STRATOSPHERIC EMISSION DATA ANALYSIS

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<td>20. ABSTRACT (Continue on reverse side if necessary and identify by block number)</td>
<td>Analysis procedure developed for the AFGL SCRIBE (Stratospheric Cryogenic Interferometer Balloon Experiment) data is described.</td>
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</table>
Introduction

The work conducted under this contract constitutes a data-processing and data analysis part of the AFGL SCRIBE [Stratospheric Cryogenic Interferometer Balloon Experiment] program. Our participation may be summarized into three major categories:

1. extraction of the interferogram data from the PCM telemetry data tape;
2. processing of the interferogram data for spectral retrieval; and
3. analysis of the obtained atmospheric emission data.

The first successful balloon flight took place during the month of October 1980. Our effort prior to the flight for preparing various electronic hardware, as well as necessary computer software for the data processing, was proved to be effective when they were applied for processing the flight data which became available. We were able to extract the data without encountering difficulties and to analyze them successfully.

Our scientific report entitled "SCRIBE I Data Analysis" describes the technical aspect of our effort.\(^1\) A paper entitled "Measurement of atmospheric emission using a balloon-borne cryogenic Fourier spectrometer" was published in the Proceedings of the 1981 International Conference on Fourier Transform Infrared Spectroscopy.\(^2\)

\(^1\) H. Sakai, "SCRIBE I Data Analysis," AFRL-TR-81-0129, April 1981.
\(^2\) A copy is supplied with this final report.
The scheme developed under this contract proved its effectiveness for the data processing performed on the SCRIBE II data of October 1981. We are able to process more than 10 interferogram data a day.

In this final report, we focus our attention to the operational aspect of our processing scheme.

SCRIBE Program

A main goal of the SCRIBE program is to obtain the atmospheric emission spectral data at a balloon altitude of 30,000 m. The spectrometer's line of sight is set at a direction within a few degrees above the horizon. The spectrometer used for observation is a cat's eye retroreflector Michelson interferometer operated at liquid nitrogen temperature with a Ge:Hg or Ge:Cu detector. The infrared radiation which we want to observe is the various molecular bands of the atmospheric species emitted under the local thermal equilibrium condition at 230°K, which is the ambient temperature at 30 Km height.

The molecular density of major molecular species at the altitude is given in Table I.

Table I

<table>
<thead>
<tr>
<th>$n_o$, Molecular Density per cm$^3$ at 30 Km Altitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>H$_2$O</td>
</tr>
<tr>
<td>CO$_2$</td>
</tr>
<tr>
<td>O$_3$</td>
</tr>
<tr>
<td>CH$_4$</td>
</tr>
<tr>
<td>N$_2$O</td>
</tr>
<tr>
<td>CO</td>
</tr>
</tbody>
</table>
Accepting the atmospheric scale height of 8 Km, we can expect the total molecular column density $N$ per cm$^2$ approximately given by

$$N = n_o (8 \times 10^5)/\cos \theta,$$

where $\theta$ is the elevation angle of the sight line. At the altitude of 30 Km, the ambient pressure is an order of 10 mb. Both the collisional broadening process and the Doppler broadening process are equally important at the altitude of 30 Km. The molecular line profile $k(\sigma)$ with the Gaussian form is given by

$$k(\sigma) = \frac{S}{\alpha_d} \sqrt{\frac{\ln^2}{\pi}} e^{-\ln^2\left(\frac{\sigma - \sigma_0}{\alpha_d}\right)^2}$$

where $S$ is the total line strength which is computed by multiplying the total column density to the absorption strength $S_0$,

$$S = S_0 N = \int k(\sigma) d\sigma.$$

The Doppler line width $\alpha_d$ is a function solely determined by the temperature $T$, the molecular mass $m$, and the line center frequency $\sigma_0$:

$$\alpha_d = \frac{\sigma_0}{c} \sqrt{\frac{3kT}{m}}.$$

The emission radiance of a molecular line calculated under the single layer assumption is given by

$$E(\sigma) = B(\sigma,T) \left[1 - \exp\left(-\frac{s N}{\alpha_d} \sqrt{\frac{\ln^2}{\pi}} e^{-\ln^2\left(\frac{\sigma - \sigma_0}{\alpha_d}\right)^2}\right)\right],$$

where $B(\sigma,T)$ is the blackbody radiation function at $\sigma$ and $T$.

If the molecular line broadening is controlled by the collisional process, the profile is Lorentzian:
\[ k(\sigma) = \frac{S_a c}{\pi [(\sigma - \sigma_o)^2 + \alpha_c^2]} . \]

Again we get

\[ S = \int k(\sigma) d\sigma. \]

The emission radiance of a molecular line calculated under the same assumption is given by

\[ E(\sigma) = B(\sigma, T) [1 - \exp \left( -\frac{S_a N c}{\pi [(\sigma - \sigma_o)^2 + \alpha_c^2]} \right)]. \]

The power available for observation of the molecular line is then determined by the radiance power \( E \) times the interferometer energy collecting power which is approximately \( 1.2 \times 10^{-4} \) steradian cm\(^2\) for our case. Taking the Doppler width of 0.0008 cm\(^{-1}\) and the blackbody radiance of \( 5 \times 10^{-6} \) W/steradian cm\(^2\) cm\(^{-1}\), the energy power for observation of a single molecular line at the 700 cm\(^{-1}\) region is found to be an order of \( 10^{-12} \) W, imposing two basic requirements for the measurement sensitivity. The detector must be extremely sensitive and the interferometer itself must be cooled to liquid nitrogen temperature.

The interferometer is driven at a rate of 30 sec to make a single complete scanning cycle. The interferogram data acquisition period lasts approximately 25 sec. The interferogram data are transmitted through the PCM telemetry link to the ground station at a rate of 11,000 72-bit words per second. The received telemetry signal is recorded on an analog tape [PCM tape] running at 60 ips. Together with the interferogram signal in a digital sequence are the PCM synchronization code, the other housekeeping signals, the time code, etc. The time code provides the information on the time of recording with the Greenwich standard time.
Extraction of the interferogram data from the PCM tape

The operation is performed using an analog TAPE recorder/playback machine, a time code generator, a PCM signal decoder, a home-made interface electronics, a PDP11 computer with a RK11 disk and a TM11 magnetic tape transport. The operational sequence is detailed below. The PDP11 computer is operated under the RT11 system software. The software written for the data transfer between the DR11B parallel input to the RK11 disk is listed in our Scientific Report I.

1. Mount the PCM tape on a playback unit. Connect the PCM signal output to a PCM decoder and the time-code output to a time-code generator.

2. Play back the PCM tape. Set the PCM decoder for a proper synch word and a proper frame word. Observe the bit pattern displayed on the PCM decoder unit. The time-code generator displays the time recorded on the PCM tape.

3. Start the PDP11. Bring the keyboard monitor up. Set the switch register to 105. Mount a magnetic tape to the TM11 tape transport. Initialize the magnetic tape by typing MT:Z under PIP. Bring back KB monitor.

4. Place the PCM tape at a proper position by checking the time code. Start the PCM tape.

5. Wait until the signal indicates the retrace mode (bit pattern 000000). Type [R A][] on the keyboard. The computer responds a bell signal indicating the program is ready. If the bell signal comes after completion of the retrace mode, go back to KB monitor and repeat the sequence (4) and (5).

6. If everything is OK, the computer signals the bell sound after it
transfers an interferogram data extracted from the PCM tape. During this period, no synch loss should occur. After the bell sound, the computer prints "DONE." Stop the PCM tape.

(7) Bring back KB monitor. Run PIP by typing R PIP. After USR responds by printing *, type MT:LFN.DAT<RK1:PCMRK1.DAT/M=1. Observe the data transfer from RK1:PCMRK1.DAT to MT:LFN.DAT (LFN; identification file name).

(8) Repeat (4) through (7) until the MT tape is full. [Normally 7 data transfers are required.]

(9) Demount the MT tape from the TM11 tape transport. Put a gummed label on the MT tape for its identification. The current label is shown below. It is preferred to have another gummed label, indicating all files on the tape.

ARFI12
SAKAI(WM5A)

Spectral recovery operation

Because of a convenience provided by the CDC computer system we have at the University of Massachusetts, in particular because of its convenient interactive feature, both the spectral recovery and the spectral analysis are performed using our central-site computing facility.

The input data for the spectral recovery process is the raw interferogram data recorded on a 7-track magnetic tape under the control of the RT11 system software.* The logical flow was described in our scientific report.

*The tape has a 7-track, odd-parity format recorded with 800 BPI density. A single data information consists of three files separated by the EOF mark, the directory, the data, and a single empty file ended by the EOF.
The decoding software was slightly modified from the source listing in our scientific report to the one in the Appendix for improvement of its operating efficiency. The phase correction, the Fourier transformation and the CRT plot software were those developed by us for other purposes, and their documentation would appear elsewhere. The processing scheme is sequenced as follows:

1. Run Program A shown in Figure 1 with a data tape ARFII2. The PCMDCC would have a file structure shown in Figure 2.

2. Use COPYBF utility program to copy the data to TAPE9.

3. Run the program on TREAD. The output result is on TAPE2.

4. Move the data on TAPE2 to TAPE8.
   Return, TAPE2, TAPE6, and TAPE9.

5. Rewind TAPE8.
   Run the program on SKXX.
   The sequences (2) through (5) are shown in Figure 3.

6. Inspect the printed numbers. An example of the printout is shown in Figure 4.
   Find where the gain switch occurs, and find M and N.
   Type M and N in (2I5) FORMAT
   The output is on TAPE1.

7. Rewind TAPE1.
   Run LFILFIX.
   Type all control parameters as asked.

8. Return, TAPE1
   Rewind, TAPE2
   Define TAPE3 for a direct access permanent file.
Run L1, L2, L3, and L4 consecutively.

The output on TAPE3 is a spectrum recorded in (1615) format. It is normalized to 1000 at the highest peak. See the example shown in Figure 4 for the sequence (7) and (8).

(9) Go back to (1).
Program A

WM5A. (JOB HSII code)
ACCOUNT ...........
VSN, TAPE1 = ARFI12.
LABEL (TAPE1, MT, D=800, LB=KU, F=S, PO=R)
Define, PMDCDC.
COPYBF, TAPE1, PMDCDC, n / n=3N-1 where N is the number of the raw interferogram data
DAYFILE, L=SKDFILE.
Replace, SKDFILE.
EXIT.
DAYFILE, L=SKDFILE.
Replace, SKDFILE.
/EOR/
/EOI/

Figure 1
Figure 2

<table>
<thead>
<tr>
<th>Directory 1</th>
<th>EOF</th>
<th>Data I</th>
<th>EOF</th>
<th>EOF</th>
<th>Directory 2</th>
<th>EOF</th>
<th>Data II</th>
<th>EOF</th>
<th>EOF</th>
</tr>
</thead>
</table>

Figure 3

/GET,TREAD,SKXX
/FTN,I=TREAD,L=0
  .271 CP SECONDS COMPILATION TIME
/FTN,I=SKXX,L=0,R=LQ
  .172 CP SECONDS COMPILATION TIME
/GET,LEVN,LFILFIX
/COPYBR,LEVN,L1=8
COPY COMPLETE.
/COPYBR,LEVN,L2=6
COPY COMPLETE.
/COPYBR,LEVN,L3=7
COPY COMPLETE.
/COPYBR,LEVN,L4=5
COPY COMPLETE.
/COPYBF,PCMDCC,X,n.
COPYBF,PCMDCC,TAPE9.
Rewind,TAPE9.
LCO
Rewind,TAPE2.
COPYCR,TAPE2,TAPE8.
Return,TAPE2,TAPE6,TAPE9.
Rewind,TAPE8.
LQ.
Gain switch occurred after this data point. N=1.

**ERROR NUMBER** 65 DETECTED BY IHPU AT ADDRESS 000152
**CALLED FROM** TT AT LINE 42
**3.617 SECONDS EXECUTION TIME.**

REWIND TAPE 1
REWIND TAPE 1

ENTER M, N, LACER
? 128 32768 1

ENTER NUMBER OF PIECES WHICH RLYE
? 1 1
ENTER FILTER ON, OFF
? 500 2000
FILTER FROM 193.75 TO 1974.75 ENTER 1 OR 0 FOR EXCM
? 1
M= 128 N= 32768 I= 4098
ENTER TRLK
? 500

MIN IS 3432 000 AT TIME 45 50 00 7 4 19
Spectral Analysis

The SCRIBE program is a technical challenge, attempting to achieve a good measurement on the atmospheric emission data which hitherto have been known to us rather poorly. Based on the primary goal set for the program, our analysis is designed to spot shortcomings which may exist on either the observed data or the presently existing theoretical model, without requiring an elaborate computational effort. In other words, our effort is focused to survey the observed data using a theoretically computed model which would provide a radiance figure within ±20% accuracy. The consideration dictated to us for our analysis effort is a cost and a speed of computation. The balloon data would be obtained anyway in a rather difficult circumstance with parameters which are determined with limited accuracies.

Upon considering these points, we decided to synthesize the theoretical spectrum primarily with an emphasis on the computational speed. At the same time the computational accuracy suffered to some extent, in order to achieve improved computational efficiency. Nonetheless, the spectral result obtained in the computation would serve to provide a reference for survey effort. We designed the computational algorithm to achieve a speed suitable for interactive study.

The atmospheric line listing compiled by the AFGL forms a theoretical base for our computation. From the beginning, we did not attempt to generate an accurate line profile in our computation, because both factors, insufficient spectral resolution and blending of lines, would conceal individual line profiles in the observed data. We did not attempt to use
the AFGL FASCOD\textsuperscript{1} for our computation because of the reason cited above.

The molecular absorptance $A(\sigma)$ at wavenumber $\sigma$ is calculated by

$$A(\sigma) = 1 - \exp\{-k_n(\sigma)\},$$

where $k_n(\sigma)$ is the line absorbance of a line $n$. The optical depth of the molecular line with which we deal in our calculation is in general relatively thin. The spectral resolution in the observed data is insufficient for allowing us to observe the individual line profile without a large distortion. Under these conditions, the absorptance averaged over a spectral resolution much wider than the individual line width, can be calculated by

$$\langle A(\sigma) \rangle_{AV} = 1 - \exp\{-\langle k_n(\sigma) \rangle_{AV} \}.$$ 

The averaging operation is taken over the resolution width; i.e., the absorbance $k_n(\sigma)$ is averaged over the lines which fall within the resolution width $\Delta \sigma$. If $n$ lines are in $\Delta \sigma$, the average absorbance $\langle k_n(\sigma) \rangle_{AV}$ is computed by

$$\langle k_n(\sigma) \rangle_{AV} = \frac{1}{\Delta \sigma} \langle S_n \rangle,$$

where $S_n$ is the line strength of the line $n$.

The energy is absorbed by the molecular system from the radiation field at a rate specified by the absorptance along the absorption path. The absorbed energy by the molecular system is redistributed within the entire system. If a thermal equilibrium is established at temperature $T$, the molecular system and the radiation field are in thermal equilibrium at that temperature. If the molecular system is capable of absorbing

\textsuperscript{1}C.A. Clough, F.X. Kneizis, and J.H. Chetwind, AFGL-TR-77-0164.
the radiation energy by the absorptance \(A(\sigma)\), the same molecular system establishes a thermal equilibrium with the radiation field which balances with the energy absorbed by the molecular system: i.e., \(A(\sigma)B(\sigma,T)\).

Therefore, the emitted energy by the molecular system to the radiation field is given by \(A(\sigma)B(\sigma,T)\).

![Diagram](image)

**Figure 5**

The situation described above is schematically shown in Figure 5. A thermal bath is a blackbody radiation of temperature \(T\). The molecular system absorbs the energy \(A(\sigma)B(\sigma,T)\) and transmits the energy \([1-A(\sigma)]B(\sigma,T)\). The absorbed energy \(A(\sigma)B(\sigma,T)\) is re-emitted isotropically from the molecular system, thereby establishing the energy balance.

The discussion made above for a single uniform layer can be extended for the case of multiple layers. If the system is as shown in Figure 6, the energy \(B(T_1)A_1\) emitted by the layer 1

<table>
<thead>
<tr>
<th>layer 1</th>
<th>layer 2</th>
<th>layer N</th>
</tr>
</thead>
<tbody>
<tr>
<td>(B(T_1)A_1)</td>
<td>(B(T_1)A_1(1-A_2))</td>
<td>(B(T_1)A_1(1-A_2)...(1-A_N))</td>
</tr>
<tr>
<td>(T_1)</td>
<td>(T_2)</td>
<td>(T_N)</td>
</tr>
</tbody>
</table>

**Figure 6**

14
becomes $B(T_1)A_1(1-A_2)\ldots(1-A_N)$ after it goes through the layers 2 through N. The emitted energy $B(T_2)A_2$ by the layer 2 yields $B(T_2)A_2(1-A_3)\ldots(1-A_N)$ at the output side of the N-th layer, and so forth. The total energy available at the output side of the N-th layer is calculated by summing all contributions:

$$E = \sum_{n=1}^{N} B(T_n) A_n \left( \prod_{j=n+1}^{N} (1-A_j) \right) + R(T_N) A_N.$$ 

The computation requires the line strengths computed for these temperatures. Since the calculations are for temperature lower than $300^\circ$K, no inherent difficulties exist. The line strength at temperature $T$ is calculated from the strength $S(T_s)$ at temperature $T_s$ by

$$S(T) = S(T_s) \frac{Q_v(T_s)Q_R(T_s)\exp(-E''/kT_s)}{Q_v(T)Q_R(T)\exp(-E''/kT)},$$

where $Q_v(T)$ and $Q_R(T)$ are the vibrational and rotational partition sum at temperature $T$.

There are two programs listed in the Appendix, one developed for the single layer computation and another for the multi-layer (up to 6) computation. The line listing input is TAPE2, and other control parameters are in TAPE5. The output spectrum produced on TAPE1 in (1615) format is a normalized emissivity with respect to the last layer (1000 for a unit emissivity). The program SPDG produces a spectrum smeared by sinc$^2$. The synthetic spectra shown in our scientific report were calculated using these programs.
PROGRAM TREAD( TAPE9, TAPE1, TAPE6, TAPE2, OUTPUT )

DIMENSION IA(2048), IC(2048)
DIMENSION ID(256), IE(512)

100 FORMAT (8(I1, DB))
101 FORMAT (16I5)
DATA IA*, IXB/777777B, 17000000B/
N=104

10 CONTINUE
DO 50 I=1, 256
   ID(I)=0,
50 CONTINUE

BUFFER IN(9, 1)(ID(1), ID(N))
IF (UNIT(9)) 11, 21, 31

11 CONTINUE
CALL TPDRCODE(ID, IE)
WRITE(6) IE(I), I=1, 256)
GO TO 10

20 CONTINUE
Rewind 6
J0=0
J1=1

20 CONTINUE
JA=1
DO 15 K=1, 8
   JB=JA+255
   READ(6)(IA(I), I=JA, JB)
   JA=JA+1
15 CONTINUE

DO 12 I=1, 2048
   IX=IA(1), AND, IXA
   IY=IA(1), AND, IXB
   IF (IY, NE, 15000000) GO TO 12
   IC(J)=IX
   J=J+1
12 CONTINUE

JJ=J-1
IF (J, LE, 1) GO TO 20
IF (J, GT, 1) JJ=J-1
JX=((JJ/16)*16)
IF (JX, GE, 16) WRITE(2, 101)(IC(I), I=1, JX)
   J0=JO+JX
   JY=JX+1
   J=1
   DO 13 I=JY, JJ
      IC(J)=IC(I)
      J=J+1
13 CONTINUE
IF (J0, LE, 81920) GO TO 20
41 CONTINUE
PRINT 101, J0
CALL EXIT
STOP
END

Copy could not be made or not permit fully indexed information.
SUBROUTINE TPUCODE(ID,IE)
DIMENSION ID(2),IE(2),IA(6),IB(5),IC(4)
DATA (IA(I),I=1,6)/777777770000000000B,777777770000B,77777777B/
177700000000000000B,7777777700000000B,77777777B/
DATA (IC(I),I=1,4)/1700B,170000B,1700000B/
I=1
J=1
DC 11 l=1,51
IX=ID(L),AND,IA(1)
IB(1)=SHIFT(IX,-36)
IX=ID(L),AND,IA(2)
IB(2)=SHIFT(IX,-12)
IX=ID(L),AND,IA(3)
IX=ID(L+1),AND,IA(4)
IU=SHIFT(IY,-48)
IZ=SHIFT(IX,12)
I6(3)=IZ+IZ
IX=ID(1+1),AND,IA(5)
IB(4)=SHIFT(IX,-24)
IE(5)=ID(L+1),AND,IA(6)
L=L+2
DO 12 K=1,5
IZ=IE(K),AND,IC(4)
IZ=IE(K),AND,IC(3)
IZ=IE(K),AND,IC(2)
IZ=IE(K),AND,IC(1)
IE(J)=SHIFT(IY,-12)+SHIFT(IZ,-2)+SHIFT(IZZ,B)+IX
J=J+1
12 CONTINUE
11 CONTINUE
IX=ID(L),AND,IA(1)
IB(1)=SHIFT(IX,-36)
IX=IB(1),AND,IC(4)
IY=IB(1),AND,IC(3)
IZ=IB(1),AND,IC(2)
IZ=IB(1),AND,IC(1)
IE(J)=SHIFT(IY,-12)+SHIFT(IZ,-2)+SHIFT(IZZ,B)+IX
RETURN
END
PROGRAM TT(TAPEB,OUTPUT,TAPE2=OUTPUT,INPUT,TAPE1)
DIMENSION IA(2048)
100 FORMAT(16I5)
      READ(B,100)(IA(I),I=1,2048)
      J=0
      DO 10 I=1,2048
      IF(IA(I).LE.0) GO TO 10
      J=J+1
10    CONTINUE
      J=2048-J
      JQ=(300+JJ)/16*16
      PRINT 100,J,JQ
      JK=300+JJ-64
      JL=JK+123
      WRITE(2,100)(IA(I),I=JK,JL)
      READ 100*JX,*JY
      JZ=JQ+(JX-3)*16+JY
      ISUMA=0
      ISUMB=0
      J=2048
      K=49
      DO 11 I=1,128
      ISUMA=ISUMA+IA(K)
      ISUMB=ISUMB+IA(J)
      K=K+1
      J=J+1
11    CONTINUE
      AAVE=FLOAT(ISUMA)/128.
      BAVE=FLOAT(ISUMB)/128.
      J=_FIX(AAVE)
      DO 12 I=1,F,JZ
      X=FLOAT(IA(I))
      Z=(X-AAVE)*5.64
      IA(I)=FIX(X)
12    CONTINUE
      JZ=JZ+1
      DO 13 I=1,JZ,2048
      GA(I)=IA(I)-IB
13    CONTINUE
      WRITE(1,100)(IA(I),I=49,2048)
      DO 14 K=1,56
      READ(B,100)(IA(I),I=1,2048)
      DO 15 I=1,2048
      IA(I)=IA(I)-IB
15    CONTINUE
      WRITE(1,100)(IA(I),I=1,2048)
14    CONTINUE
      CALL EXIT
      STOP
      END
Appendix C  
Source Program to calculate a synthetic spectrum (a single layer)

PROGRAM SPSPLUT1 TAPE1=200B, TAPE2=200B, OUTPUT=200B, TAPE5=200B, TAPE6
1=OUTPUT, TAPE8=200B;
INTEGER ID(6),DU
DIMENSION AG(0,2),IA(0,248),B(1,024)
DIMENSION D(8),DD(8)
DIMENSION QCSF(7)
DIMENSION RUIJ(7)
EQUIVALENCE (A(1)*1A(1)), (A(2049), B(1))
100 FORMAT(F10.3,E10.3,F5.4,F10.3,2A9,3A3,8A3)
102 FORMAT(16.5)
101 FORMAT(F16.10,4E16.4)
102 FORMAT(’SPECTRUM IS CALCULATED FROM ’, 10.4*’ CR -1 TD’,
1F10.4*’ CR -1 , ’)
105 FORMAT(4E10.3)
106 FORMAT(’END51 ’)
DATA (BD(1)) = 1.11, 3H 1.3H 2.3H 3.3H 4.3H 5.3H 6.3H 7.
DATA (K01(1)) = 1.1, 1.5, 1.0, 1.5, 1.0, 1.0, 1.5, 1.0
PI=3.1415926
T=330.
INDEX=0
N=1
G=.32
ALN2=AL06(2)
AX=v.12
T=375.
READ (5,106) (QCSF(I),I=1,7)
TIT=(TT-1)/(T*1)
PSUM=0.1
READector (S,101) WX,W,WA,WE
READector (S,102) N
WX=WXX(-1.)
WD=WXX512.
WE=WXX2.
WDD=(WX+WX) -(WA-WX)/(2.*WE)
JEND=IFIX(WDD)+1
WX=WA-WD
WXB=WXA+WLE*2.
WXC=WXB+WD
AX=WX
DO 10 I=1,30?2
A(I)=0.
10 CONTINUE
DO 20 J=1,JEND
IF. INDEX.EQ.0,2) GO TO 17
INDEX=0
20 CONTINUE
READ(2,100) PS,QR,(D(1),I=1,2),(1B(I),I=1,6)
DO 6 I=1,7
6 IF (1B(I), EU, BB(I)) GO TO
60 10 11

19
   7  AJ=K12J(1)
      QCONS=QS3(1)
      IF(P.LT.WXT) GO TO 11
      IF(P.GT.WXC) INDEX=1
      IF(N.NE.0) WRITE(6,100) P,0
     17 CONTINUE
      QA=Q*QCONS
      QX=(1.449)*11**D(2)
      QRI=(-(1/I))**AJ
      QA=QA*PSUM*QRI*(EXP(QX))
      QC=Q**SUM*QRI*(EXP(QX))
      WRITE(8,100) P,QC*(D(I),I=1,2),ID(I),I=1,6
      QD=QA/WX
      IF(N.NE.0) WRITE(6,105) D,QA,UB
      PR=(P-WX)/WX
      IPR=IFIX(PR) + 1
      A(IPR)=A(IPR) + QA
     12 CONTINUE
      IF(INDEX.NE.1) GO TO 11
     13 CONTINUE
      DO 15 I=1,2048
        X=A(I)
        IF(X.LE.10) GO TO 14
        IF(X.GE.740.) X=100.
        IF(X.LE.-670.) X=-100.
        A(I)=1.-(1./(EXP(X)))
     14 X=1000.*A(I)
        IA(I)=IFIX(X)
     15 CONTINUE
      WRITE(6,103) WX,WWB
      WRITE(1,102) (A(I),I=1,2048)
      IF=1025
      DO 16 I=1,1024
        A(I)=B(I)
        A(I)=0.
        B(I)=0.
        I1=I1+1
     16 CONTINUE
      GO TO 19
     21 CONTINUE
      INDEX=2
      GO TO 13
     19 CONTINUE
      WX=WXB
      WX=WX+WEY%2,
      WX=W*BWD
     20 CONTINUE
      CALL EXIT
      STOP
      END
Appendix D

Source Program to calculate a synthetic spectrum (6-layer)

PROGRAM HCO2GEN(TAPE=200B, TAPE2=200B, OUTPUT=200B, TAPE5=200B, TAPE6=200B)

C THIS PROGRAM IS MODIFIED FROM CO2GEN WHICH IS GOOD FOR
C ONE LAYER, and use FOR TO CALCULATE 6 LAYER ATMOSPHERE
C EACH LAYER HAS DIFFERENT TEMPERATURE AND DIFFERENT CONCENTRATION
C OF H2O, CO2, O3, N2O, CO, CH4, O2
INTEGER I0(I6), IA
DIMENSION A(I6,512), AA(I6,512), IA(I6)
DIMENSION IB(I8), ID(I8)
DIMENSION QCST(I8,I8), BB(I8), TT(I8)
DIMENSION ROT(I8), T(I8)
EQUIVALENCE (AA(I), IA(I))

100 FORMAT (10,3E10.3,5S,4,F16.3,7AY*5A8,A3)
101 FORMAT (16f16.4)
102 FORMAT (16f16.4)
103 FORMAT ( "SPECTRUM IS CALCULATED FROM " , F16.4 , " CM TO " ,
F16.4 , " CM-1" , ""
104 FORMAT (4E10.3)
105 FORMAT (7E10.3)
106 FORMAT (8F16.4)
107 FORMAT (8F16.4)
DATA (DD(I),I=1:7)/3H 1,3H 2,3H 3,3H 4,3H 5,3H 6,3H 7/
DATA (ROT(I),I=1:7)/1.5,1.0,1.5,1.0,1.5,1.0,1.5,1.0/
DATA C1,C2/1.1Y09E-12,1.338/
PI=3.1415926
INDEX=0
N=1
G=.32
ALN2=ALOG(2.)
AX=0.12
TEP=.295
READ (5,107) (T(1),1=1:6)
DO 1 I=1:6
READ (5, 08) (QCST(I,J),J=1:7)
1 CONTINUE
READ (5,101) WX,W,WA,WB
READ (5,102) N
DO 3 I=1:6
3 TTI(I)=(TT(I)-TEP)/(TEP*TT(I))
WRITE(6,107) (TT(I),I=1:6)
WRITE (6,106) ((QCST(I,J),J=1:7),I=1:6)
PSUM=0.1
WX=W*X(-1.)
WD=W*X*80.
WE=WD*2.
WDD=((WE+WX)-(WA-WX))/(2.*WE)
JEND=IFIX(WDD)+1
WXA=WA-WD
WXB=WXA+WE*2.
WXC=WXB+WD
AX=WX
DO 9 J=1,3
DO 10 I=1:512
A(J,I)=0.1

21
CONTINUE
10 CONTINUE
   DO 60 J=1,NEN
      INDEX=0
   11 CONTINUE
      READ (2,100) F*,Q*,(B(I),I=1,2),(ID(I),I=1,6)
      IF (F*,.LE.WXA) 60 TO 11
      IF (F*,.LE.WXC) INDEX=1
      GO TO 17
      6 IF (ID(I),.NE.,0,0) GO TO 7
      GO TO 11
   7   a=K01(K,I)
      IF (A,A,0) WRITE(6,100) Pr0
         DO 17 K=1,6
         QC0ST=QC0ST(K,I)
         QA=QA*K0ST
         QX=(1.455)**(11.0*K0ST
         QRT=(A*K0ST)/K0ST
         QA=QA*P0*0.5*(1.0+QRT)
         QC0ST=QC0ST+P0**0.5*(1.0+QRT)
         IF (K*,EQ.,1) WRITE(6,100) Pr0,QL,(A(I),I=1,2),(ID(I),I=1,6)
         QB=QA/QW
         IF (A,A,0) WRITE(6,100) QA,00,00
         PR0=(F* WXA)/W0
         IPR=IPR+(PR0)+1
         A(I) = IP0 = NIPR = 0
   17 CONTINUE
      IF (IPR*,EQ.,1) GO TO 11
      IF (INDEX,A,0,0) GO TO 11
      INDEX=1
      IP0=1
      PRINT *, *IMAX=*,IMAX
      DO 20 J=1,320
         F=WXA + W0 * Const/(1.0 + 0.5*W0)
         DO 19 K=1,6
            QC0ST=QC0ST(K)
            IF (K*,.LE.10) GO TO 25
            IF (K*,.LE.740.) X=100,
            IF (K*,.LE.-670.) X=-100,
            GO TO 26
         20 CONTINUE
         IF (X*,.EQ.,1.0) X=10
         25 CONTINUE
         26 CONTINUE
         EX=K01 (K,I)*EXP(X)
         ...
27 CONTINUE
   AA(I)=(1-T(1))*BB(1)
   2 +T(1)*(1-T(2))*BB(2)
   3 +T(1)*T(2)*(1-T(3))*BB(3)
   4 +T(1)*T(2)*T(3)*(1-T(4))*BB(4)
   5 +T(1)*T(2)*T(3)*T(4)*(1-T(5))*BB(5)
   6 +T(1)*T(2)*T(3)*T(4)*T(5)*(1-T(6))*BB(6)
   XX=(1000.0 * AA(1))/BB(1)
   IA(I)=IFIX(XX)
35 CONTINUE
   WRITE(6,103) WXA,WXB
   WRITE(1,102)(IA(I),I=1,320)
   IL=IMAX - 320
   DO 45 K=1,6
      II=IL + 1
      JJ=321
      DO 46 I=1,IL
         A(K,I)=A(K,JJ)
         A(K,II)=0.0
         II=II+1
         JJ=JJ+1
   46 CONTINUE
   DO 47 I=II,512
      A(K,I)=0.0
   47 CONTINUE
45 CONTINUE
   WXA=WXB
   WXB=WXA+WE*2.
   WXC=WXB+WD
50 CONTINUE
   CALL EXIT
   STOP
END
PROGRAM SPGRD(TAPE1=200B,TAPE2=200B,OUTPUT=200B,TAPE6=OUTPUT)
DIMENSION IA(1024),A(4096),S(512),INV(512),M(3)
DIMENSION IC(128)
COMMON IA,S,INV
100 FORMAT(1615)
101 FORMAT(1H)
   M(1)=11
   M(2)=0
   M(3)=0
   LM=1
   XA=1./512.
READ(1,100)(IC(I),I=1,128)
IF (EOF(1) ,NE. 0) GO TO 60
DO 50 L=1,108
  DO 9 I=1,128
  IA(I)=IC(I)
  CONTINUE
READ(1,100)(IA(I),I=129,1024)
IF (EOF(1) ,NE. 0) GO TO 60
   J=897
   DO 8 I=1,128
   IC(I)=IA(J)
   J=J+1
   CONTINUE
   K=2047
   J=1024
   DO 10 I=1,1024
   IX=IA(J)
   A(K)=FLOAT(IX)
   A(K+1)=0.
   K=K-2
   J=J-1
10 CONTINUE
   A(2049)=0.
   A(2050)=0.
   J=4095
DO 11 I=3,2048,2
  A(J)=A(I)
  A(J+1)=A(I+1)
  J=J-2
11 CONTINUE
  CALL HARM(A,M,INV,S,1,IERR)
  AX=1.-XX
  J=4095
  DO 12 I=3,1024,2
    A(I)=A(I)*AX
    A(J)=A(J)*AX
    J=J-2
    AX=AX-XX
12 CONTINUE
  DO 13 I=1025,2048,2
    A(I)=0.
    A(J)=0.
    J=J-2
13 CONTINUE
  CALL HARM(A,M,INV,S,-1,IERR)
  J=1
  DO 14 I=1,2048,2
    IA(J)=1.FIX(A(I))
    J=J+1
14 CONTINUE
  IF(L,NE.1) LM=65
  WRITE(2,100)(IA(I),I=LM,960)
50 CONTINUE
60 CALL EXIT
STOP
END
Measurement of atmospheric emission using a balloon-borne cryogenic Fourier spectrometer

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In lower atmosphere, the tropopause and the stratosphere, the infrared emission radiance level directly relates to temperature and concentration of the molecules responsible for the emission. Our experiment was planned to obtain high-resolution data on absolute profile of various atmospheric parameters (temperature, humidity, etc) by measuring the infrared emission spectrum of the atmosphere from a balloon-borne platform. The emission measurement distinguished itself from the absorption measurement in the following apparatus. A major distinction is derived from the fact that to obtain any required information, the instrument can only see a very small part of the total, thereby not dictated by the diurnal change in the solar radiation. The atmospheric radiant line structure sensitivity can be made high in our experiment, because all lines are observed through a very long path in the atmosphere. Weak lines are observable in a well defined line structure, while strong lines show a saturation with respect to the black-body radiation. The diurnal variations, if they exist, are readily observable in the data.

A central feature of the experiment is a cryogenic interferometer having a resolution of 0.1 cm⁻¹. It operates at liquid nitrogen temperature. The interferometer, pump, and detector, fabricated, and assembled by J. Bredward, Idealab, Inc. It is a Michelson type interferometer consisting of a 76-channel cross correlate beam substrate with a movable and a fixed entrance mirror-reflector. The entire interferometer is housed in a cryogenic chamber, which contains liquid nitrogen for more than 10 hours with its liquid nitrogen reservoir filled. The reference laser which provides the optical path difference monitoring signal is fed into the interferometer chamber through fiber optics.

The University of Denver was responsible for modification of various components suitable for the balloon-borne measurements, and assembling them into an appropriate package. The balloon flight operation was in the charge of the balloon branch of Air Force Geophysics Lab. The data reduction and analysis were done by the University of Massachusetts. The entire project was directed by George Vanasse of AFGL.

The balloon flight took place on October 8, 1980, at Holloman AFB, producing analyzable data during the first 20 minutes; the balloon being then at an altitude of 1000 m.

The spectrum shown in Fig. 1(a) was recovered from interferogram data taken at an altitude of approximately 5000 m. The maximum optical path difference was approximately 4 cm, producing a corresponding resolution of 0.1 cm⁻¹. Since no radiance level calibration were made during the flight, only qualitative discussions are applicable to the present analysis. For comparison to the observed data, several synthetic spectra are shown in Fig. 1(d) through 1(d). They are scaled by the ordinates against the blackbody radiation of the highest temperature used in the synthetic atmosphere. The line parameters are taken from the latest AFGL atmospheric line listing (version 1981). The observed spectrum shows a sharp cut-off at 775 cm⁻¹ corresponding to a helium detector sensitivity limit. The feature observed below 775 cm⁻¹ is a CO₂ emission between (1100)-(1800) transition. Other observable CO₂ features are (10011-10002) and (90011-10002). It is interesting to note that even at a temperature much below 300K of the earth's surface temperature, these CO₂ bands of 12 & 3000 cm⁻¹ are clearly observable. The observed CO₂ band in the 775 cm⁻¹ & 5000 cm⁻¹ region are those of the non-radiative band. The features above 5000 cm⁻¹ were shown 1000 lines of the (214-500) transition. Again, these lines having initial energy levels exceeding 3000 cm⁻¹ and a very weak radiative probability are clearly observable. The data indicate excellent sensitivity for detecting weak model lines. The CO₂ feature is in the 1000 cm⁻¹ & 5000 cm⁻¹ region consists of many bands (main feature...
being $\Delta v_1 = 1$). A presence of the $N_2O$ band in the observed data is rather questionable and it will be addressed when improved data becomes available from the future flight.

The measurement during the initial flight was not carried out at the optimum conditions. The signal-to-noise ratio was down-graded by unexpected instrumentation problems. Even with the unfavorable conditions, the data provided more than ample evidence that the experiment is extremely effective for atmospheric study. The project was and will be carried out under a code name of SCRIBE (Stratospheric Cryogenic Interferometer Balloon Experiment).

Acknowledgment

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(a)

(b)

(c)

(d)

![Graphs](image)

**Fig. 1(a)** Observed spectrum at altitude of approximately 5000 m and elevation angle of 40°. The spectrum was processed with a resolution of 0.12 cm$^{-1}$. (A triangular function was multiplied to the interferogram data for normalization. The data convoluted at 4.0 cm of the optical path difference.)

**Fig. 1(b)** Theoretically synthesized spectrum having a single layer specified below:

<table>
<thead>
<tr>
<th>Temperature</th>
<th>$H_2O$ (cm$^{-1}$)</th>
<th>$CO_2$ (cm$^{-1}$)</th>
<th>$O_3$ (cm$^{-1}$)</th>
<th>$N_2O$ (cm$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>250°F</td>
<td>$3.7 \times 10^{-4}$</td>
<td>$3.2 \times 10^{-3}$</td>
<td>$1.42 \times 10^{19}$</td>
<td>$2.4 \times 10^{19}$</td>
</tr>
</tbody>
</table>
Fig. 1(c) Theoretically synthesized spectrum assuming six layers specified below:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Temperature</th>
<th>$H_2O$</th>
<th>$CO_2$</th>
<th>$O_3$</th>
<th>$N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2500°C</td>
<td>$1.2 \times 10^{26}$</td>
<td>$6 \times 10^{17}$</td>
<td>$7 \times 10^{19}$</td>
<td>$3 \times 10^{18}$</td>
</tr>
<tr>
<td>2</td>
<td>245</td>
<td>$0.6 \times 10^{26}$</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{17}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>3</td>
<td>240</td>
<td>$0.6 \times 10^{26}$</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{19}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>4</td>
<td>230</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>5</td>
<td>220</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>6</td>
<td>220</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
</tbody>
</table>

Fig. 1(d) Theoretically synthesized spectrum assuming six layers specified below:

<table>
<thead>
<tr>
<th>Layer</th>
<th>Temperature</th>
<th>$H_2O$</th>
<th>$CO_2$</th>
<th>$O_3$</th>
<th>$N_2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>250°C</td>
<td>$1.2 \times 10^{26}$</td>
<td>$6 \times 10^{17}$</td>
<td>$7 \times 10^{19}$</td>
<td>$3 \times 10^{18}$</td>
</tr>
<tr>
<td>2</td>
<td>245</td>
<td>$0.6 \times 10^{26}$</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{17}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>3</td>
<td>240</td>
<td>$0.6 \times 10^{26}$</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{19}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>4</td>
<td>230</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>5</td>
<td>220</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
<tr>
<td>6</td>
<td>220</td>
<td>0</td>
<td>$4 \times 10^{17}$</td>
<td>$7 \times 10^{18}$</td>
<td>$4 \times 10^{18}$</td>
</tr>
</tbody>
</table>