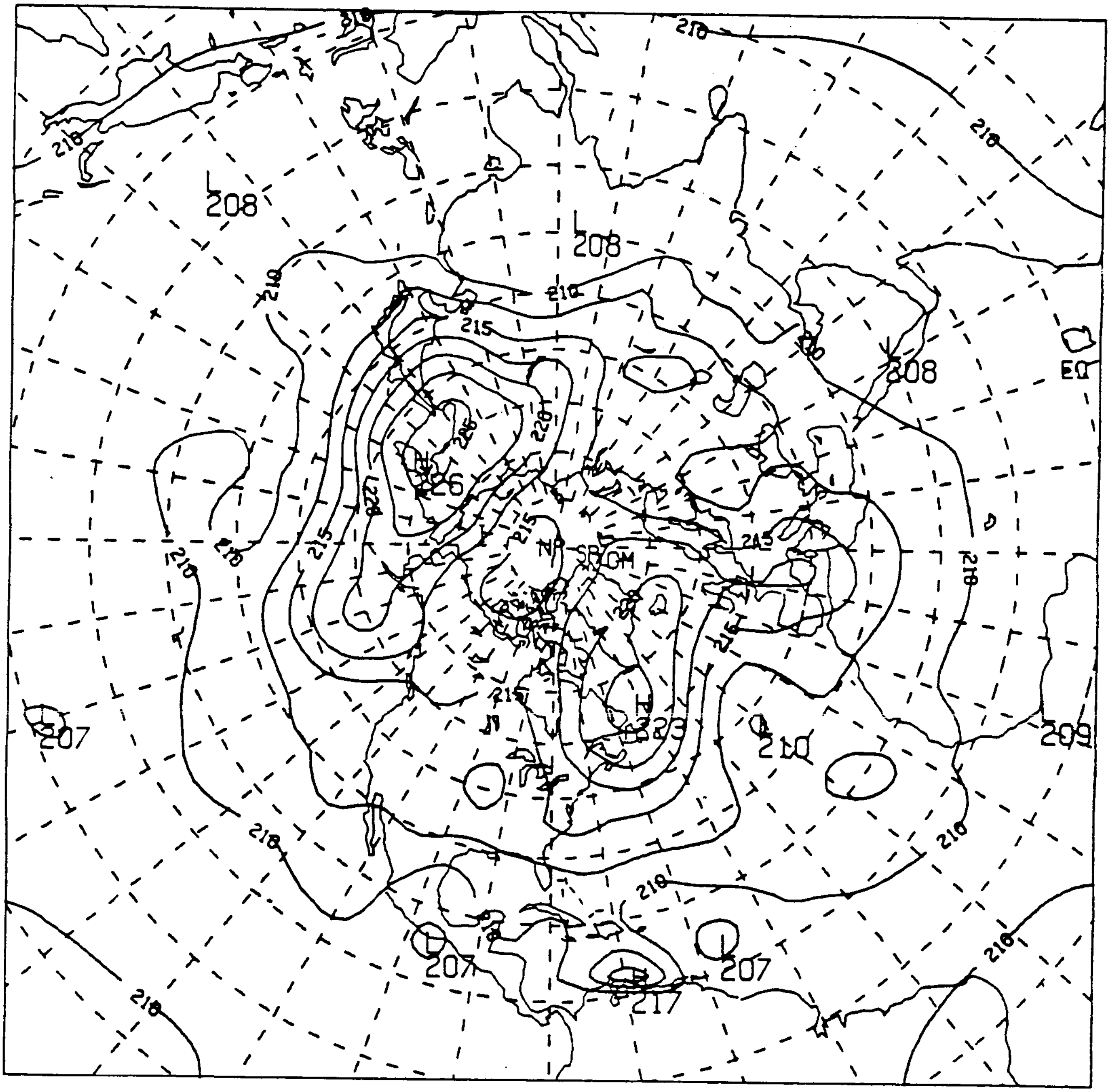


Fig. 5. 50 mb temperature fields for October 6, 1984, 12 Z.

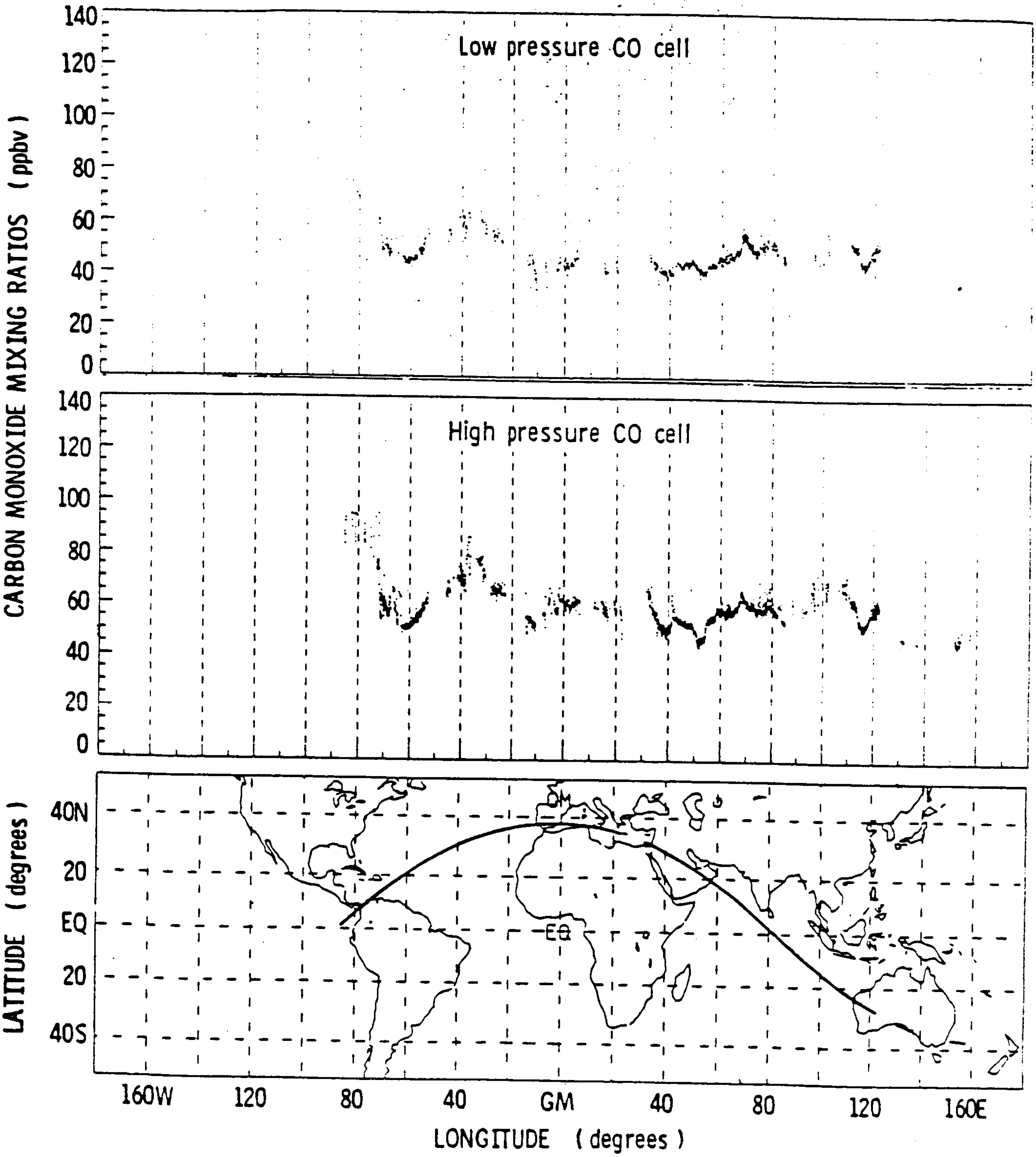


Fig. 6. CO mixing ratios measured by the MAPS experiment during Orbit 31 of flight STS-2/OSTA-1.

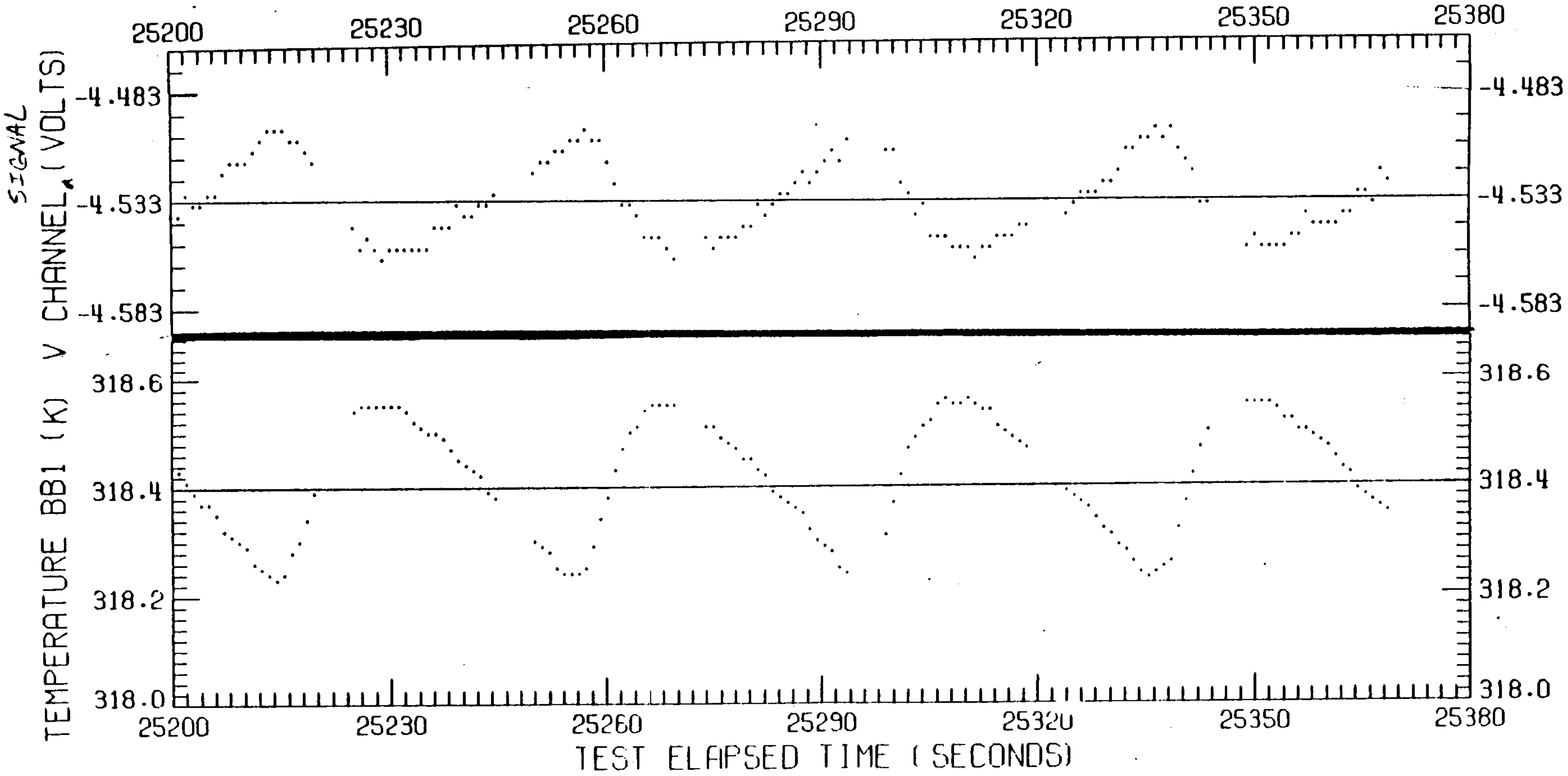


Fig. 7. Cyclic variations with time of internal reference blackbody (BB1) temperature and V channel voltage.

Group (PGOWG) at KSC. Among the volumes of documentation which ODU personnel helped draft, review, modify, and review again were the Test and Assembly Procedures (TAP), the Ground Interface Requirements Document (GIRD), and the Payload Integration Plan (PIP).

ODU researchers were active in other avenues of scientific and technological exchange. They gave oral presentations at events ranging from university seminars to international scientific conferences. They authored and co-authored technical papers for both internal use and public circulation. Appendix II is a listing of the journal articles, technical papers, and oral presentations of ODU personnel during the period covered by this report.

The MAPS experiment has been guided since its inception by a Science Team drawn from academia and research organizations located across the nation and abroad. Not only have these scientists provided expertise during the design and data collecting phases of the experiment, but also they have interest in further specialized study of the data acquired. To facilitate their studies, members of the Science Team have been provided data ranging in format from copies of magnetic tapes containing meteorological analyses to multicolored plots of the global distribution of inferred CO.

The OSTA-1 data set is currently available to the scientific community at large through the National Space Science Data Center (NSSDC) in Washington, D.C. In addition to the inferred CO data, relevant time, trajectory, and meteorological parameters, along with supporting documentation, were turned over to the NSSDC. Likewise, when the OSTA-3 data reduction has been completed, this data set will also be achieved at the NSSDA.

APPENDIX I

ODURF TN NCC1-34-85-15

MEMORANDUM

TO: Warren Hypes

FROM: Joe Casas and Mary Saylor

SUBJECT: MAPS OSTA-3 Calibration

DATE: August 5, 1985

V CHANNEL

1. Generate time history of the emitting surface of BB-1

   a. $\tau \equiv$ period of BB1 (seconds) is given by a simple regression equation (See attachment A)

   b. $A_c \equiv$ peak to peak amplitude is 0.33 K and is independent of mainframe temperature TBB2

   c. V channel signal output lags the BB1 thermistor reading by 2 seconds and is independent of TBB2

2. $N_{DATA} = (1/R) * (V_{DATA} - OFFSET) + N_{BB1}$

   a. R $\equiv$ V channel responsivity as a function of TBB2 (K) (See attachment B)

   b. OFFSET $\equiv$ V channel offset voltage as a function of TBB2 (K) (See attachment C)

   c. NBB1 = radiance of BB1 as a function of TBB1 (K) (See attachment D)

ΔV and ΔV' Channels

1. Calculate $\Delta V_{zero\ ref}$ and $\Delta V'_{zero\ ref}$ voltages using the bivariate fit coefficients (See attachments E and F).

   a. $\Delta V_{zero\ ref}$ (V,TBB2), where V is the V channel signal in volts and TBB2 is the mainframe temperature TBB2 (K)

b. $\Delta V'_{zero\ ref}$ (V,TBB2), where V is the V channel signal in volts and TBB2 is the mainframe temperature TBB2 (K)

c. Program CKFIT84/UN=777475E

2. a. $\Delta N_{DATA} = (1/R_{\Delta V}) * (\Delta V_{DATA} - \Delta V_{zero\ ref})$

$R_{\Delta V}$ = the responsivity of the ΔV channel as a function of TBB2 (See attachment G)

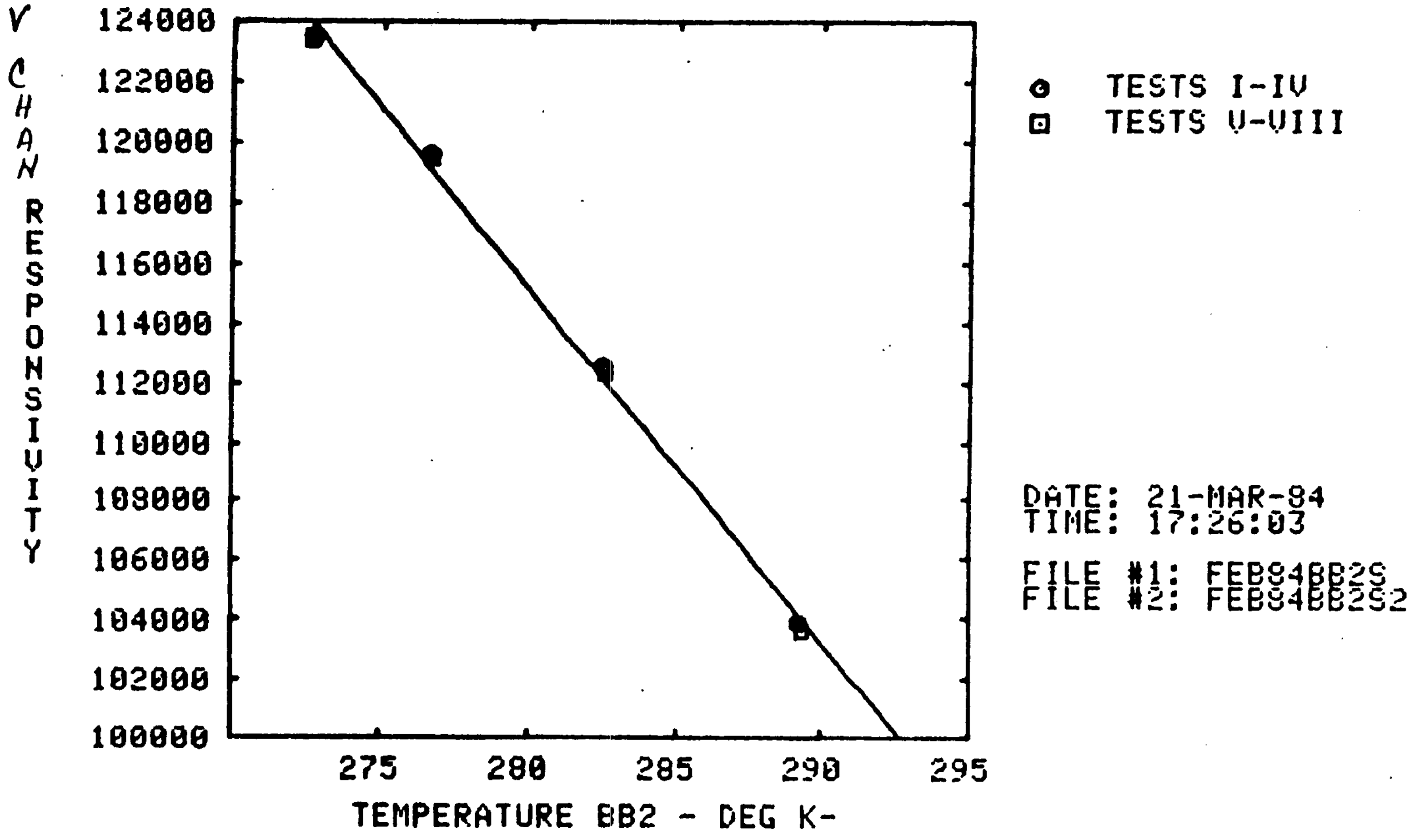
b. $\Delta V'_{DATA} = (1/R_{\Delta V'}) * (\Delta V'_{DATA} - \Delta V'_{zero\ ref})$

$R_{\Delta V'}$ = the responsivity of the ΔV' channel as a function of TBB2 (See attachment H)

3. This approach should be used on the OSTA-3 flight data during periods of temperature stable conditions for TBB2, i.e., when the data are taken at a TBB2 temperature which is within 1.5 K of the TBB2 temperature during the balance cycle.

4. Results of the ΔV' channel responsivity (spread in data) reflect a need for further study as previously discussed. Several approaches could be taken.

MAPS THERMAL VACUUM TEST 2/84
TESTS I - VIII



DATE: 21-MAR-84
TIME: 17:26:03

FILE #1: FEB84BB2S
FILE #2: FEB84BB2S2

Attachment B

```
SELECT BEST FIT

EQUATION
     A                 B               RES ERROR    R-SQUARE     MAX DEVIATION

Y = A*X
 4.0879E+002                         1.3582E+008 -8.0057E-001    1.4670E+004

Y = A + B*X
 4.4944E+005     -1.1940E+003        2.1662E+005  9.9713E-001    5.2673E+002

Y = A*EXP(B*X)
 2.1956E+006     -1.0537E-002        4.6198E+005  9.9388E-001    7.6359E+002

Y = 1/(A + B*X)
-1.7373E-005      9.3204E-008        8.2393E+005  9.8908E-001    1.0404E+003

Y = A + B/X
-2.2122E+005      9.4129E+007        3.7039E+005  9.9509E-001    6.5228E+002

Y = A + B*LOG(X)
 2.0045E+006     -3.3531E+005        2.8795E+005  9.9618E-001    5.8999E+002

Y = A*X↑B
 1.9946E+012     -2.9585E+000        5.6695E+005  9.9248E-001    8.3088E+002

Y = X/(A + B*X)
-7.3418E-003      3.4958E-005        1.1169E+006  9.8519E-001    1.1833E+003

 EQUATION Y = A + B*X HAS MAXIMUM R-SQUARE

 EQUATION Y = A + B*X HAS MINIMUM MAXIMUM ABSOLUTE RESIDUAL

USING SIMPLE REGRESSION USER DEFINABLE KEYS, SELECT THE FIT YOU WANT
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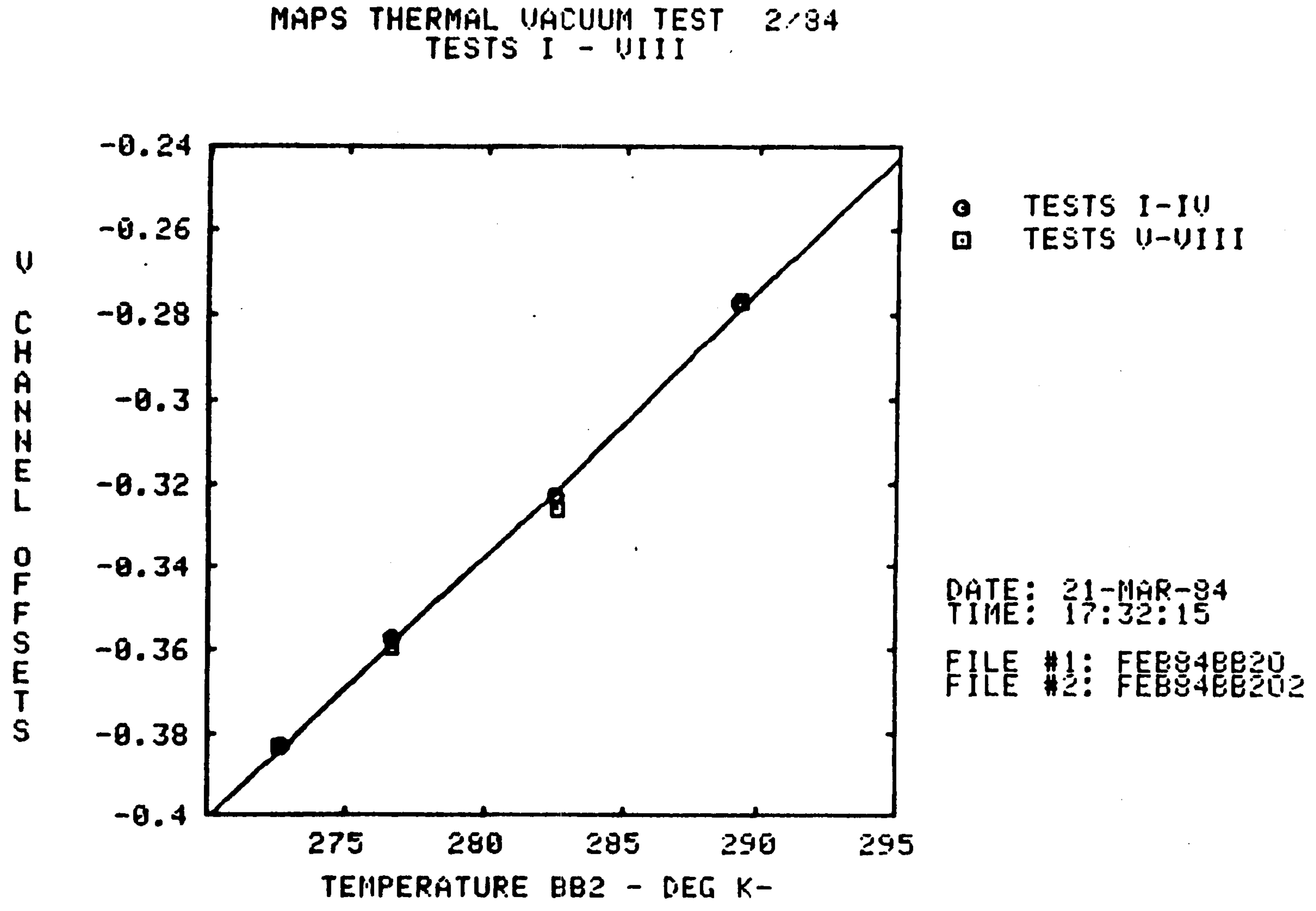
V chan
Slopes Tests I - VIII

31-MAR-84

Attachment B (Con.)



Attachment C

```
SELECT BEST FIT

EQUATION                                  RES ERROR    R-SQUARE      MAX DEVIATION
       A                 B

Y = A*X                                   2.9945E-003 -4.1258E-001   6.8891E-002
-1.1943E-003

Y = A + B*X                               5.3220E-006  9.9749E-001   4.4912E-003
-2.1101E+000        6.3308E-003

Y = A + B/X                               8.7722E-006  9.9586E-001   5.3208E-003
 1.4462E+000       -4.9919E+002

Y = A + B*LOG(X)                          6.8964E-006  9.9675E-001   4.9088E-003
-1.0356E+001        1.7781E+000

 EQUATION Y = A + B*X HAS MAXIMUM R-SQUARE

 EQUATION Y = A + B*X HAS MINIMUM MAXIMUM ABSOLUTE RESIDUAL

USING SIMPLE REGRESSION USER DEFINABLE KEYS, SELECT THE FIT YOU WANT
```

Tests I - VIII,
V. Chan offsets
31-MAR-84

Attachment C (Cont.)

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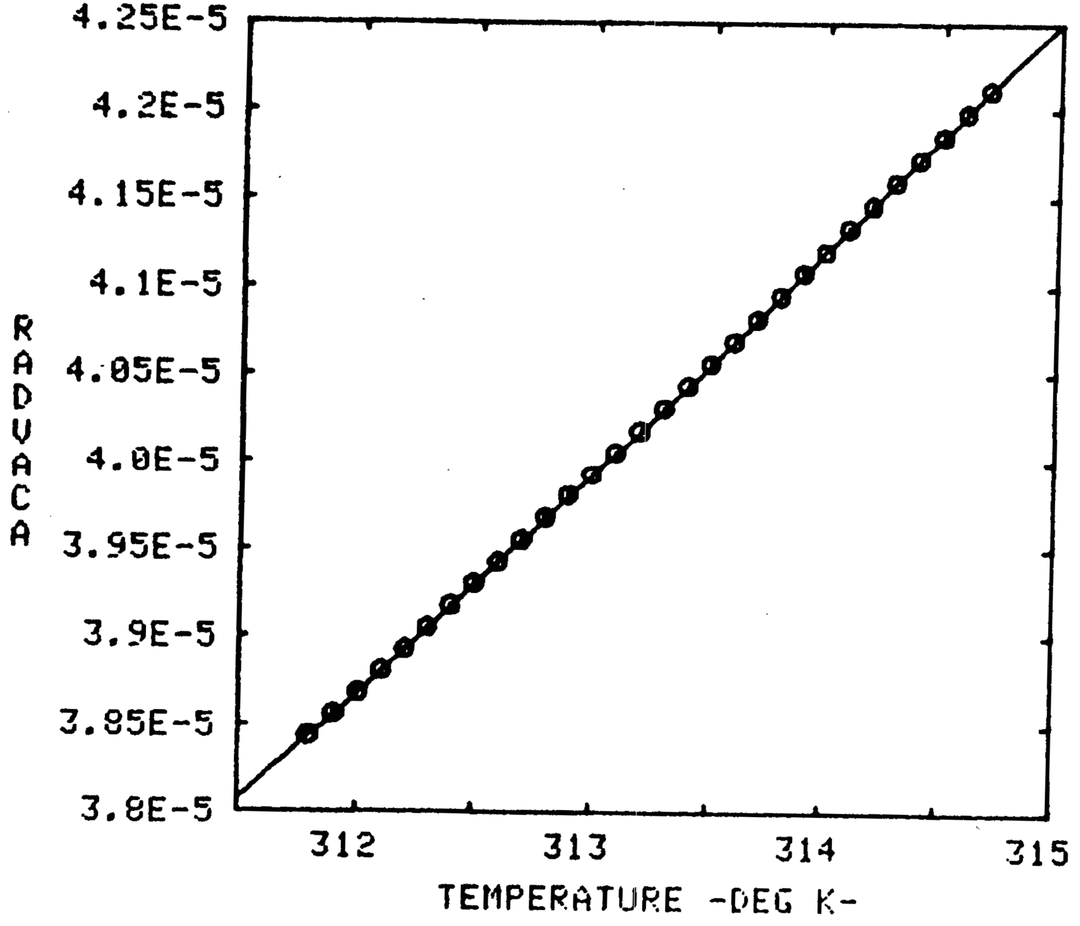

● INT REF BB1

≈ 313.3

DATE: 26-JAN-84
TIME: 16:52:36

FILE #1: TV1083BB1 ≠ 53

" BB1 Rigmo RAD 1083 "
(Stand values)

$Y = AX^B$

Attachment D

```
SELECT BEST FIT
EQUATION                                 RES ERROR    R-SQUARE     MAX DEVIATION
        A                B
                                         1.0456E-012  1.9213E-001  1.6742E-006
Y = A*X
 1.2850E-007
                                         1.2451E-016  9.9990E-001  2.2114E-008
Y = A + B*X              1.2697E-006
-3.5750E-004
                                         7.4740E-018  9.9999E-001  5.4218E-009
Y = A*EXP(B*X)           3.1554E-002
 2.0508E-009
                                         2.7738E-016  9.9979E-001  3.4931E-008
Y = 1/(A + B*X)         -7.8448E+002
 2.7060E+005
                                         1.9500E-016  9.9985E-001  2.7641E-008
Y = A + B/X             -1.2459E-001
 4.3798E-004
                                         1.5779E-016  9.9988E-001  2.4878E-008
Y = A + B*LOG(X)         3.9774E-004
-2.2456E-003
                                         1.8109E-018  1.0000E+000  2.7955E-009
Y = A*X↑B                9.8842E+000
 8.6048E-030
                                         1.9149E-016  9.9985E-001  2.8987E-008
Y = X/(A + B*X)         -2.2088E+005
 7.6979E+007
EQUATION Y = A*X↑B HAS MAXIMUM R-SQUARE
EQUATION Y = A*X↑B HAS MINIMUM MAXIMUM ABSOLUTE RESIDUAL
USING SIMPLE REGRESSION USER DEFINABLE KEYS, SELECT THE FIT YOU WANT
```

TV1083331
26-JAN-84

Attachment D (Cont.)

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```
  PROGRAM CKFIT       73/17
)=-LONG/-OT,ARG= COMMON/-FIXED,CS= USER/-FIXED,DB=-TB/-SB/-SL/-ER/-ID/-PMD/-ST,PL=500
FN5,I=CKFIT84,L=LISTCK,OPT=2.

            PROGRAM CKFIT (TAPE4,OUTPUT)
            DIMENSION BDV(3,3),BDVP(3,3),A(3),AP(3)
      C *****  COEFFICIENTS ENTIRE TEST (TESTS I - VIII)
            DATA BDV /
           *    6.404454E-01, 9.687657E-03, -3.919071E-05,
           *   -9.545659E-01, 7.685837E-03, -1.470475E-05,     Attachment E
           *   -1.327136E-01, 9.566349E-04, -1.746016E-06/
            DATA BDVP /
           *    2.851316E+00,-1.684088E-02,  2.566835E-05,
           *   -2.177732E+00, 1.531484E-02, -2.716984E-05,     Attachment F
           *   -4.896634E-01, 3.510853E-03, -6.327937E-06/
      C
            PRINT 910
        910 FORMAT (///"    TBB2          V",13X,"DV      FIT_DV       DIFF",
           *    12X,"DVP   FIT DVP       DIFF"/)
          5 READ (4,456,END=500) V,DV,DVP,T
        456 FORMAT (19X,3F6.3,F7.2/)
            DO 30 I = 1,3
            A(I) = BDV(1,I) + BDV(2,I)*T + BDV(3,I)*T**2
            AP(I) = BDVP(1,I) + BDVP(2,I)*T + BDVP(3,I)*T**2
         30 CONTINUE
            CDV = A(1) + A(2)*V + A(3)*V**2


  PROGRAM CKFIT       73/17    OPT=2,ROUND= A/ S/ M/-D,-DS      FTN 5.1+587          84/04

            CDVP = AP(1) + AP(2)*V + AP(3)*V**2
            RDV = DV - CDV
            RDVP = DVP - CDVP
            PRINT 900, T,V,DV,CDV,RDV,DVP,CDVP,RDVP
        900 FORMAT (F8.2,F10.3,5X,3F10.3,5X,3F10.3)
            GO TO 5
        500 STOP
            END


 MAP--(LO=A)
)DRESS --BLOCK-----PROPERTIES-------TYPE---------SIZE     -NAME---ADDRESS --BLOCK----
```

Program file CKFIT84/
UN=777475E

V = V-Channel (volts)

T = T_{BB2} (°K)

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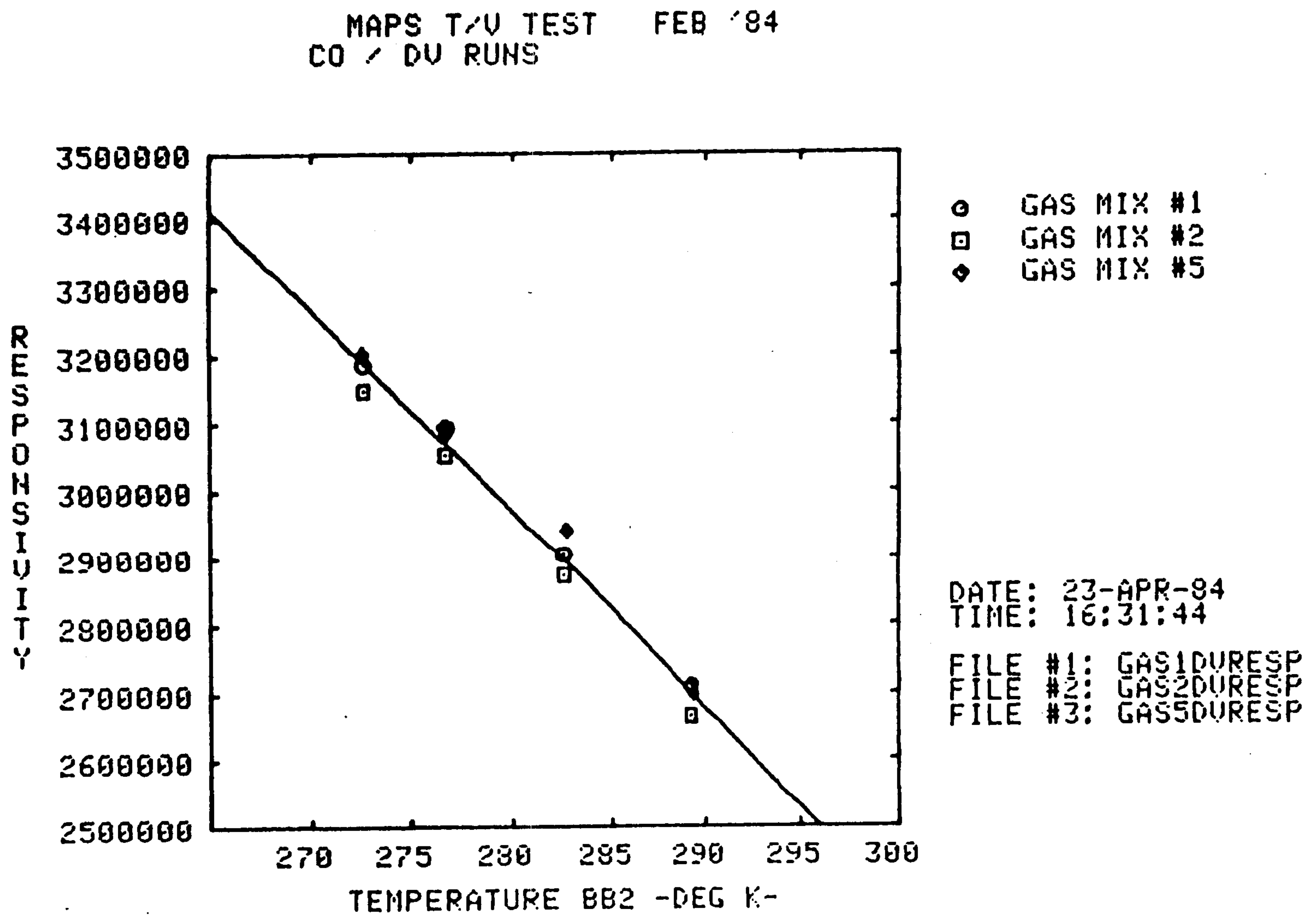


Attachment G

```
SELECT BEST FIT

EQUATION
        A                   B              RES ERROR    R-SQUARE     MAX DEVIATION

Y = A*X
 1.0551E+004                               7.6738E+010 -8.2810E-001   3.8784E+005

Y = A + B*X
 1.1247E+007       -2.9556E+004            7.0934E+008  9.8310E-001   4.7940E+004

Y = A*EXP(B*X)
 5.0115E+007       -1.0098E-002            8.2860E+008  9.8026E-001   5.3818E+004

Y = 1/(A + B*X)
-6.3014E-007        3.4574E-009            1.0045E+009  9.7607E-001   5.9652E+004

Y = A + B/X
-5.3552E+006        2.3302E+009            7.8772E+008  9.8123E-001   5.1750E+004

Y = A + B*LOG(X)
 4.9742E+007       -8.3007E+006            7.4553E+008  9.8224E-001   4.9859E+004

Y = A*X↑B
 2.5715E+013       -2.8353E+000            8.8212E+008  9.7899E-001   5.5696E+004

Y = X/(A + B*X)
-2.7236E-004        1.3111E-006            1.1544E+009  9.7250E-001   6.3291E+004

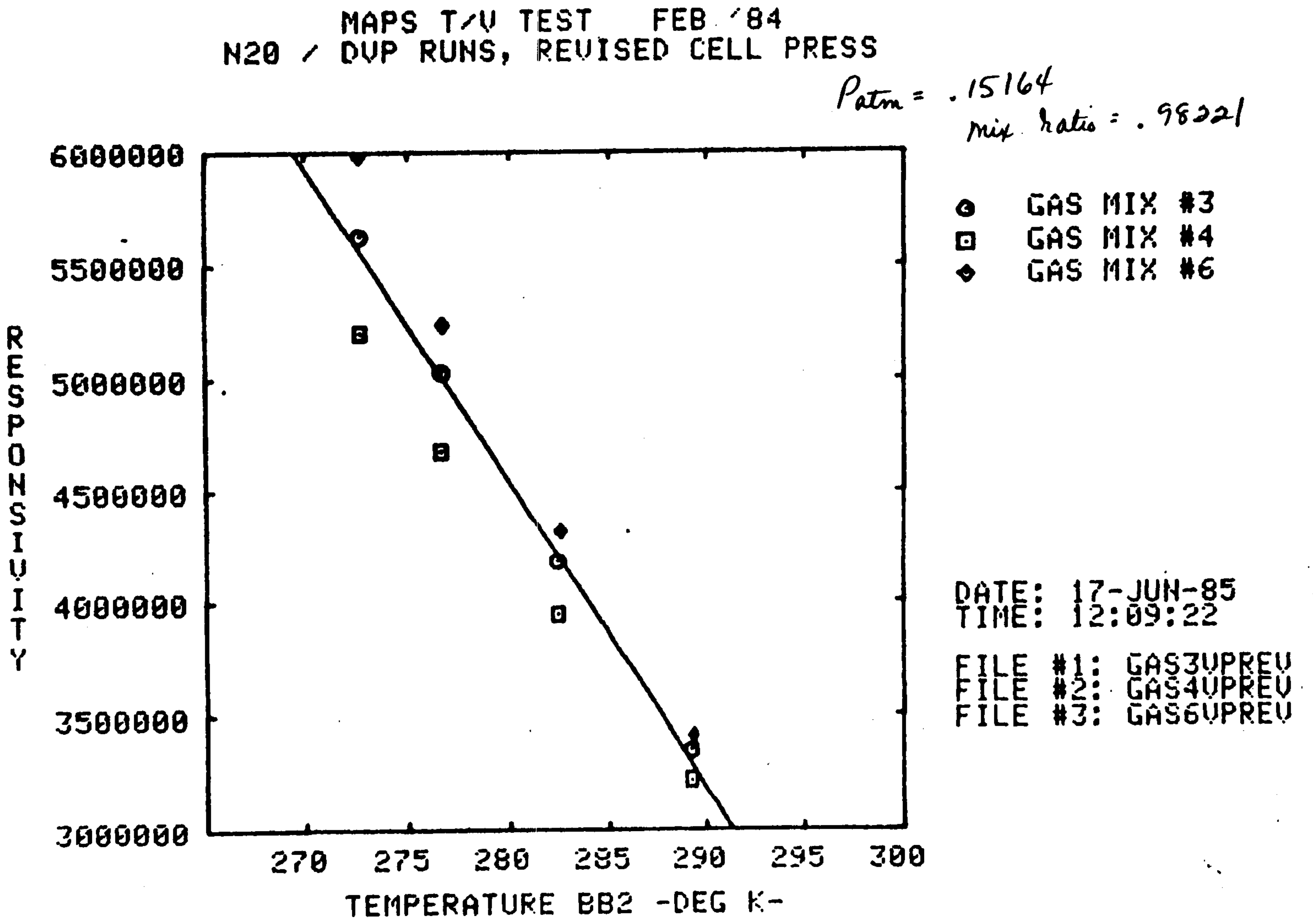
 EQUATION Y = A + B*X HAS MAXIMUM R-SQUARE

 EQUATION Y = A + B*X HAS MINIMUM MAXIMUM ABSOLUTE RESIDUAL

USING SIMPLE REGRESSION USER DEFINABLE KEYS, SELECT THE FIT YOU WANT
```

CAS1,2,5 DV RESP
03-APR-84

Attachment G (Cont.)



P_{atm} = .15164
mix ratio = .98221

#53
(random)

Attachment II

```
SELECT BEST FIT

EQUATION
        A                B                 RES ERROR    R-SQUARE     MAX DEVIATION

Y = A*X
 1.6028E+004                            1.1631E+012 -2.3279E-001    1.6157E+006

Y = A + B*X
 4.2944E+007    -1.3712E+005            5.8105E+010  9.3841E-001    4.1445E+005

Y = A*EXP(B*X)
 2.9644E+010    -3.1433E-002            5.6513E+010  9.4010E-001    4.1582E+005

Y = 1/(A + B*X)
-1.8347E-006     7.3692E-009            6.6879E+010  9.2911E-001    5.2233E+005

Y = A + B/X
-3.4136E+007     1.0827E+010            5.6869E+010  9.3972E-001    3.9816E+005

Y = A + B*LOG(X)
 2.2170E+008    -3.8538E+007            5.7423E+010  9.3913E-001    4.0626E+005

Y = A*X↑B
 1.7961E+028    -8.8289E+000            5.6971E+010  9.3961E-001    4.2503E+005

Y = X/(A + B*X)
-5.8041E-004     2.3026E-006            7.0947E+010  9.2480E-001    5.4506E+005
 EQUATION Y = A*EXP(B*X) HAS MAXIMUM R-SQUARE

 EQUATION Y = A + B/X HAS MINIMUM MAXIMUM ABSOLUTE RESIDUAL

USING SIMPLE REGRESSION USER DEFINABLE KEYS, SELECT THE FIT YOU WANT
```

Attachment II (Cont.)

APPENDIX II

Journal Articles

Doherty, G. M., Casas, Condon, Newell, Reichle, Wallio, "Analysis of Remote Measurements of Tropospheric Carbon Monoxide Concentrations Made During the 1979 Summer Monsoon Experiment," J. Geophysical Research.

Reichle, H. G., Jr., Beck, Haynes, Hesketh, Holland, Hypes, Orr, Sherrill, Wallio, Casas, Saylor, Gormsen, 1982. "Carbon Monoxide Measurements in the Troposphere," Science, Vol. 218, No. 4576.

Reichle, H. G., Jr., Connors, Holland, Hypes, Wallio, Casas, Gormsen, Saylor, Hesketh, "Middle and Upper Tropospheric Carbon Monoxide Ratios as Measured by a Satellite Borne Remote Sensor During November 1981," submitted to J. Geophysical Research - Atmospheres (Nov. 1985).

Wallio, H. Andrew, Casas, Gormsen, Reichle, Saylor, 1983. "Carbon Monoxide Mixing Ratio Inference from Gas Filter Radiometer Data," J. Applied Optics, Vol. 22, No. 5.

Other Technical Papers

Casas, J. C., Koziana, Saylor, 1982. "Development of Data Processing, Interpretation and Analysis System for the Remote Sensing of Trace Atmospheric Gas Species," NASA Grant NCC1-34, ODU Technical Report GSTR No. 82-6.

Hesketh, Wilfred D., Sherrill, Holland, Haynes, Casas, 1986. "The Development and Flight of a Gas Filter Correlation Radiometer for Measuring the Global Distribution of Carbon Monoxide from Space," NASA TP.

Koziana, James V. 1982. "The Use of a Gas Filter Correlation Radiometer to Measure Atmospheric Carbon Monoxide," thesis presented to Old Dominion University.

Lambeth, James D. 1983. "The Effect of Wind Shear and Domain Size on a Warm Cumulus Cloud," thesis presented to Old Dominion University.

Orr, Harry D., III, Wallio, Reichle, Gormsen, Casas, Saylor, 1983. "Review of the Data Management Procedures for the MAPS/OSTA-1 Experiment," NASA TP.

Conference and Oral Presentations

Fourth Conference on Atmospheric Radiation of the American Meteorological Society, Toronto, Canada (1981):

Henry G. Reichle, Jr., Condon, Saylor, "First Results of the MONEX Remote Sensor Measurements of Carbon Monoxide"

H. Andrew Wallio, Reichle, Casas, Gormsen, "A New Method for Inferring Carbon Monoxide Concentrations from Gas Filter Radiometer Data"

Virginia Academy of Science, Norfolk, Virginia (1981):

James V. Koziana, "A Comparison of the Initial Data Used by the Fleet Numerical Oceanographic Center and the National Weather Service Utilizing a Barotropic Primitive Equation Model"

James V. Koziana and James D. Lambeth, "An Evaluation of Satellite Data Utilizing a Primitive Equation (PE) Barotropic Model"

Virginia Academy of Science, Blacksburg, Virginia (1982):

James V. Koziana, "Evolution of a Passive Remote Sensor to Measure Atmospheric CO"

James V. Koziana, "CO Measurements Around St. Petersburg, Florida, in August 1978"

James D. Lambeth, "An Interpolation Technique to Obtain Meteorological Parameters from FNOC and NMC Data Tapes"

Mary S. Saylor, "Preliminary Results of the Measurement of Air Pollution from Satellites (MAPS) Experiment Flown Aboard the STS-2 (Shuttle)"

Department of Geophysical Sciences Seminar Series, ODU, Norfolk, Virginia (1982):

Joseph C. Casas, "A Review of the STS-2 Mission"

Fleet Numerical Oceanography Center, Monterey, California (1982):

Joseph C. Casas, "Applications of FNOC Meteorological Data to the MAPS/OSTA-1 Experiment"

AIAA Aerospace Sciences Meeting, Reno, Nevada (1984):

Warren D. Hypes and Joseph C. Casas, "Flying a Scientific Experiment Aboard the Space Shuttle -- A Perspective from the Viewpoint of the Experimenter"