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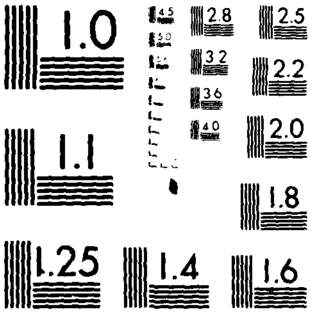
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STRATOSPHERIC EMISSION DATA ANALYSIS

Hajime Sakai

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University of Massachusetts
Amherst MA 01003

February 1982

Final Report
1 January 1979 to 31 January 1982

AIR FORCE GEOPHYSICS LABORATORY
AIR FORCE SYSTEMS COMMAND
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HANSCOM AFB, MASSACHUSETTS 01731

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Analysis procedure developed for the AFGL SCRIBE [Stratospheric Cryogenic Interferometer Balloon Experiment] data is described.

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STRATOSPHERIC EMISSION DATA ANALYSIS

Introduction

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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]

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[1] H. Sakai, "SCRIBE I Data Analysis," AFGL-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 retroflector 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

n_o, Molecular Density per cm^3 at 30 Km Altitude

H_2O	1.33×10^{13}
CO_2	8.06×10^{13}
O_3	2.50×10^{12}
CH_4	3.91×10^{11}
N_2O	8.55×10^{10}
CO	1.71×10^{10}

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 θ 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

$$k(\sigma) = \frac{S}{\alpha_d}\sqrt{\frac{\ell n^2}{\pi}}\, e^{-\ell n^2 (\frac{\sigma-\sigma_o}{\alpha_d})^2}$$

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

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

The Doppler line width α_d is a function solely determined by the temperature T, the molecular mass m, and the line center frequency σ_o:

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

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

$$E(\sigma) = B(\sigma,T)\ [1 - \exp(-\frac{s_o N}{\alpha_d}\sqrt{\frac{\ell n^2}{\pi}}\, e^{-\ell n^2(\frac{\sigma-\sigma_o}{\alpha_d})^2})],$$

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

If the molecular line broadening is controlled by the collisional process, the profile is Lorentzian:

$$k(\sigma) = \frac{S\alpha_c}{\pi[(\sigma-\sigma_o)^2 + \alpha_c^2]} .$$

Again we get

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

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

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

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 x 10^{-4} steradian cm^2 for our case. Taking the Doppler width of 0.0008 cm^{-1} and the blackbody radiance of 5 x 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 MT0:LFN.DAT<RK1:PCMRK1.DAT/M=1↵. Observe the data transfer from RK1:PCMRK1.DAT to MT0: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.

ARFII2
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.

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*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 Li, L2, L3, and L4 consecutively.

The output on TAPE3 is a spectrum recorded in (16I5) 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  HASH code)
ACCOUNT ...........
VSN, TAPE1 = ARFII2.
LABEL (TAPE1, MT, D=800, LB=KU, F=S, PO=R)
Define, PCMDCC.
COPYBF, TAPE1, PCMDCC, 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

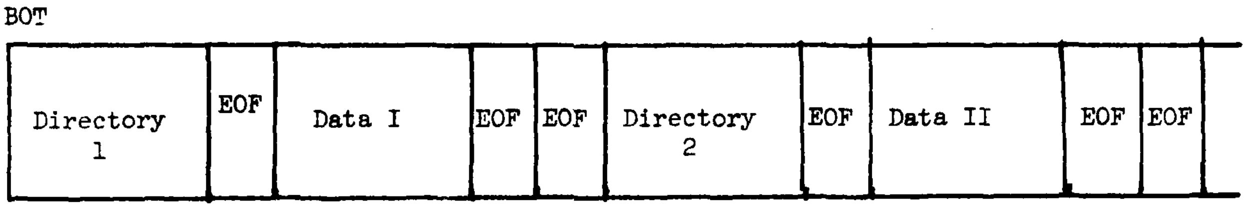

Figure 2

```
/GET,TREAD,SKXX
/FTN,I=TREAD,L=0
     .271 CP SECONDS COMPILATION TIME
/FTN,I=SKXX,L=0,B=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.
```

Figure 3

```
   [illegible]ACH,TAPE3-[illegible]
 [illegible]
     0   800                                                                                     M
 2046 2029 1975 1974 1973 2015 2055 2029 2054 2020 1951 1957 1980 2006 2119 1999                -1
 2077 2012 1973 1980 1997 2030 2077 2060 2107 2015 1991 1975 2013 2030 2070 2044                 0
 2063 1982 1942 1767 1989 1998 2001 2044 2042 1996 1964 1989 2013 2044 1991 2033                 1
 2078 2006 1991 1798 2014 2037 1996 2054 2046 1991 1966 1974 2005 2047 1916 2013                 2
 1900 1606 1509 1547 1754 2005 1866 2061 1951 [illegible] 1606 1748 1934 2284 1571 2086          3
 1982 1767 1717 1798 1950 2222 2092 2276 1941 1662 1559 1765 1887 2444 1903 2132                 4
 1760 1510 1581 1772 1861 1964 2096 2263 1828 1621 1733 1903 2076 1940 2143 2286                 5
 1806 1644 1685 1563 1909 1828 2084 2133 1708 1541 1654 1815 1980 1447 1935 2076                 6
 1727
       3    1          Gain switch occurred after this data point.   N=1.
OEND-OF-FILE ENCOUNTERED, FILENAME        TAPES
 ERROR NUMBER   55    DETECTED BY INPC=    AT ADDRESS 000152
 CALLED FROM TT        AT  LINE 42
     3.617 CP SECONDS EXECUTION TIME.
/REWIND,TAPE1
$REWIND,TAPE1.
/LFILFIX
  ENTER M, N, LASER
? 128,32768,1
 ENTER NUMBER OF PIECES, WHICH PIECE
? 1,1
 ENTER FILTER ON, OFF
? 500,,2000,,
 FILTER FROM  [illegible] TO 1974.78 [illegible]
? 1
 M=  128 N=   32768 [illegible] 4096
 ENTER TITLE
? SPAR


  MAX IS     3437.[illegible] AT    [illegible]    [illegible]     [illegible]


     19,776 CP SECONDS EXECUTION TIME.
 DEFINE,TAPE7=SPAR
/CALL,SQ
 N=    32768
 RETURN,TAPE2,TAPE3,TAPE4,TAPE8,TAPE[illegible]
```

Figure 4

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[1] for our computation because of the reason cited above.

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

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

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

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

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

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

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

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[1] S.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 $A(\sigma)B(\sigma,T)$.

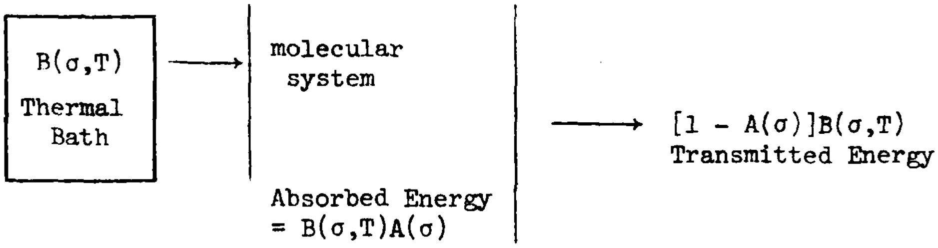

Figure 5

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 $B(T_1)A$, emitted by the layer 1

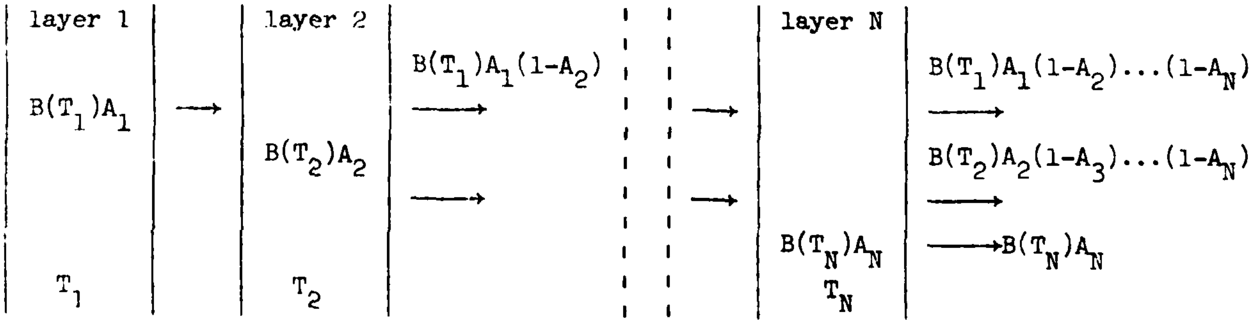

Figure 6

becomes $B(T_1)A_1(A-A_2)\ldots(1-A_N)$ 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:

$$E = [\sum_{n=1}^{N} B(T_N)A_N(\prod_{j=n+1}^{N} (1-A_j))] + B(T_N)A_N .$$

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

$$S(T) = S(T_s) \frac{Q_V(T_s)Q_R(T_s)\ell^{-E''/kT_s}}{Q_V(T)Q_R(T)\ell^{-E''/kT}} ,$$

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 (16I5) 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 TREAID(TAPE9,TAPE1,TAPE6,TAPE2,OUTPUT)
      DIMENSION IA(2048),IC(2048)
      DIMENSION 1D(256),IE(512)
  100 FORMAT(8(1X,O8))
  101 FORMAT(16I5)
      DATA 1XA,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 TPDCODE(ID,IE)
      WRITE(6)(IE(I),I=1,256)
      GO TO 10
   21 CONTINUE
   31 CONTINUE
      REWIND 6
      JQ=0
      J=1
   20 CONTINUE
      JA=1
      DO 15 K=1,8
      JB=JA+255
      READ(6)(IA(I),I=JA,JB)
      JA=JB+1
   15 CONTINUE
      DO 12 I=1,2048
      IX=IA(I).AND.IXA
      IY=IA(I).AND.IXB
      IF(IY.NE.15000000B) 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)
      JQ=JQ+JX
      JY=JX+1
      J=1
      DO 13 I=JY,JJ
      IC(J)=IC(I)
      J=J+1
   13 CONTINUE
      IF(JQ.LE.81920) GO TO 20
   41 CONTINUE
      PRINT 101, JQ
      CALL EXIT
      STOP
      END
```

```
      SUBROUTINE TFDCODE(ID,IE)
      DIMENSION ID(2),IE(2),IA(6),IB(5),IC(4)
      DATA (IA(I),I=1,6)/77777777000000000000B,777777770000B,7777B,
     177770000000000000000B,7777777700000000B,77777777B/
      DATA (IC(I),I=1,4)/17B,1700B,170000B,17000000B/
      L=1
      J=1
      DO 11 I=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)
      IY=ID(L+1).AND.IA(4)
      IZZ=SHIFT(IY,-48)
      IZ=SHIFT(IX,12)
      IB(3)=IZZ+IZ
      IX=ID(L+1).AND.IA(5)
      IB(4)=SHIFT(IX,-24)
      IB(5)=ID(L+1).AND.IA(6)
      L=L+2
      DO 12 K=1,5
      IX=IB(K).AND.IC(4)
      IY=IB(K).AND.IC(3)
      IZ=IB(K).AND.IC(2)
      IZZ=IB(K).AND.IC(1)
      IE(J)=SHIFT(IY,-12)+SHIFT(IZ,-2)+SHIFT(IZZ,8)+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)
      IZZ=IB(1).AND.IC(1)
      IE(J)=SHIFT(IY,-12)+SHIFT(IZ,-2)+SHIFT(IZZ,8)+IX
      RETURN
      END
```

Appendix B Source Program SKXX

```
      PROGRAM TT(TAPE8,OUTPUT,TAPE2=OUTPUT,INPUT,TAPE1)
      DIMENSIONIA(2048)
  100 FORMAT(16I5)
      READ(8,100)(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
      JJ=2048-J
      JQ=((800+JJ)/16)*16
      PRINT 100,JJ,JQ
      JK=800+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.
      IB=IFIX(BAVE)
      DO 12 I=49,JZ
      X=FLOAT(IA(I))
      X=(X-AAVE)*5.64
      IA(I)=IFIX(X)
   12 CONTINUE
      JZZ=JZ+1
      DO 13 I=JZZ,2048
      IA(I)=IA(I)-IB
   13 CONTINUE
      WRITE(1,100)(IA(I),I=49,2048)
      DO 14 K=1,256
      READ(8,100)(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 SPSPLOT(TAPE1=200B,TAPE2=200B,OUTPUT=200B,TAPE5=200B,TAPE6
     1=OUTPUT,TAPE8=200B)
      INTEGER ID(6),DD
      DIMENSION A(3072),IA(2048),B(1024)
      DIMENSION D(8),DD(8)
      DIMENSION QCST(7)
      DIMENSION ROTJ(7)
      EQUIVALENCE (A(1),IA(1)),(A(2049),B(1))
  100 FORMAT(F10.3,E10.3,F5.4,F10.3,2A9,3A8,A3)
  102 FORMAT(16I5)
  101 FORMAT(F16.10,4F16.4)
  103 FORMAT( "SPECTRUM IS CALCULATED FROM ", F10.4," CM-1 TO",
     1F10.4, " CM-1 .   "   )
  105 FORMAT(4E10.3)
  106 FORMAT(7E10.3)
      DATA (DD(I),I=1,7)/3H  1,3H  2,3H  3,3H  4,3H  5,3H  6,3H  7/
      DATA (ROTJ(I),I=1,7)/1.5,1.0,1.5,1.0,1.0,1.5,1.0/
      PI=3.1415926
      TT=230.
      INDEX=0
      N=1
      G=.32
      ALN2=ALOG(2.)
      AX=0.12
      T=295.
      READ (5,106) (QCST(I),I=1,7)

      TTT=(TT-T)/(T*TT)
      PSUM=0.1
      READ(5,101) WX,W,WA,WB
      READ(5,102) N
      WX=WX*(-1.)
      WD=WX*512.
      WE=WD*2.
      WDD=((WB+WX)-(WA-WX))/(2.*WE)
      JEND=IFIX(WDD)+1
      WXA=WA-WD
      WXB=WXA+WE*2.
      WXC=WXB+WD
      AX=WX
      DO 10 I=1,3072
      A(I)=0.
   10 CONTINUE
      DO 20 J=1,JEND
      IF(INDEX.EQ.2) GO TO 17
      INDEX=0
   11 CONTINUE
      READ(2,100) P,Q,(D(I),I=1,2),(ID(I),I=1,6)
      DO 6 I=1,7
    6 IF (ID(6) .EQ. DD(I)) GO TO 7
      GO TO 11
```

```
 7 AJ=ROTJ(1)
   QCONST=QCST(1)
   IF(P.LE.WXA) GO TO 11
   IF(P.GT.WXC) INDEX=1
   IF(N.NE.0) WRITE(6,100) P,Q
17 CONTINUE
   QA=Q*QCONST
   QX=(1.439)*TTT*D(2)
   QRT=(TT/T)**AJ
   QA=QA*PSUM*QRT*(EXP(QX))
   QC=Q*PSUM*QRT*(EXP(QX))
   WRITE(8,100) P,QC,(D(I),I=1,2),(ID(I),I=1,6)
   QB=QA/WX
   IF(N.NE.0) WRITE(6,105) Q,QA,QB
   PR=(P-WXA)/WX
   IPR=IFIX(PR) + 1
   A(IPR)=A(IPR) + QB
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) WXA,WXB
   WRITE(1,102)(IA(I),I=1,2048)
   II=1025
   DO 16 I=1,1024
   A(I)=B(I)
   A(II)=0.
   B(I)=0.
   II=II+1
16 CONTINUE
   GO TO 19
21 CONTINUE
   INDEX=2
   GO TO 13
19 CONTINUE
   WXA=WXB
   WXB=WXA+WE*2.
   WXC=WXB+WD
20 CONTINUE
   CALL EXIT
   STOP
   END
```

Appendix D

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

```
      PROGRAM MCO2GEN(TAPE1=200B,TAPE2=200B,OUTPUT=200B,TAPE5=200B,TAPE6
     1=OUTPUT,TAPE8=200B)
C       THIS PROGRAM IS MODEFIED FROM CO2GEN (WHICH IS GOOD FOR
C       ONE LAYER) , AND USE FOR TO CALCULATE 6 LAYER ATMOSPHERE
C       EACH LAYER HAS DEFFERENT TEMPERATURE AND DIFFERENT CONCENTRATION
C      OF H2O, CO2,O3,N2O,CO,CH4,O2
      INTEGER ID(6),DD
      DIMENSION A(6,512),AA(512),IA(512)
      DIMENSION D(8),DD(8)
      DIMENSION QCST(8,8),BB(8),TT(8),TTT(8)
      DIMENSION ROTJ(8),T(8)
      EQUIVALENCE (AA(1),IA(1))
  100 FORMAT(F10.3,E10.3,F5.4,F10.3,2A9,3A8,A3)
  102 FORMAT(16I5)
  101 FORMAT(F16.10,4F16.4)
  103 FORMAT( "SPECTRUM IS CALCULATED FROM ", F10.4," CM 1 TO",
     1F10.4, " CM-1 .  "   )
  105 FORMAT(4E10.3)
  106 FORMAT(7E10.3)
  107 FORMAT(8F6.1)
      DATA (DD(I),I=1,7)/3H  1,3H  2,3H  3,3H  4,3H  5,3H  6,3H  7/
      DATA (ROTJ(I),I=1,7)/1.5,1.0,1.5,1.0,1.0,1.5,1.0/
      DATA C1,C2/1.1909E-12,1.4388/
      PI=3.1415926
      INDEX=0
      N=1
      G=.32
      ALN2=ALOG(2.)
      AX=0.12
      TEP=295.
      READ (5,107) (TT(I),I=1,6)
      DO 1 I=1,6
      READ (5,106) (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 TTT(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=WX*(-1.)
      WD=WX*80.
      WE=WD*2.
      WDD=((WB+WX)-(WA-WX))/(2.*WE)
      JEND=IFIX(WDD)+1
      WXA=WA-WD
      WXB=WXA+WE*2.
      WXC=WXB+WD
      AX=WX
      DO 9 J=1,8
      DO 10 I=1,512
      A(J,I)=0.
```

```
10 CONTINUE
9  CONTINUE
   DO 60 J=1,JEND
   INDEX=0
11 CONTINUE
   READ(2,100) P,Q,(D(I),I=1,2),(ID(I),I=1,6)
   IF(P.LE.WXA) GO TO 11
   IF(P.GE.WXC) INDEX=1
   DO 6 I=1,7
 6 IF (ID(6) .EQ. DD(I)) GO TO 7
   GO TO 11
 7 AJ=ROTJ(I)
   IF(N.NE.0) WRITE(6,100) P,Q
   DO 19 K=1,6
   QCONST=QCST(K,I)
   QA=Q*QCONST
   QX=(1.439)*TT(K)*D(2)
   QRT=(TT(K)/TEF)**AJ
   QA=QA*PSUM*QRT*(EXP(QX))
   QC=Q*PSUM*QRT*(EXP(QX))
   IF(K.EQ.1)WRITE(8,100) P,QC,(D(I),I=1,2),(ID(I),I=1,6)
   QB=QA/WX
   IF(N.NE.0) WRITE(6,105) Q,QA,QB
   PR=(P-WXA)/WX
   IPR=IFIX(PR) + 1
   A(K,IPR)=A(K,IPR) + QB
19  CONTINUE
   IF ((IPR.GT.480).AND.(P.GT.WXB))INDEX=1
12 CONTINUE
   IF(INDEX.NE.1) GO TO 11
13 CONTINUE
   IMAX=IPR
   PRINT *, "IMAX=   ",IMAX
   DO 35 I=1,320
   P=WXA + WX * FLOAT(I) + 0.5*WX
   DO 27 K=1,6
   TEMP=TT(K)
C       BLACK BODY (PLANCK FUNCTION) FUNCTION
C       C1,C2 ARE SOME CONSTANT, P IS WAVE NO. TEMP IS TEMPERATURE
   BB(K)=C1*(P**3)*1.0/(EXP((C2*P)/TEMP)-1.0)
   X=A(K,I)
   IF(X.LE.(.10)) GO TO 25
   IF(X.GE.740.)X=100.
    IF(X.LE.-670.) X=-100.
   GO TO 26
25 T(K)=1.0    X
   GO TO 27
26 T(K)=1.0/(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(I))/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
60 CONTINUE
   CALL EXIT
   STOP
   END
```

Appendix E   Source Program SPDG

```
      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(16I5)
  101 FORMAT(1H  )
      M(1)=11
      M(2)=0
      M(3)=0
      LM=1
      XX=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)
    9 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
    8 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)=IFIX(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
```

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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 precision data on altitude profiles of various atmospheric parameters (temperature, chemical composition, etc.) by measuring the infrared emission spectrum of the atmosphere from a balloon-borne platform. The emission measurement distinguished itself from the absorption measurement on the following aspects. A major distinction is derived from the fact that no definite source is required. The interferometer can point to any direction through the atmosphere, thereby not dictated by the diurnal change in the solar position. The atmospheric pollutant detection 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 a corresponding black-body radiance. 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, per se, was designed, fabricated, and assembled by J. Pritchard of Idealab, Inc. It is a Michelson type interferometer consisting of a Ge beamsplitter coated on a KCl substrate with a movable and a fixed cat's-eye retro-reflector. The entire interferometer is housed in a cryogenic chamber, which retains liquid N_2 temperature for more than 16 hours with its liquid N_2 reservoir filled. The reference laser which provides the optical path difference monitoring signal is fed into the interferometer chamber through fibre optics.

The University of Denver was responsible for modification of various components suitable for the balloon-borne measurement, and assembling them into an air-worthy package. The balloon flight operation was in the charge of the balloon branch of Air Force Geophysics Laboratory. 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 6000 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 .12 cm^{-1}. Since no radiance level calibrations were made during the flight, only qualitative discussions are applicable to the spectral analysis. For comparison to the observed data, several synthetic spectra are shown in Fig. 1(b) through 1(d). They are scaled by the emissivity against the black-body radiance of the highest temperature used in the synthetic atmosphere. The line parameters are taken from the latest AFGL atmospheric line listing (version 1980). The observed spectrum shows a sharp cut-off at 725 cm^{-1} corresponding to a Ge:Hg detector sensitivity limit. The feature observable below 775 cm^{-1} is a CO_2 emission of the (11101-02201) transition. Other observable CO_2 features are (00011-10002) and (00011-10001). It is interesting to note that even at a temperature much below 300°K of the earth's surface temperature, these CO_2 bands of E' ≳ 3000 cm^{-1} are clearly observable. The observed H_2O lines in the 785 cm^{-1} ∿ 1000 cm^{-1} region are those of the pure rotational band. The lines above 1050 cm^{-1} are those H_2O lines of the (010-000) transition. Again, those lines having initial energy levels exceeding 3000 cm^{-1} and a very weak transition probability are clearly observable. The data indicate excellent sensitivity for detecting weak spectral lines. The O_3 feature in the 1000 cm^{-1} ∿ 1075 cm^{-1} region consists of many bands (main feature being $\Delta v_3 = 1$). 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).

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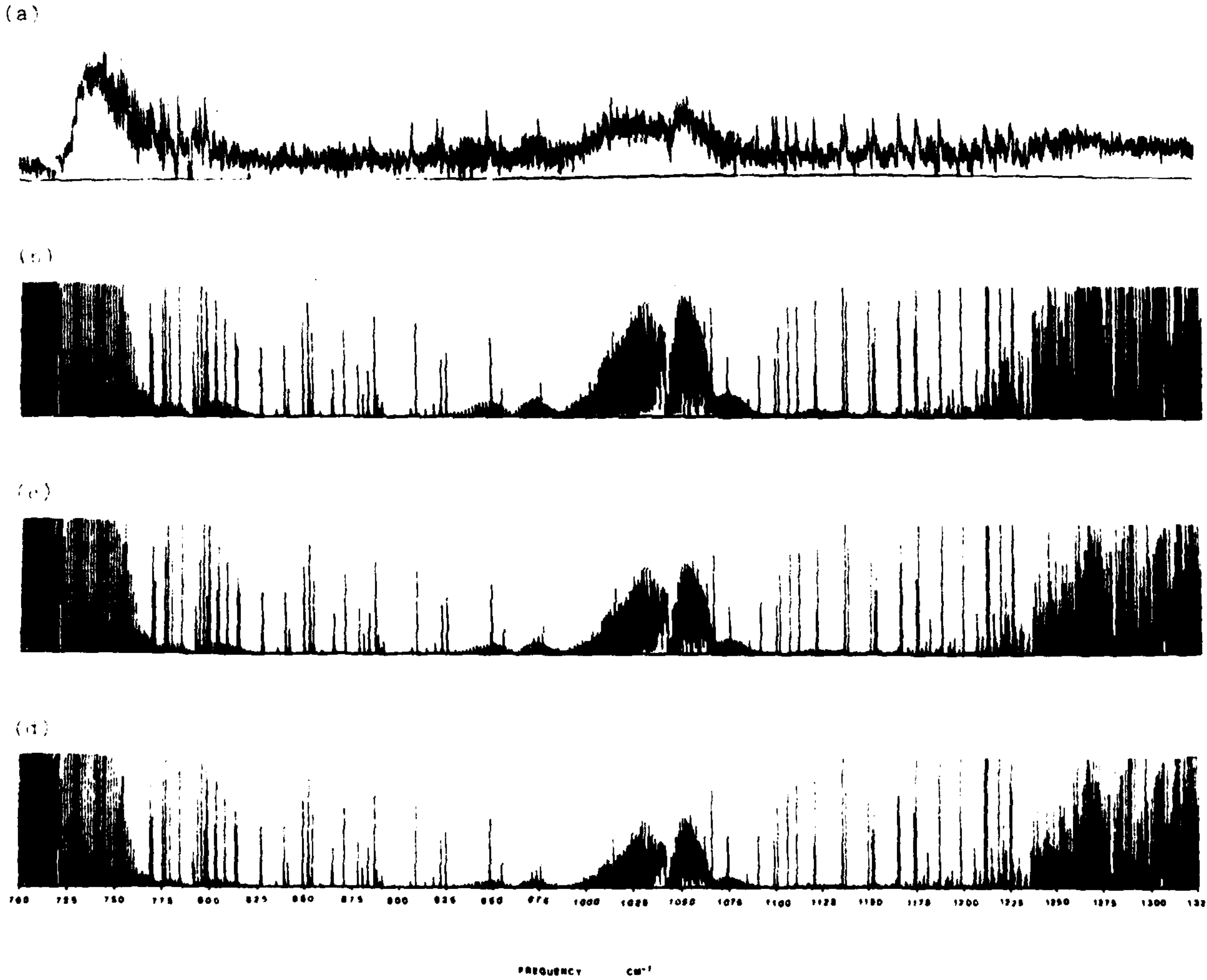

Fig. 1(a) Observed spectrum at altitude of approximately 5000 m and elevation angle of 10°. The spectrum was processed with a resolution of .12 cm^{-1}. (A triangular function was multiplied to the interferogram data for apodization. The data terminated at 4.0 cm of the optical path difference.)

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

	Total Column Density			
Temperature	H_2O	CO_2	O_3	N_2O
250°K	$.23 \times 10^{24}$	$.24 \times 10^{23}$	1.42×10^{19}	$.24 \times 10^{19}$

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

Layer	Temperature	Total Column Density H_2O	CO_2	O_3	N_2O
1	250°K	$.12 \times 10^{24}$	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
2	245	$.06 \times 10^{24}$	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
3	240	$.05 \times 10^{24}$	$.4 \times 10^{22}$	$.5 \times 10^{19}$	$.4 \times 10^{18}$
4	230	0	$.4 \times 10^{22}$	$.5 \times 10^{19}$	$.4 \times 10^{18}$
5	220	0	$.4 \times 10^{22}$	$.01 \times 10^{19}$	$.4 \times 10^{18}$
6	220	0	$.4 \times 10^{22}$	$.01 \times 10^{19}$	$.4 \times 10^{18}$

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

Layer	Temperature	Total Column Density H_2O	CO_2	O_3	N_2O
1	250°K	$.12 \times 10^{24}$	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
2	245	$.06 \times 10^{24}$	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
3	240	$.05 \times 10^{24}$	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
4	230	0	$.4 \times 10^{22}$	$.2 \times 10^{19}$	$.4 \times 10^{18}$
5	220	0	$.4 \times 10^{22}$	$.01 \times 10^{19}$	$.4 \times 10^{18}$
6	220	0	$.4 \times 10^{22}$	$.01 \times 10^{19}$	$.4 \times 10^{18}$

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