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13. ABSTRACT *(Maximum 200 Words)*

The objective of this project was to analyze observational atmospheric data collected by the University of Wisconsin for the investigation of issues in spectroscopy and remote sensing. The specific tasks performed under this research were the preparation of a data set for the International Radiation Commission and a preliminary effort at determining refinements to the water vapor continuum as used in the line-by-line transmittance model, FASCODE.

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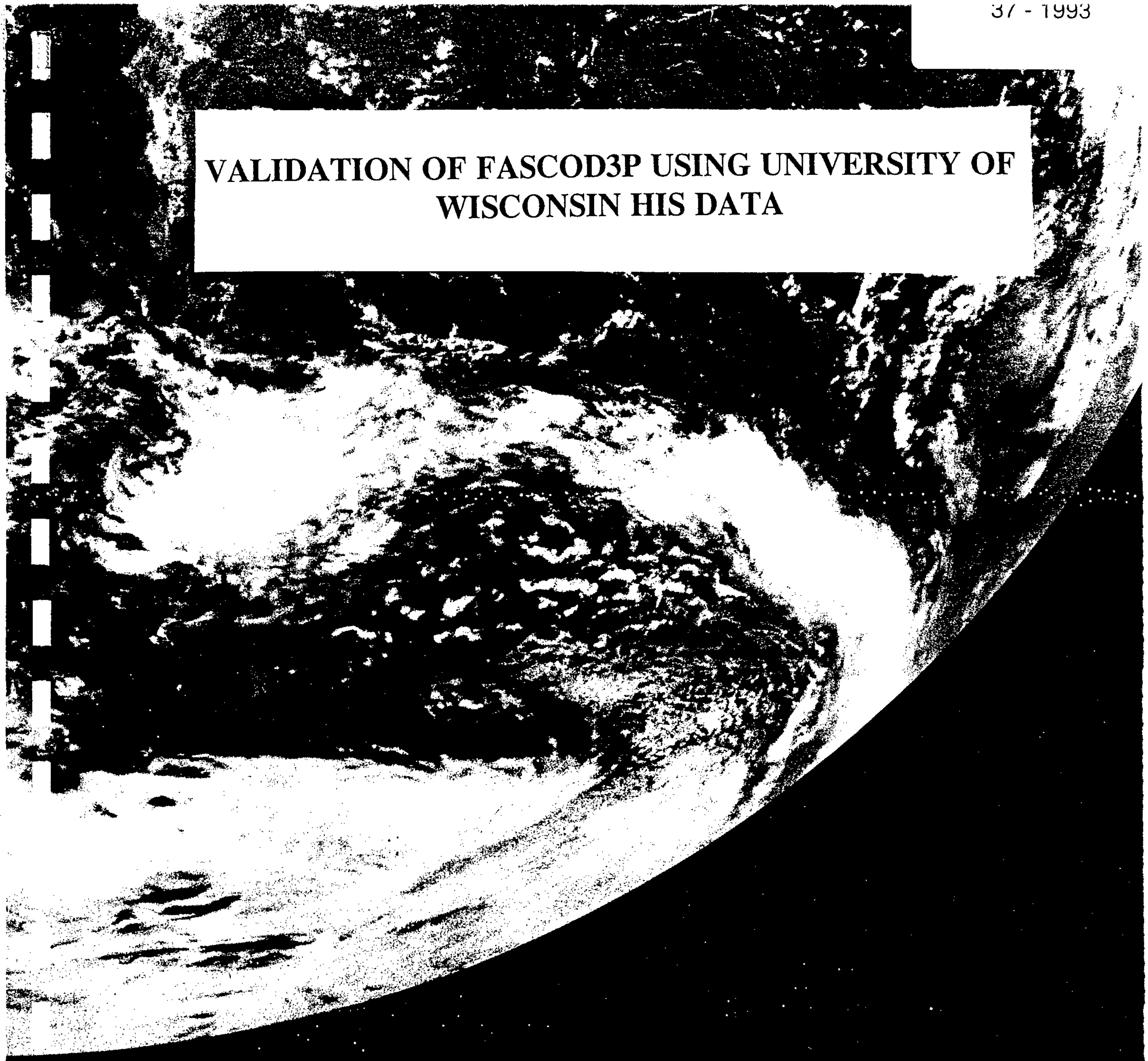
VALIDATION OF FASCOD3P USING UNIVERSITY OF WISCONSIN HIS DATA



A REPORT

from the space science and engineering center
the university of wisconsin-madison
madison, wisconsin

VALIDATION OF FASCOD3P USING UNIVERSITY OF WISCONSIN HIS DATA

A Report to the

Air Force Geophysics Laboratory
Hanscom, AFB, MA 01731

Under contract # F19628-91-K-0007 (mod #6)

by the

University of Wisconsin-Madison
Space Science and Engineering Center
1225 W. Dayton St.
Madison, WI 53706

Project Director: Henry E. Revercomb

November 12, 1993

TABLE OF CONTENTS

I. PROJECT DESCRIPTION

This report summarizes work performed at the University of Wisconsin - Madison during FY93 under contract #F19628-91-K-0007 for the Air Force Phillips Laboratory. The portion of work summarized here is restricted to the efforts under the direction of Dr. Henry E. Revercomb (mod #6 of the above contract) and includes the contributions of R. O. Knuteson, S. C. Lee and others at the Space Science and Engineering Center at the UW.

The objective of this funding was to support the analysis of observational atmospheric data collected by the UW for the investigation of issues in spectroscopy and remote sensing. The specific tasks performed under this research were the preparation of a data set for the International Radiation Commission and a preliminary effort at determining refinements to the water vapor continuum as used in the line-by-line transmittance model, FASCODE.

II. ITRA DATA SET

One of the main tasks performed under this contract was the final preparation of a small data sample containing both observations of atmospheric radiance and coincident observations of the atmospheric state for use in validating atmospheric line-by-line transmittance models. This section provides some background information on the observations and on the international working group using the data, lists the contents of the compiled data set, and documents the comparison of observations to the Phillips Laboratory FASCOD3 radiative transfer model calculations.

A. Background.

The atmospheric radiance contained within this data set was observed using the High-resolution Interferometer Sounder (HIS), a Fourier transform spectrometer developed at the University of Wisconsin (W.L. Smith, PI) for remote sensing of the atmosphere and earth at high spectral resolution and with high absolute accuracy [Revercomb, H. E., et al, Mikrochimica Acta, 1988, II, 439-444]. The instrument is a Michelson interferometer with laser sampling for wavenumber accuracy and onboard precision blackbodies for radiometric accuracy. The HIS has been operated both from aircraft looking down at the atmosphere and the earth's surface and from the surface looking upward to measure the upwelling and downwelling atmospheric radiance, respectively. The HIS data consists of atmospheric radiance divided into three broad bands (I, II, and III) spanning the infrared spectrum from 3.7 to 16.7 μm at a spectral resolution of between 0.3 and 1.0 cm^{-1} depending on band. The instrument field of view is approximately 2 km at 20 km range.

The HIS data was collected during three separate field deployments of the HIS; (1) test flights of the HIS from the NASA AMES flight center in California over the Eastern Pacific ocean, (2) groundbased observations in Denver, Colorado as part of the Ground-based Atmospheric Profiling EXperiment (GAPEX), and (3) aircraft data flights over Kansas during the joint agency field experiment known as STORMFEST. The aircraft data is from the NASA high altitude U2/ER-2 research aircraft which flies in the lower stratosphere at about 20 km altitude. Balloon sonde data was used to characterize the atmospheric state at times coincident with the HIS observations.

The motivation for the compilation of this HIS data set was to provide the Intercomparison of Transmittance and Radiance Algorithms (ITRA) working group, a sub-committee of the International Radiation Commission, with real atmospheric data for use in analyzing the performance of state-of-the-art radiative transfer models. The current ITRA chairperson, Dr. Noell Scott of the Polytechnique Institute of Paris, is the person responsible for the distribution of this data set to interested users. The Phillips Laboratory model FASCODE has been and continues to be included in the model intercomparisons.

B. UW ITRA Data Set 1993.

The HIS and coincident radiosonde data together are referred to by the shorthand notation UWITRA93 data set. The following table contains a listing of the contents file containing the file names which comprise the UWITRA93 data set.

TABLE 1. CONTENTS.DOC

##

CONTENTS.DOC   Version 2.0   16 Sept 93   ROK

This directory contains the following files:

```
CONTENTS.DOC  --  This file.
UWITRA93.DOC  --  Description of the UW HIS DATA SET - UWITRA93


DOWNLOOKING CASES:

-- 14 April 1986  Pacific Ocean
HIS104B1.TXT  -- HIS BAND 1
HIS104B2.TXT  -- HIS BAND 2
HIS104B3.TXT  -- HIS BAND 3
14AP1800.TXT  -- Average profile from NWS balloon sondes
                 (OAKLAND+SAN DIEGO: 0Z+12Z: Time and Space Average)

-- 01 March 1992  Seneca, Kansas
HIS1MRB1.TXT -- HIS BAND 1
HIS1MRB2.TXT -- HIS BAND 2
HIS1MRB3.TXT -- HIS BAND 3
01MR1221.TXT -- Profile data from NCAR CLASS balloon sonde.


UPLOOKING CASES from  GAPEX  Experiment:

--  31 October 20 UTC  Denver (Surface)
GPXO31B1.TXT  -- HIS BAND 1
GPXO31B2.TXT  -- HIS BAND 1
              -- HIS Band 3  Not Available for GAPEX Data.
GPXO3120.TXT -- Profile data from NCAR CLASS balloon sonde

--  1 November 11 UTC  Denver (Surface)
GPXN01B1.TXT  -- HIS BAND 1
GPXN01B2.TXT  -- HIS BAND 2
              -- HIS Band 3  Not Available for GAPEX Data.
GPXN0111.TXT -- Profile data from NCAR CLASS balloon sonde

NOTE:  See the headers of all files (including radiance data)
       for more information on the observations.

Directory UWITRA93:
CONTENTS DOC      2089   9-16-93
UWITRA93 DOC      8426   8-29-93

HIS104B1 TXT     40838   8-29-93
HIS104B2 TXT     35111   8-29-93
HIS104B3 TXT     34146   8-29-93
14AP1800 TXT      3069   8-30-93

HIS1MRB1 TXT     40836   8-29-93
HIS1MRB2 TXT     35110   8-29-93
HIS1MRB3 TXT     34143   8-29-93
01MR1221 TXT      4320   9-16-93

GPXO31B1 TXT     33872   8-29-93
GPXO31B2 TXT     14950   8-29-93
GPXO3120 TXT      4288   8-30-93

GPXN0111 TXT      4290   8-30-93
GPXN01B1 TXT     33872   8-29-93
GPXN01B2 TXT     14950   8-29-93
##########################################################################
```

The contents of the document file describing the dataset is given in Table 2.

Table 2. UWITRA93.DOC

```
#################################################################################

              UWITRA93.DOC     Version 2.0         29 August 1993   ROK

     This file describes the infrared spectral data and temperature
and moisture profiles provided by the University of Wisconsin to the
ITRA line-by-line intercomparison (1993).
     The High-resolution Interferometer Sounder (HIS) is a Fourier Transform
Spectrometer (FTS) which uses laser controlled sampling and on-board
blackbodies to achieve highly accurate wavelength and spectral radiance
absolute calibration.  The HIS data described below was collected under
United States and State of Wisconsin funded projects lead by Principal
Investigator William L. Smith, Professor of Meteorology, and
Director of the Cooperative Institute for Meterological Satellite Studies at
the University of Wisconsin -- Madison.  The scientist responsible for
the HIS instrument development and calibration is Dr. Henry E. Revercomb
also of the University of Wisconsin -- Madison.
     The HIS data are unapodized and the interferometer finite field of view
effect has been removed.  All wavenumbers listed in the following tables
are in reciprocal centimeters (cm-1).  Only the data within the optical filter
bandpass has been included in the HIS data files.  Also, the large number
of points in the balloon sonde data from the CLASS sondes (400-500) has been
reduced to 50 profile points spanning the range of pressures measured.
The file 14AP1800.TXT containing the raob data for April 14th deserves special
mention since it is composed of a time and space average of NWS radiosondes
which make the characterization of the atmosphere much more uncertain for
that case.  Only measured data has been provided. This means that some
quantities must default to their climatic means.

DATA FILES:  (See CONTENTS.DOC for further information)

NAMING CONVENTION:
  HIS104 -- 14 APRIL 1986       (HIS on NASA ER-2 Aircraft during TEST FLIGHT)
  HIS1MR --  1 MARCH 1992       (HIS on NASA ER-2 Aircraft during STORMFEST)
  GPXO31 -- 31  OCTOBER 1988    (Ground-Based Atmospheric Profiling
Experiment)
  GPXN01 --  1 NOVEMBER 1988    (Ground-Based Atmospheric Profiling
Experiment)

HIS OBSERVATIONAL BAND LIMITS:
  BAND 1 :  600 - 1080 CM-1
  BAND 2 : 1080 - 1850 CM-1
  BAND 3 : 2000 - 2600 CM-1  (Band 3 not available for GAPEX data)

-----------------------------------------------------------------------------
-----------------------------------------------------------------------------

IMPORTANT INFORMATION ABOUT THE HIS DATA PROVIDED IN UWITRA93.

-----------------------------------------------------------------------------

WAVENUMBER SCALE OF HIS DATA:
 The wavenumber scale of the HIS data is determined by an on-board HeNe laser.
 For UWITRA93 the laser wavenumber has been assumed to be 15799.00 cm-1.
 A numerical filter applies a reduction factor (R=14,8,8 for bands 1,2,3)
 to the observed data which defines a starting (or reference) wavenumber for
```

each HIS band. The reference wavenumbers which correspond to the laser wavenumber 15799.00 cm-1 are 564.25 cm-1, 987.4375 cm-1, and 1974.875 cm-1 for bands 1, 2, and 3, respectively. The point spacing of the output data also depends on the laser wavenumber assumed and the reduction factor appropriate for each HIS band. In addition, the point spacing in wavenumber depends on the number of points used in the FFT to transform from the Fourier domain to the spectral domain. The difference in point spacing between the Band 2 uplooking and downlooking observed data is due to using 2048 points versus 1024 points in the data processing.

SPECTRAL RESOLUTION OF HIS DATA:
Spectral resolution here refers to the information content of the observation and is always equal to (minimally sampled) or greater than (oversampled) the data's point spacing in wavenumber. Since the instrument used to obtain the observation is a Fourier Transform Spectrometer, the spectral resolution is defined in terms of the maximum Optical Path Difference of the measurement. Since the HeNe laser is used to define the optical path difference, the maximum OPD as well as the spectral resolution depends on the assumed laser wavenumber. The differences in spectral resolution between HIS bands and from one observation to the next reflect different choices made during data processing; the same instrument hardware was used to make all the observations in UWITRA93.

RADIOMETRIC CALIBRATION OF HIS DATA:
All the HIS data was calibrated using a two point calibration scheme whereby periodic views of hot and cold reference sources are used to remove the background contributions of the instrument. In flight configuration two high precision cavity blackbodies are used as reference sources. During surface operations, the cold reference target is replaced with an open mouthed dewar of liquid nitrogen. Note especially that the HIS instrument operates in ambient air, that is the path between the calibration reference sources and the interferometer contains both CO2 and H2O normal atmospheric concentrations. This means that certain individual channels, e.g. near 667 cm-1, 1500 cm-1, and 2380 cm-1, can be "blinded" by very opaque absorption near the instrument. The result is that these few channels appear anomolous (spikes) because they are much noisier than less opaque channels nearby. In particular, the HIS calibration is undefined in the narrow spectral range 667.016 to 669.771 cm-1. This narrow region should *not* be used for spectroscopic comparisons.

POINT SPACING OF HIS DATA (CM**-1)
[DVspacing = VLASER/(2*R*N)]

DATA	BAND 1	BAND 2	BAND 3
HIS104	0.2755127	0.4821472	0.4821472
HIS1MR	0.2755127	0.4821472	0.4821472
GPXO31	0.2755127	0.9642944	
GPXN01	0.2755127	0.9642944	

SPECTRAL RESOLUTION (UNAPODIZED) (CM**-1)
[DVres = 1./(2.*X)]

DATA	BAND 1	BAND 2	BAND 3
HIS104	0.3640322	0.6370564	0.6370564
HIS1MR	0.3224285	0.6809913	0.9642944

GPXO31	0.3640322	0.9642944
GPXN01	0.3640322	0.9642944

MAXIMUM OPTICAL PATH DIFFERENCE (CM)
[X = DX * DSPTS / 2.]

DATA	BAND 1	BAND 2	BAND 3
HIS104	1.373505	0.7848598	0.7848598
HIS1MR	1.550731	0.7342236	0.5185138
GPXO31	1.373505	0.5185138	
GPXN01	1.373505	0.5185138	

NUMBER OF POINTS USED IN DOUBLE SIDED INTERFEROGRAM (DSPTS)
[Exclusive of ZPD]

DATA	BAND 1	BAND 2	BAND 3
HIS104	3100	3100	3100
HIS1MR	3500	2900	2048
GPXO31	3100	2048	
GPXN01	3100	2048	
DX	8.861320E-4	5.063612E-4	5.063612e-4

Please refer questions about HIS data to:

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Cooperative Institute for Meterological Satellite Studies
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fax (608-262-5974)
email (bobk@ssecmail.ssec.wisc.edu)

##

The radisonde data is contained in four files the contents of which are contained in Tables 3-6.

Table 3. 14AP1800.TXT

##

Filename: 14AP1800.TXT (Created 30 August 1993, ROK)
Date: 14 April 1986
Time: 1800 UTC
Location: Off the California Coast (-120.5,+34.7)
Comment: Area and Time Average of Conventional NWS sondes. Retrieved O3.
Surface Skin Temperature: 287.3 K (HIS estimate)
Surface Skin Emissivity: Unknown (Ocean surface)
Surface Altitude: Unknown (Ocean surface)
Surface Pressure: Unknown
Surface Air Temperature: Unknown
Surface Air Relative Humidity: Unknown
Raob Source File: HIS86104.RAO (average of four raobs:

Oakland 0Z+12Z and San Diego 0Z+12Z)
Number of Profile Points: 25
Notes:
(1) The upper level H2O retrieval is for diagnostic purposes only and should not be considered a realistic representation of the true atmospheric state.
(2) All other constituents should default to the climatological mean found in the AFGL U.S. Standard Atmosphere.
Recommended Profile Values:

				SONDE		RETRIEVED	RETRIEVED
Index	Altitude (km)	Pressure (mb)	Temp (K)	H2O RH (%)	CO2 (ppmv)	O3 (g/kg)	H2O RH (%)
1	0.0000	1000.0	286.9	62.9	349.0	0.045E-3	62.9
2	0.4310	950.0	285.2	44.4	349.0	0.045E-3	43.7
3	0.6990	920.0	284.6	26.5	349.0	0.046E-3	33.9
4	1.3570	850.0	282.2	15.7	349.0	0.047E-3	17.5
5	2.0630	780.0	278.6	11.9	349.0	0.048E-3	14.7
6	2.9390	700.0	273.4	27.2	349.0	0.050E-3	24.4
7	3.2880	670.0	271.0	30.7	349.0	0.050E-3	29.3
8	3.9000	620.0	267.0	39.0	349.0	0.050E-3	36.5
9	4.5530	570.0	263.0	47.1	349.0	0.052E-3	39.4
10	5.5500	500.0	256.1	36.9	349.0	0.057E-3	40.3
11	5.9330	475.0	253.6	61.1	349.0	0.059E-3	46.1
12	6.6650	430.0	248.4	44.5	349.0	0.066E-3	65.1
13	7.1870	400.0	244.7	21.4	349.0	0.070E-3	56.5
14	8.1310	350.0	237.9	17.9	349.0	0.085E-3	42.2
15	9.1870	300.0	229.7	2.8	349.0	0.120E-3	21.2
16	10.3880	250.0	220.2	2.5	349.0	0.173E-3	12.3
17	11.7930	200.0	211.5	11.9	349.0	0.270E-3	30.9
18	13.5900	150.0	213.7	4.8	349.0	0.500E-3	12.6
19	14.2480	135.0	213.3	4.9	349.0	0.600E-3	14.2
20	15.2450	115.0	211.1	10.1	349.0	0.850E-3	40.2
21	16.1090	100.0	211.3	3.5	349.0	1.150E-3	31.2
22	17.1180	85.0	212.8	1.2	349.0	1.650E-3	14.2
23	18.3270	70.0	212.4	1.2	349.0	2.400E-3	16.9
24	19.2870	60.0	212.6	1.0	349.0	3.200E-3	17.7
25	20.4230	50.0	213.1	.6	349.0	4.200E-3	12.1

##

Table 4. 01MR1221.TXT

##
Filename: 01MR1221.TXT (created 30 August 1993 ROK)
Date: 1 March 1992
Time: 12:21 UTC
Location: Seneca, Kansas, USA (-96.11,+39.83)
Comment: NCAR CLASS data using a Vaisala sonde
Surface Skin Temperature: 278.2 K (HIS estimate)
Surface Skin Emissivity: Unknown (land surface)
Surface Altitude: 0.3840 km
Surface Pressure: 966.0 mb
Surface Air Temperature: 9.5 degrees Celsius
Surface Air Relative Humidity: 53.3 %
Raob Source File: X3011221.62K
Number of Profile Points: 42
Notes:
(1) Raob ends at index 40. Index 41 is an interpolated point. Index 42 is from in-situ ER-2 aircraft measurements.
(2) The upper level H2O retrieval is for diagnostic purposes only and should not be considered a realistic representation of the true atmospheric state.
(3) All other constituents should default to the climatological mean found in the AFGL Mid-latitude Winter atmosphere.

Recommended Profile Values:

Index	Altitude (km)	Pressure (mb)	OBS Temp(K)	OBS H2O RH (%)	CO2 (ppmV)	RET O3 (g/kg)	RET H2O RH (%)
1	0.3840	966.0	282.65	53.3	358.0	0.0492E-3	53.3
2	0.4139	962.5	284.85	43.5	358.0	0.0492E-3	43.5
3	0.5900	942.5	285.15	44.7	358.0	0.0492E-3	44.7
4	0.7644	923.1	287.65	40.6	358.0	0.0497E-3	40.6
5	0.8199	917.1	289.15	37.7	358.0	0.0498E-3	37.7
6	0.9976	898.1	290.95	23.5	358.0	0.0503E-3	23.5
7	1.0603	891.6	291.25	19.0	358.0	0.0504E-3	19.0
8	1.1210	885.2	291.35	16.9	358.0	0.0506E-3	16.9
9	1.1847	878.7	290.95	16.2	358.0	0.0505E-3	16.2
10	1.3681	859.9	290.15	15.9	358.0	0.0502E-3	15.9
11	1.5575	841.0	288.75	17.1	358.0	0.0498E-3	17.1
12	1.7545	821.6	287.15	20.4	358.0	0.0495E-3	20.4
13	2.2027	778.7	283.25	19.8	358.0	0.0498E-3	19.8
14	2.2674	772.6	282.65	20.1	358.0	0.0499E-3	20.1
15	3.3921	672.9	272.95	26.4	358.0	0.0530E-3	26.4
16	4.1703	609.6	265.25	39.2	358.0	0.0587E-3	39.2
17	4.8998	554.4	259.35	19.1	358.0	0.0679E-3	19.1
18	5.6913	499.0	255.35	10.4	358.0	0.0799E-3	8.7
19	6.4632	449.6	250.45	5.2	358.0	0.0940E-3	8.5
20	7.2221	404.9	244.05	16.3	358.0	0.1102E-3	18.7
21	8.0661	359.1	236.05	25.3	358.0	0.1325E-3	36.9
22	8.7221	326.2	230.55	26.6	358.0	0.1578E-3	38.6
23	9.2548	301.2	227.35	21.0	358.0	0.1815E-3	32.1
24	9.8361	275.8	223.35	24.1	358.0	0.2079E-3	29.4
25	10.4052	252.6	219.15	25.0	358.0	0.2328E-3	30.5
26	10.9721	231.1	215.35	26.7	358.0	0.2584E-3	37.0
27	11.6103	208.7	214.25	22.7	358.0	0.3005E-3	28.2
28	12.1833	190.6	216.05	7.9	358.0	0.3584E-3	9.9
29	12.7633	173.9	218.15	3.2	358.0	0.4328E-3	3.5
30	13.3402	159.0	218.95	2.0	358.0	0.5154E-3	2.2
31	13.9400	144.8	219.25	2.0	358.0	0.5990E-3	1.7
32	14.5449	131.7	216.75	1.8	358.0	0.6731E-3	1.9
33	15.1320	120.0	214.85	1.4	358.0	0.7440E-3	1.9
34	15.7184	109.2	211.75	2.0	358.0	0.8154E-3	2.0
35	16.3412	98.7	208.75	2.0	358.0	0.9349E-3	2.0
36	16.9451	89.5	209.75	2.0	358.0	1.1005E-3	2.0
37	17.5520	81.0	209.05	2.0	358.0	1.2250E-3	2.0
38	18.1670	73.3	208.85	2.0	358.0	1.4729E-3	2.0
39	18.7692	66.4	209.55	2.0	358.0	1.9356E-3	2.0
40	18.9227	64.8	211.15	2.0	358.0	2.1408E-3	2.0
41	19.2500	61.0	210.65	2.0	358.0	2.6400E-3	2.0
42	19.5300	57.9	210.15	2.0	358.0	3.0000E-3	2.0

##

Table 5. GPXO3120.TXT

##

Filename: GPXO3120.TXT (Created 30 August 1993 ROK)
Date: 31 October 1988
Time: 20:36 UTC
Location: Denver, Colorado USA (-104.867,+39.767)
Comment: Combined NCAR CLASS and ECC Ozone sonde data
Surface Skin Temperature: Unknown
Surface Skin Emissivity: Unknown
Surface Altitude: 1.6110 km
Surface Pressure: 841.8 mb
Surface Air Temperature: 21.2 degrees Celsius
Surface Air Relative Humidity: 14.4 %

Raob Source File: GPXO3120.CLS / ECC SONDE 4A3061
Number of Profile Points: 50
Notes:
(1) The CLASS sounding was used from the surface to 43 mb. The temperature above this level was obtained from the 1 Nov 18:30 UTC ozone sonde as was the entire ozone profile. The H2O profile above 43 mb has been set to 1 %.
(2) All other constituents should default to the climatological mean found in the AFGL U.S. Standard Atmosphere.
Recommended Profile Values:

Index	Altitude (km)	Pressure (mb)	Temp (C)	H2O RH (%)	CO2 (ppmv)	O3 (ppmv)
1	1.6110	841.8	21.2	14.4	349.0	0.044
2	1.6425	838.7	21.1	16.7	349.0	0.045
3	1.8486	818.8	18.2	18.0	349.0	0.045
4	2.1812	787.4	14.7	19.8	349.0	0.047
5	2.3595	770.8	12.9	20.2	349.0	0.047
6	2.6253	746.7	11.8	12.9	349.0	0.049
7	2.8982	722.6	9.6	10.0	349.0	0.051
8	3.2162	695.3	6.8	6.1	349.0	0.052
9	3.4859	672.7	4.8	4.5	349.0	0.053
10	4.0035	631.0	1.2	4.0	349.0	0.053
11	4.4501	596.6	-2.6	6.0	349.0	0.054
12	4.8648	566.0	-6.2	5.2	349.0	0.054
13	5.2470	538.8	-9.4	7.7	349.0	0.054
14	5.9380	492.3	-14.0	12.3	349.0	0.045
15	6.3049	469.0	-15.6	11.0	349.0	0.042
16	6.7553	441.6	-19.7	15.0	349.0	0.040
17	7.2969	410.2	-24.3	26.7	349.0	0.040
18	7.7733	384.0	-28.0	35.3	349.0	0.040
19	8.2508	359.1	-31.8	29.1	349.0	0.040
20	8.7027	336.7	-34.6	26.8	349.0	0.037
21	9.1372	316.3	-37.9	35.0	349.0	0.038
22	10.0707	275.8	-43.9	28.0	349.0	0.043
23	11.0421	238.1	-50.6	21.0	349.0	0.052
24	11.6053	218.2	-54.5	20.5	349.0	0.052
25	12.9823	175.7	-57.6	5.0	349.0	0.100
26	13.4876	162.1	-59.5	4.0	349.0	0.133
27	13.9817	149.8	-62.1	3.0	349.0	0.178
28	14.5011	137.6	-64.1	2.0	349.0	0.236
29	15.0537	125.7	-67.3	3.0	349.0	0.217
30	15.5728	115.2	-69.5	3.0	349.0	0.208
31	16.0665	106.1	-69.8	3.0	349.0	0.298
32	16.5479	97.8	-70.0	3.0	349.0	0.325
33	17.0944	89.2	-71.4	3.0	349.0	0.500
34	17.7471	79.9	-71.2	3.4	349.0	0.600
35	18.8780	66.2	-62.5	1.6	349.0	1.230
36	19.7623	57.3	-60.4	1.0	349.0	1.530
37	20.4393	51.4	-63.3	1.0	349.0	2.130
38	21.0696	46.4	-63.0	1.0	349.0	2.420
39	21.5199	43.1	-61.6	1.0	349.0	2.960
40	23.1810	33.5	-56.3	1.0	349.0	3.631
41	24.7630	26.1	-56.7	1.0	349.0	4.220
42	26.4210	20.1	-54.1	1.0	349.0	5.030
43	28.0910	15.6	-49.9	1.0	349.0	5.829
44	29.8280	11.9	-50.2	1.0	349.0	6.530
45	31.5420	9.2	-49.9	1.0	349.0	6.115
46	33.3200	7.0	-50.1	1.0	349.0	6.116
47	35.0330	5.4	-43.3	1.0	349.0	6.228
48	36.7370	4.2	-42.4	1.0	349.0	6.197
49	38.3900	3.3	-36.5	1.0	349.0	5.042
50	39.6380	2.8	-31.1	1.0	349.0	4.400

##

Table 6. GPXN011.TXT

##

```
Filename:  GPXN0111.TXT         (Created  30 August 1993  ROK)
Date:  1 November 1988
Time:  11:30 UTC
Location:  Denver, Colorado USA (-104.867,+39.767)
Comment:   Combined NCAR CLASS and ECC Ozone sonde data
Surface Skin Temperature:  Unknown
Surface Skin Emissivity:   Unknown
Surface Altitude:  1.6100 km
Surface Pressure:  840.7 mb
Surface Air Temperature:         4.9 degrees Celsius
Surface Air Relative Humidity: 37.0 %
Raob Source File:  GPXN0111.CLS / ECC SONDE 4A3061
Number of Profile Points:  50
Notes:
(1)  The CLASS sounding was used from the surface to 60.8 mb.  The
     temperature above this level was obtained from the 1 Nov 18:30 UTC
     ozone sonde as was the entire ozone profile.  The H2O above
     60.8 mb has been set to 1 %.
(2)  All other constituents should default to the climatological mean
     found in the AFGL U.S. Standard Atmosphere.
Recommended Profile Values:
```

Index	Altitude (km)	Pressure (mb)	Temp (C)	H2O RH (%)	CO2 (ppmv)	O3 (ppmv)
1	1.6100	840.7	4.9	37.0	349.0	0.044
2	1.6421	837.4	7.0	29.4	349.0	0.044
3	1.7405	827.5	13.1	15.5	349.0	0.045
4	1.8215	819.6	15.0	11.2	349.0	0.045
5	1.9822	804.2	15.4	11.8	349.0	0.047
6	2.1350	789.8	14.4	12.9	349.0	0.048
7	2.4684	759.0	12.4	10.0	349.0	0.049
8	2.7448	734.3	10.4	11.0	349.0	0.050
9	3.0580	707.0	7.9	10.3	349.0	0.050
10	3.5379	666.7	4.8	10.2	349.0	0.052
11	3.8604	640.7	1.7	12.0	349.0	0.052
12	4.1385	618.8	-0.6	13.0	349.0	0.052
13	4.4339	596.2	-2.8	9.1	349.0	0.052
14	4.6846	577.6	-4.7	4.8	349.0	0.054
15	4.9322	559.6	-6.3	4.6	349.0	0.054
16	5.2812	535.1	-7.9	12.7	349.0	0.053
17	5.6560	509.9	-8.8	11.1	349.0	0.053
18	6.0574	483.9	-12.4	17.3	349.0	0.052
19	6.5614	452.8	-15.7	15.0	349.0	0.051
20	7.0921	421.8	-19.5	18.3	349.0	0.045
21	7.6374	391.7	-24.7	24.5	349.0	0.041
22	8.1761	363.4	-29.4	27.5	349.0	0.040
23	8.7293	336.1	-33.6	26.9	349.0	0.040
24	9.2769	310.6	-38.0	27.0	349.0	0.042
25	10.3387	265.5	-46.6	23.6	349.0	0.043
26	10.8618	245.1	-50.6	25.6	349.0	0.049
27	12.0724	202.9	-57.9	29.0	349.0	0.072
28	12.6893	183.8	-62.5	29.0	349.0	0.090
29	13.8798	151.0	-69.9	20.0	349.0	0.178
30	15.5737	114.0	-67.3	7.0	349.0	0.208
31	16.2209	102.4	-67.4	5.0	349.0	0.280
32	16.6908	94.7	-67.7	4.0	349.0	0.400
33	17.9167	77.1	-69.7	3.0	349.0	0.640

34	18.5671	69.3	-63.4	3.0	349.0	1.000
35	19.2243	62.2	-65.4	2.0	349.0	1.250
36	19.3638	60.8	-65.1	2.0	349.0	1.300
37	19.9640	55.9	-60.4	1.0	349.0	1.727
38	20.7690	49.2	-60.8	1.0	349.0	2.274
39	21.6010	43.0	-57.5	1.0	349.0	2.956
40	23.1810	33.5	-56.3	1.0	349.0	3.631
41	24.7630	26.1	-56.7	1.0	349.0	4.220
42	26.4210	20.1	-54.1	1.0	349.0	5.030
43	28.0910	15.6	-49.9	1.0	349.0	5.829
44	29.8280	11.9	-50.2	1.0	349.0	6.530
45	31.5420	9.2	-49.9	1.0	349.0	6.115
46	33.3200	7.0	-50.1	1.0	349.0	6.116
47	35.0330	5.4	-43.3	1.0	349.0	6.228
48	36.7370	4.2	-42.4	1.0	349.0	6.197
49	38.3900	3.3	-36.5	1.0	349.0	5.042
50	39.6380	2.8	-31.1	1.0	349.0	4.400

```
##########################################################################
```

The HIS radiance files are too large to print in their entirety, so only the first 25 lines of the files are included in tables 7-10.

Table 7. 14 April 1986 HIS Radiance data

```
##########################################################################
FILENAME: HIS104B1.ASC
COMMENT: DOWNLOOKING HIS DATA BAND 1 (UWITRA93)
DATE:  14 APRIL 1986
TIME:  18:00 UTC
LOCATION:  PACIFIC OCEAN OFF CALIFORNIA COAST (-120.5,+34.7)
OBSERVATION ALTITUDE: 19.637 km  (NASA U2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.3640322  CM-1
REFERENCE WAVENUMBER (V0):  564.2500
WAVENUMBER INCREMENT (DV): 0.2755127
NUMBER OF RADIANCE VALUES IN THIS FILE: 1743
WAVENUMBER UNITS:  CM**-1
RADIANCE UNITS: mW/(M**2 CM**-1 SR)
 NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
HIS MEASUREMENT:
       INDEX  RADIANCE
         131   54.7433
         132   88.8154
         133  103.5435
         134  107.2112

##########################################################################

FILENAME: HIS104B2.ASC
COMMENT: DOWNLOOKING HIS DATA BAND 2 (UWITRA93)
DATE:  14 APRIL 1986
TIME:  18:00 UTC
LOCATION:  PACIFIC OCEAN OFF CALIFORNIA COAST (-120.5,+34.7)
OBSERVATION ALTITUDE: 19.637 km  (NASA U2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.6370564  CM-1
REFERENCE WAVENUMBER (V0):  987.43750
WAVENUMBER INCREMENT (DV): 0.4821472
```

```
NUMBER OF RADIANCE VALUES IN THIS FILE: 1494
WAVENUMBER UNITS:  CM**-1
RADIANCE UNITS: mW/(M**2 CM**-1 SR)
NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
HIS MEASUREMENT:
       INDEX  RADIANCE
         194  68.0208
         195  63.9362
         196  65.1847
         197  66.5262

########################################################################

FILENAME: HIS104B3.ASC
COMMENT: DOWNLOOKING HIS DATA BAND 3 (UWITRA93)
DATE:  14 APRIL 1986
TIME:  18:00 UTC
LOCATION:  PACIFIC OCEAN OFF CALIFORNIA COAST (-120.5,+34.7)
OBSERVATION ALTITUDE: 19.637 km  (NASA U2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.6370564  CM-1
REFERENCE WAVENUMBER (V0):  1974.8750
WAVENUMBER INCREMENT (DV): 0.4821472
NUMBER OF RADIANCE VALUES IN THIS FILE: 1452
WAVENUMBER UNITS:  CM**-1
RADIANCE UNITS: mW/(M**2 CM**-1 SR)
 NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
HIS MEASUREMENT:
       INDEX  RADIANCE
          54   4.0110
          55   4.0897
          56   4.1655
          57   4.2416

########################################################################
```

Table 8. 1 March 1992 HIS Radiance data

```
########################################################################
FILENAME: HIS1MRB1.TXT
COMMENT: DOWNLOOKING HIS DATA BAND 1 (UWITRA93)
DATE:   1 MARCH 1992
TIME:   12:21 UTC
LOCATION:  SENECA, KANSAS, USA (-96.11,+39.83)
OBSERVATION ALTITUDE:     19.725 km  (NASA ER-2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.3224285  CM-1
REFERENCE WAVENUMBER (V0):  564.2500 CM-1
WAVENUMBER INCREMENT (DV):  0.2755127 CM-1
NUMBER OF RADIANCE VALUES IN THIS FILE: 1743
WAVENUMBER UNITS:  CM-1
RADIANCE UNITS: mW/(M**2 CM-1 SR)
NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
```

```
HIS MEASUREMENT:
        INDEX  RADIANCE
          131  59.2751
          132  92.1262
          133 108.6515
          134 110.7373
```

##

```
FILENAME: HIS1MRB2.TXT
COMMENT: DOWNLOOKING HIS DATA BAND 2 (UWITRA93)
DATE:    1 MARCH 1992
TIME:    12:21 UTC
LOCATION:  SENECA, KANSAS, USA (-96.11,+39.83)
OBSERVATION ALTITUDE:     19.725 km   (NASA ER-2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.6809913  CM-1
REFERENCE WAVENUMBER (V0):  987.4375 CM-1
WAVENUMBER INCREMENT (DV):  0.4821472 CM-1
NUMBER OF RADIANCE VALUES IN THIS FILE: 1494
WAVENUMBER UNITS:  CM-1
RADIANCE UNITS: mW/(M**2 CM-1 SR)
 NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)   (Double Precision)
HIS MEASUREMENT:
        INDEX  RADIANCE
          194  54.2272
          195  55.7616
          196  54.9653
          197  54.4897
```

##

```
FILENAME: HIS1MRB3.TXT
COMMENT: DOWNLOOKING HIS DATA BAND 3 (UWITRA93)
DATE:    1 MARCH 1992
TIME:    12:21 UTC
LOCATION:  SENECA, KANSAS, USA (-96.11,+39.83)
OBSERVATION ALTITUDE:     19.725 km   (NASA ER-2)
OBSERVATION VIEW ANGLE:  NADIR TO EARTH (DOWNLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.9642944  CM-1
REFERENCE WAVENUMBER (V0):  1974.875 CM-1
WAVENUMBER INCREMENT (DV):  0.4821472 CM-1
NUMBER OF RADIANCE VALUES IN THIS FILE: 1452
WAVENUMBER UNITS:  CM-1
RADIANCE UNITS: mW/(M**2 CM-1 SR)
NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)   (Double Precision)
HIS MEASUREMENT:
        INDEX  RADIANCE
           54   3.0723
           55   3.1365
           56   3.1947
           57   3.2477
```

##

Table 9. 31 Oct 1988 HIS Radiance data

```
################################################################################

 FILENAME: GPXO31B1.TXT
 COMMENT: UPLOOKING GAPEX HIS DATA BAND 1 (UWITRA93)
 DATE:    31 OCTOBER 1988
 TIME:    20:36 UTC
 LOCATION:  DENVER, COLORADO, USA (-104.867, +39.767)
 OBSERVATION ALTITUDE:    SURFACE
 OBSERVATION VIEW ANGLE:  VERTICAL TO SPACE (UPLOOKING)
 SPECTRAL RESOLUTION (UNAPODIZED): 0.3640322  CM-1
 REFERENCE WAVENUMBER (V0):  564.2500 CM-1
 WAVENUMBER INCREMENT (DV):  0.2755127 CM-1
 NUMBER OF RADIANCE VALUES IN THIS FILE: 1743
 WAVENUMBER UNITS:  CM-1
 RADIANCE UNITS: mW/(M**2 CM-1 SR)
 NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
 HIS MEASUREMENT:
   INDEX RADIANCE
     131 145.8298
     132 134.9205
     133 117.6674
     134  88.0585

################################################################################

 FILENAME: GPXO31B2.TXT
 COMMENT: UPLOOKING GAPEX HIS DATA BAND 2 (UWITRA93)
 DATE:    31 OCTOBER 1988
 TIME:    20:36 UTC
 LOCATION:  DENVER, COLORADO, USA (-104.867, +39.767)
 OBSERVATION ALTITUDE:    SURFACE
 OBSERVATION VIEW ANGLE:  VERTICAL TO SPACE (UPLOOKING)
 SPECTRAL RESOLUTION (UNAPODIZED): 0.9642944  CM-1
 REFERENCE WAVENUMBER (V0):  987.4375 CM-1
 WAVENUMBER INCREMENT (DV):  0.9642944 CM-1
 NUMBER OF RADIANCE VALUES IN THIS FILE: 747
 WAVENUMBER UNITS:  CM-1
 RADIANCE UNITS:     mW/(M**2 CM-1 SR)
 NOTES:
  (1)  Use the following formula to compute the correct
       wavenumber value corresponding to the index number provided.
          V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
 HIS MEASUREMENT:
   INDEX RADIANCE
      98   2.5099
      99   5.9017
     100  -0.8277
     101   5.4657

################################################################################
```

Table 10. 1 Nov 1988 HIS Radiance data

```
################################################################################

 FILENAME: GPXN01B1.TXT
```

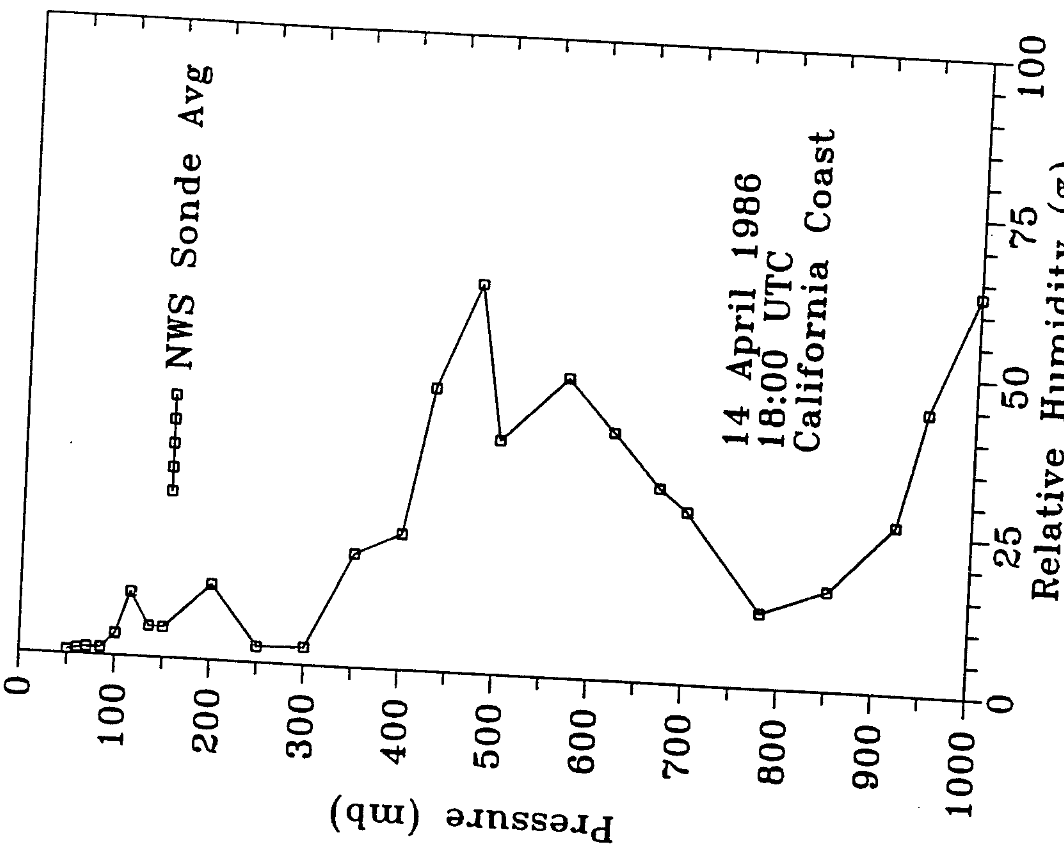
```
COMMENT: UPLOOKING GAPEX HIS DATA BAND 1 (UWITRA93)
DATE:    1 NOVEMBER 1988
TIME:    11:30 UTC
LOCATION:  DENVER, COLORADO, USA (-104.867, +39.767)
OBSERVATION ALTITUDE:     SURFACE
OBSERVATION VIEW ANGLE:  VERTICAL TO SPACE (UPLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.3640322  CM-1
REFERENCE WAVENUMBER (V0):  564.2500 CM-1
WAVENUMBER INCREMENT (DV):  0.2755127 CM-1
NUMBER OF RADIANCE VALUES IN THIS FILE: 1743
WAVENUMBER UNITS:  CM-1
RADIANCE UNITS: mW/(M**2 CM-1 SR)
NOTES:
 (1)  Use the following formula to compute the correct
      wavenumber value corresponding to the index number provided.
         V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
HIS MEASUREMENT:
  INDEX RADIANCE
    131 129.7319
    132 121.7713
    133 107.3717
    134  77.4460
```

##

```
FILENAME: GPXN01B2.TXT
COMMENT: UPLOOKING GAPEX HIS DATA BAND 2 (UWITRA93)
DATE:    1 NOVEMBER 1988
TIME:    10:30 UTC
LOCATION:  DENVER, COLORADO, USA (-104.867, +39.767)
OBSERVATION ALTITUDE:     SURFACE
OBSERVATION VIEW ANGLE:  VERTICAL TO SPACE (UPLOOKING)
SPECTRAL RESOLUTION (UNAPODIZED): 0.9642944  CM-1
REFERENCE WAVENUMBER (V0):  987.4375 CM-1
WAVENUMBER INCREMENT (DV):  0.9642944 CM-1
NUMBER OF RADIANCE VALUES IN THIS FILE: 747
WAVENUMBER UNITS:  CM-1
RADIANCE UNITS:    mW/(M**2 CM-1 SR)
NOTES:
 (1)  Use the following formula to compute the correct
      wavenumber value corresponding to the index number provided.
         V = V0 + DV * FLOAT(INDEX-1)  (Double Precision)
HIS MEASUREMENT:
  INDEX RADIANCE
     98   1.6226
     99   5.2298
    100   0.3932
    101   4.8593
```

##

The contents of the UWITRA93 dataset are best represented graphically. Figures 1-5 represent the radiosonde measurements for the four case days. Figures 6-9 represent the HIS radiance spectra corresponding to those days. In addition to the observed data, the retrieved profiles of ozone and upper level water vapor are included in the downlooking cases.



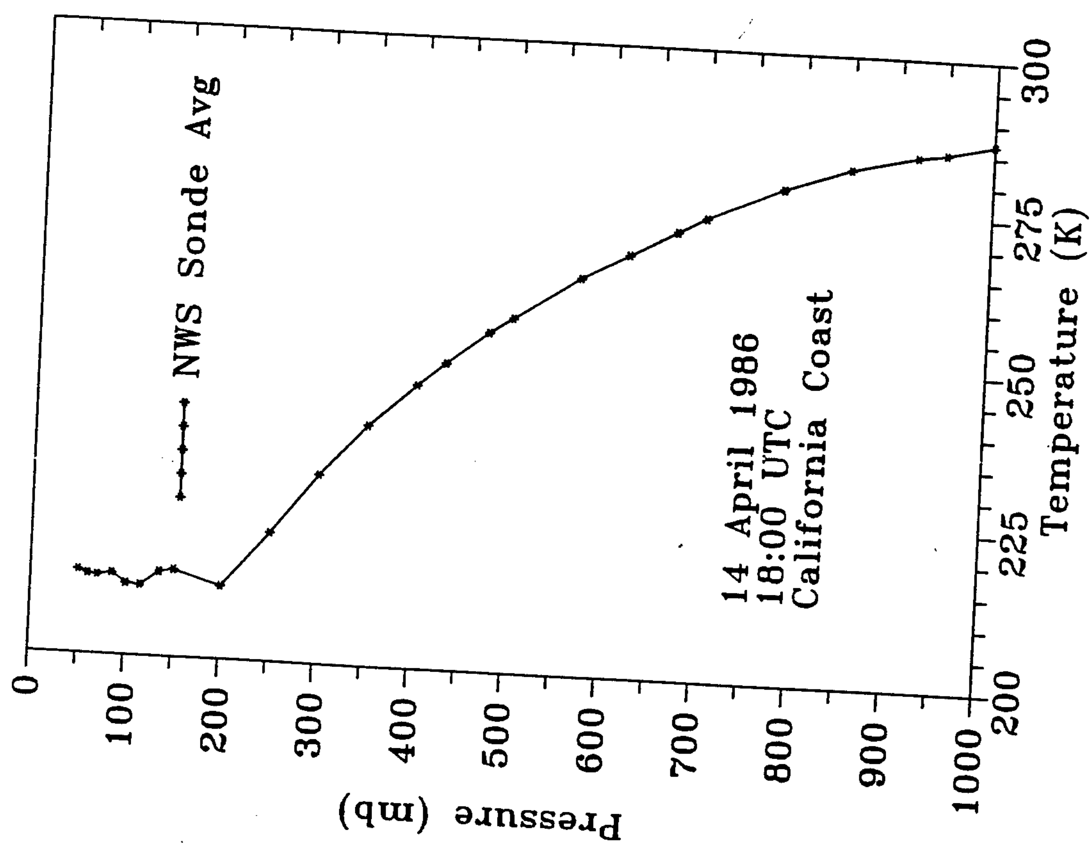
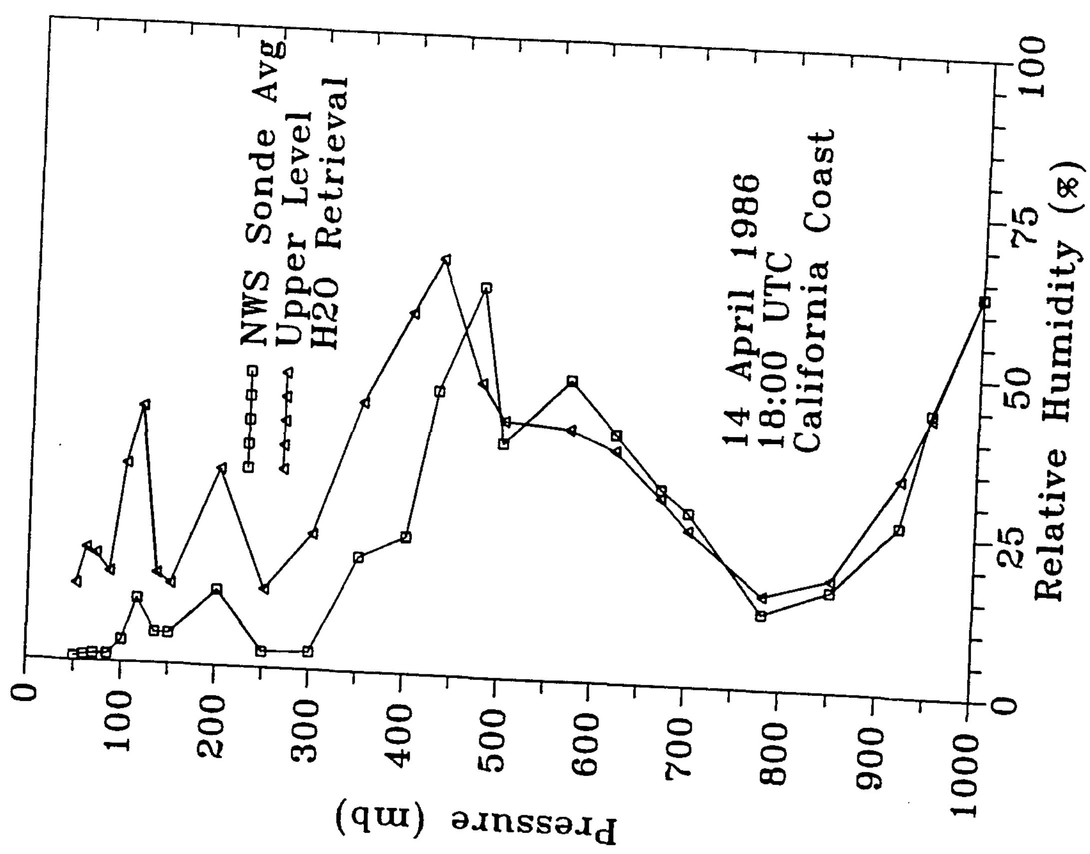


Figure 1a. 14 April 1986 Observed temperature and moisture profiles.



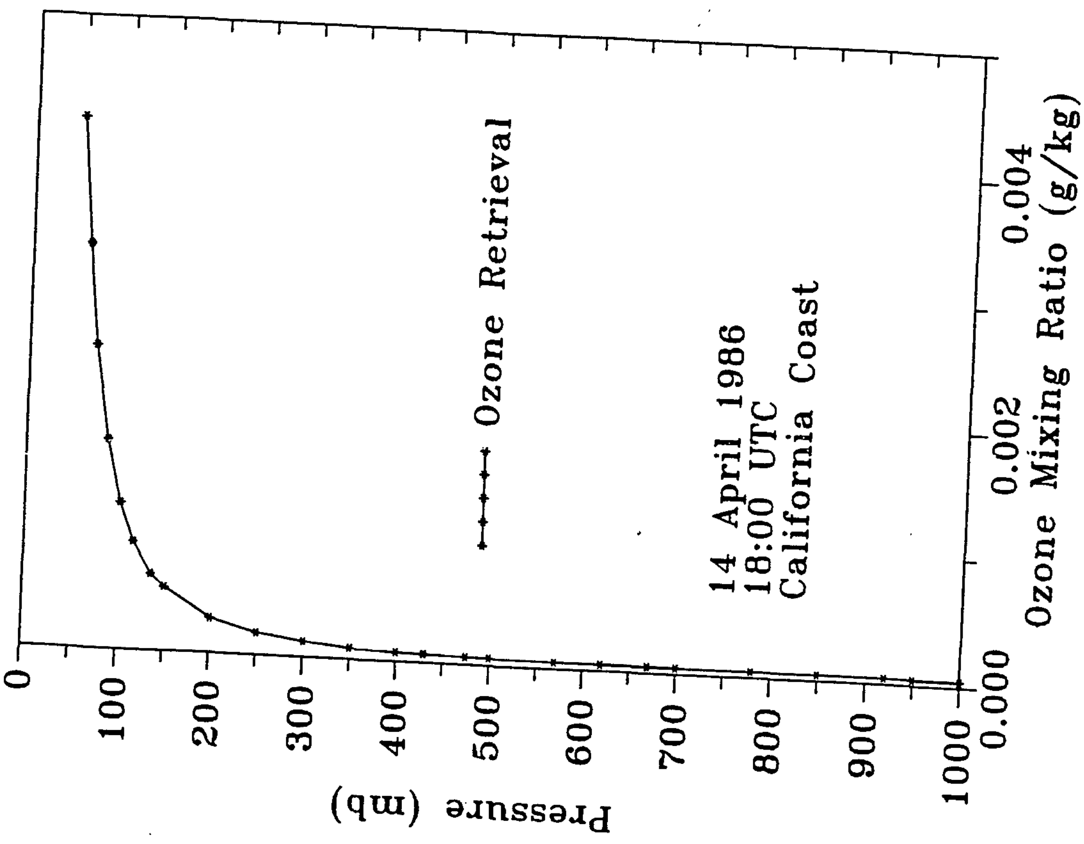


Figure 1b. 14 April 1986 Retrieved ozone and upper level H2O profiles.

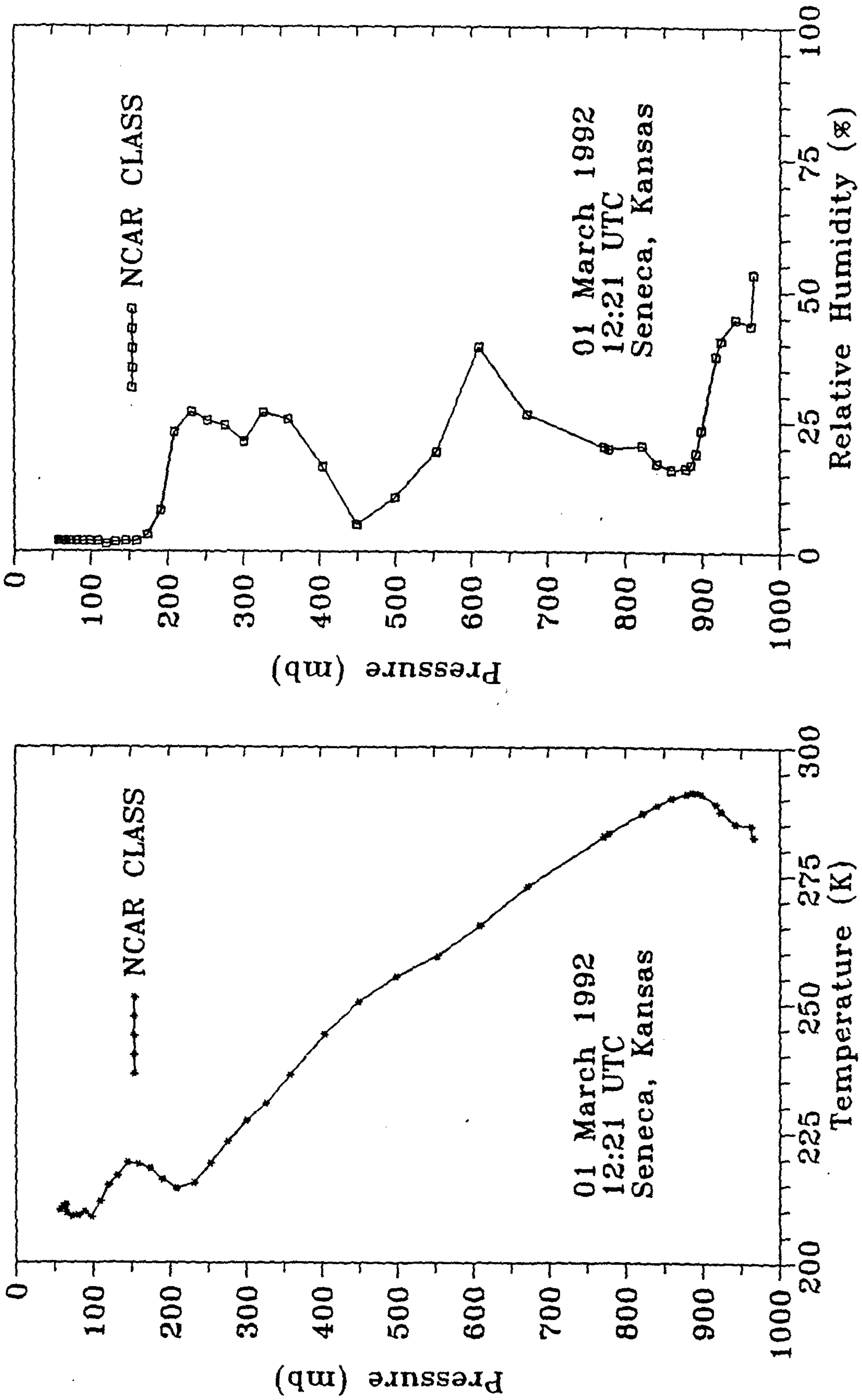


Figure 2a. 1 March 1992 Observed temperature and moisture profiles.

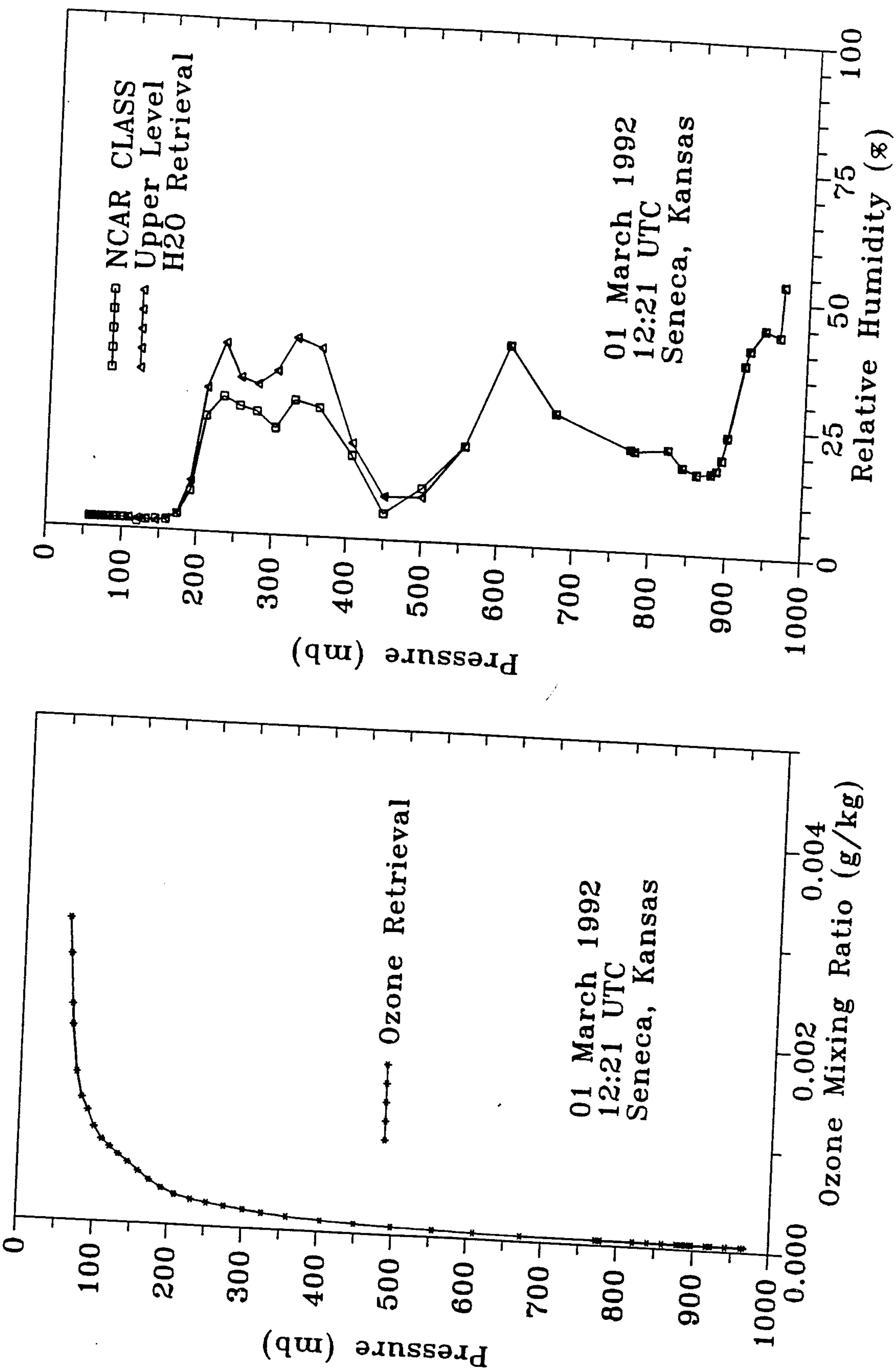


Figure 2b. 1 March 1992 Retrieved ozone and upper level H2O profiles.

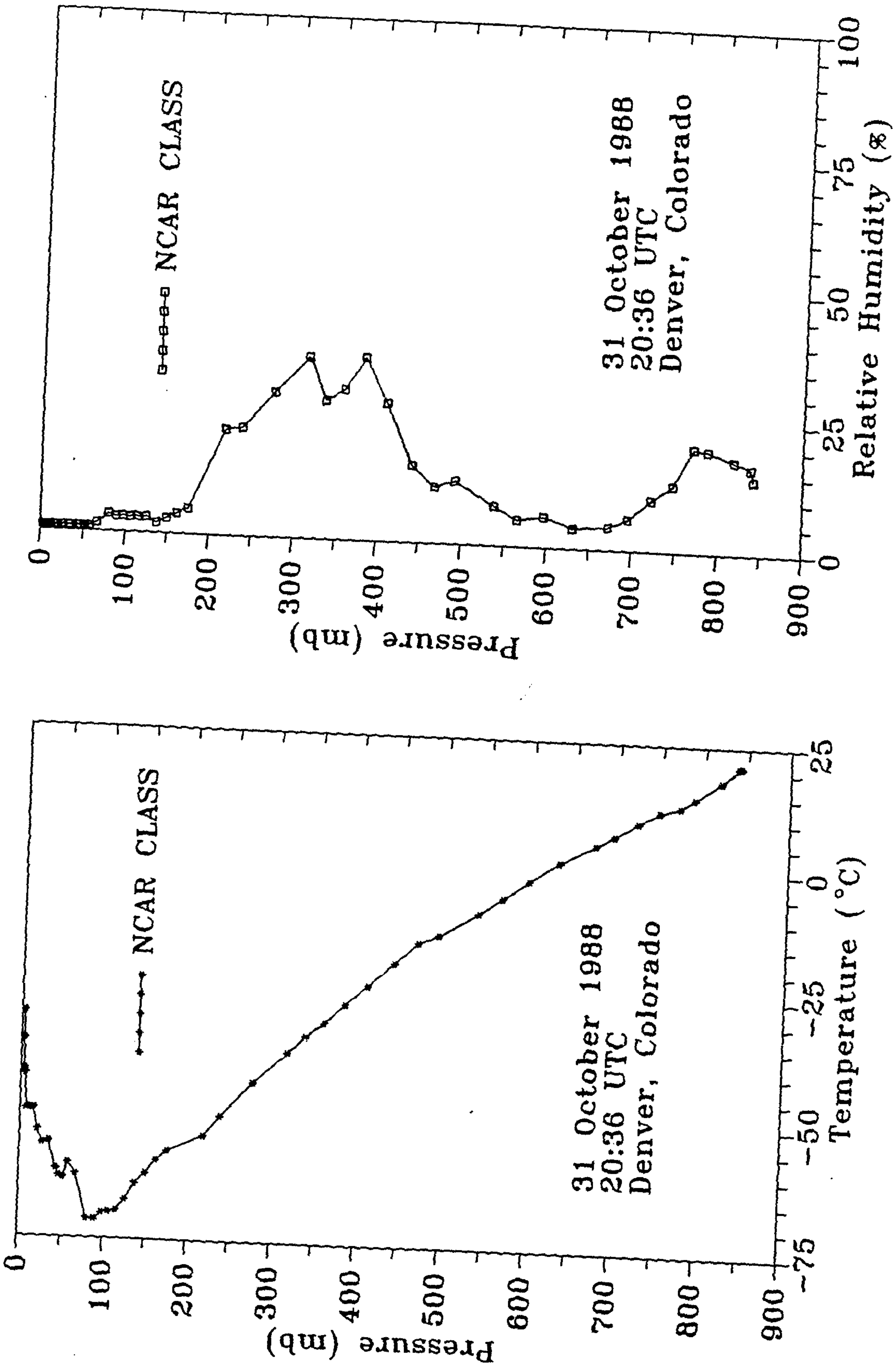
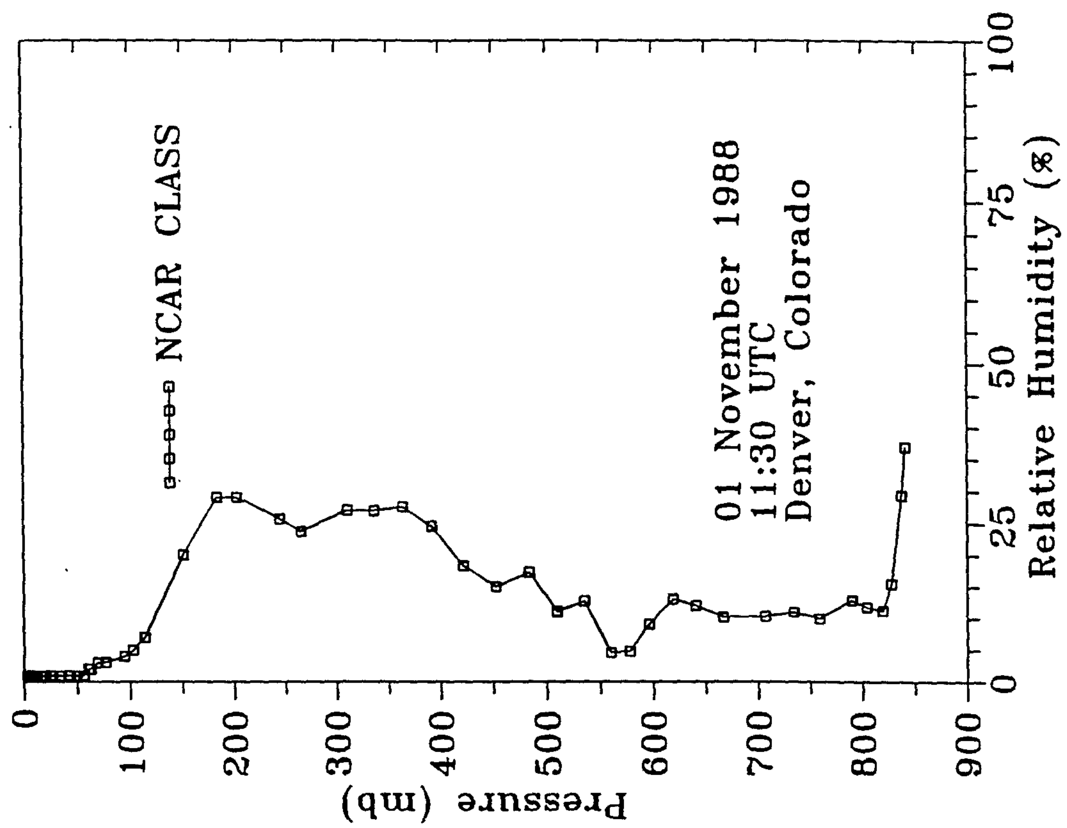


Figure 3. 31 October 1988 Observed temperature and moisture profiles.



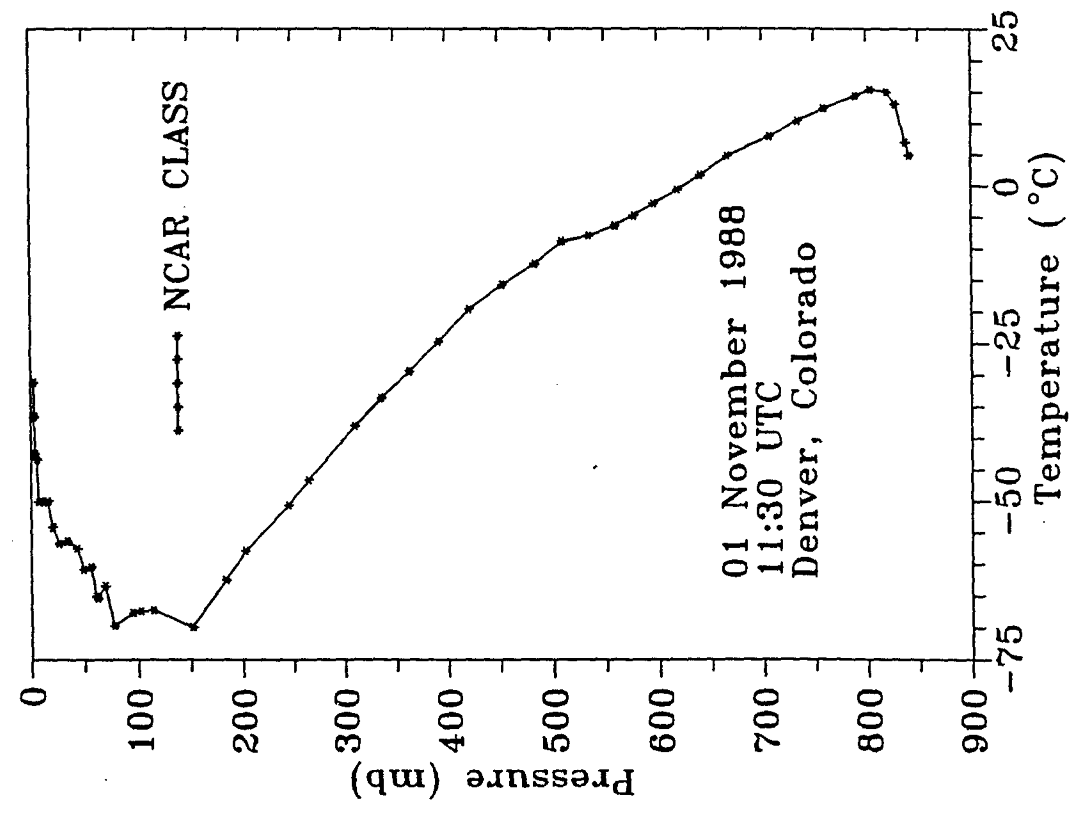


Figure 4. 1 November 1988 Observed temperature and moisture profiles.

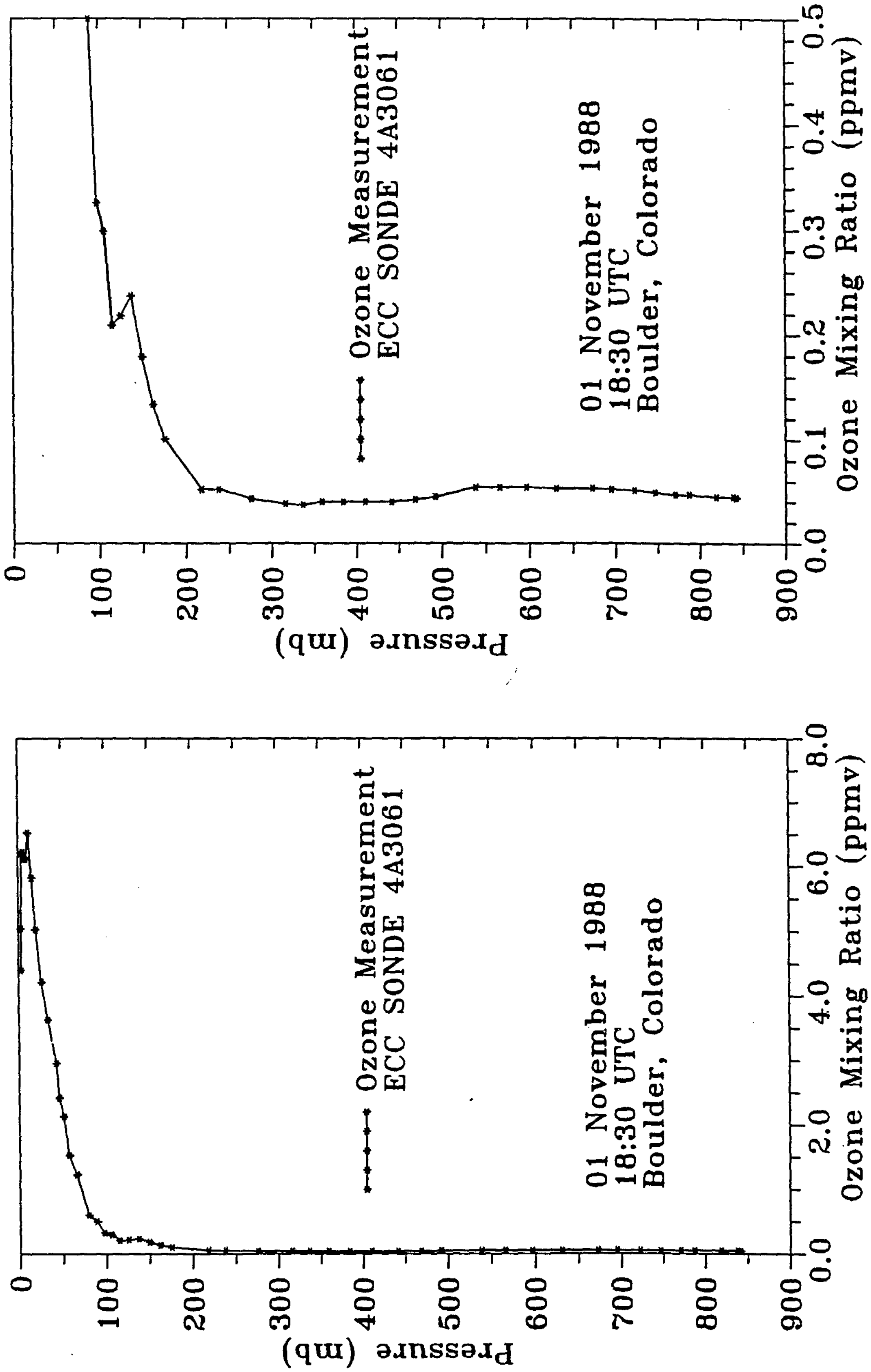


Figure 5. GAPEX Observed ozone profile. 1 November 1988 18:30 UTC.

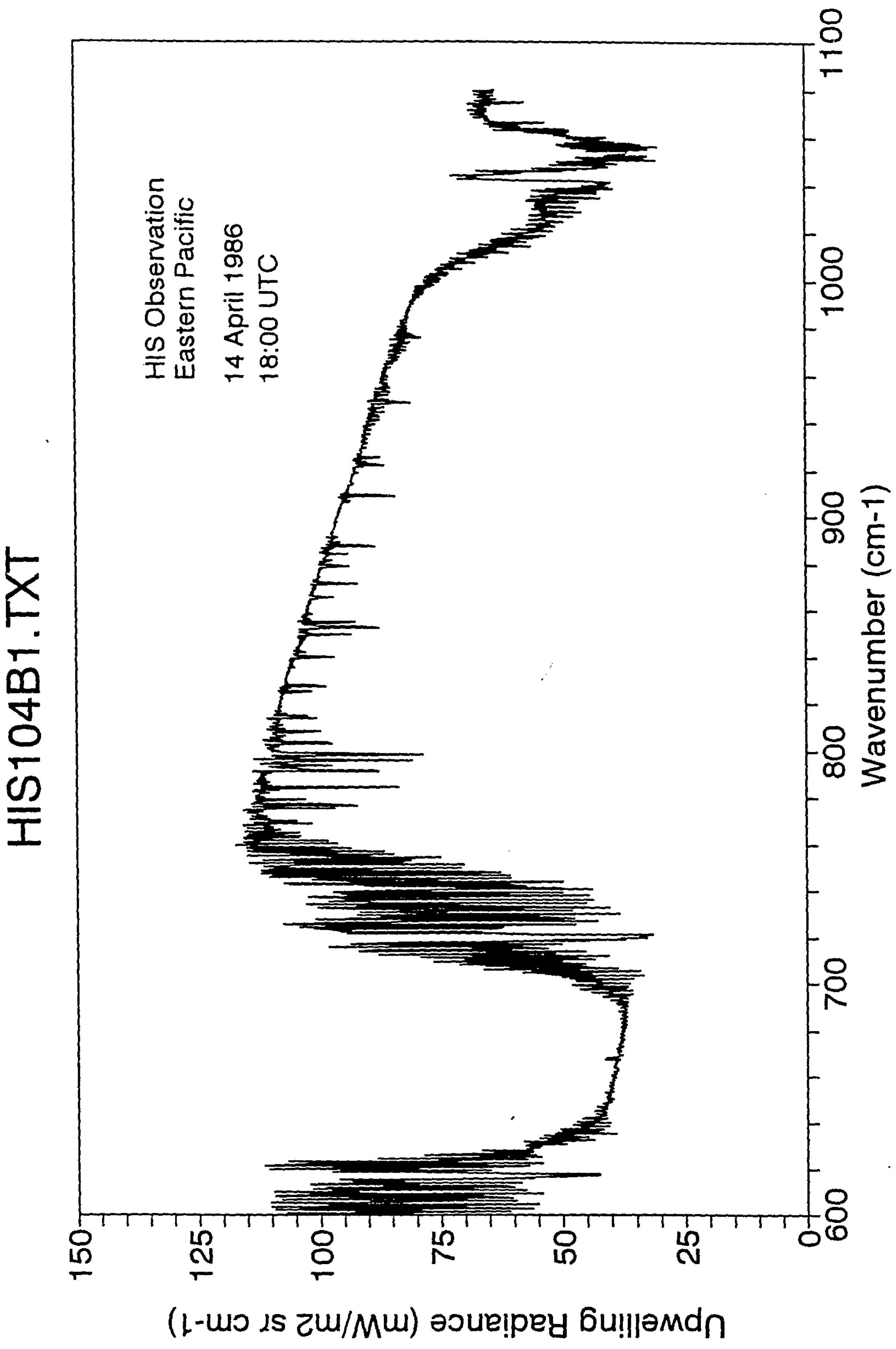


Figure 6a. 14 April 1986 HIS observed radiance data. Band I.

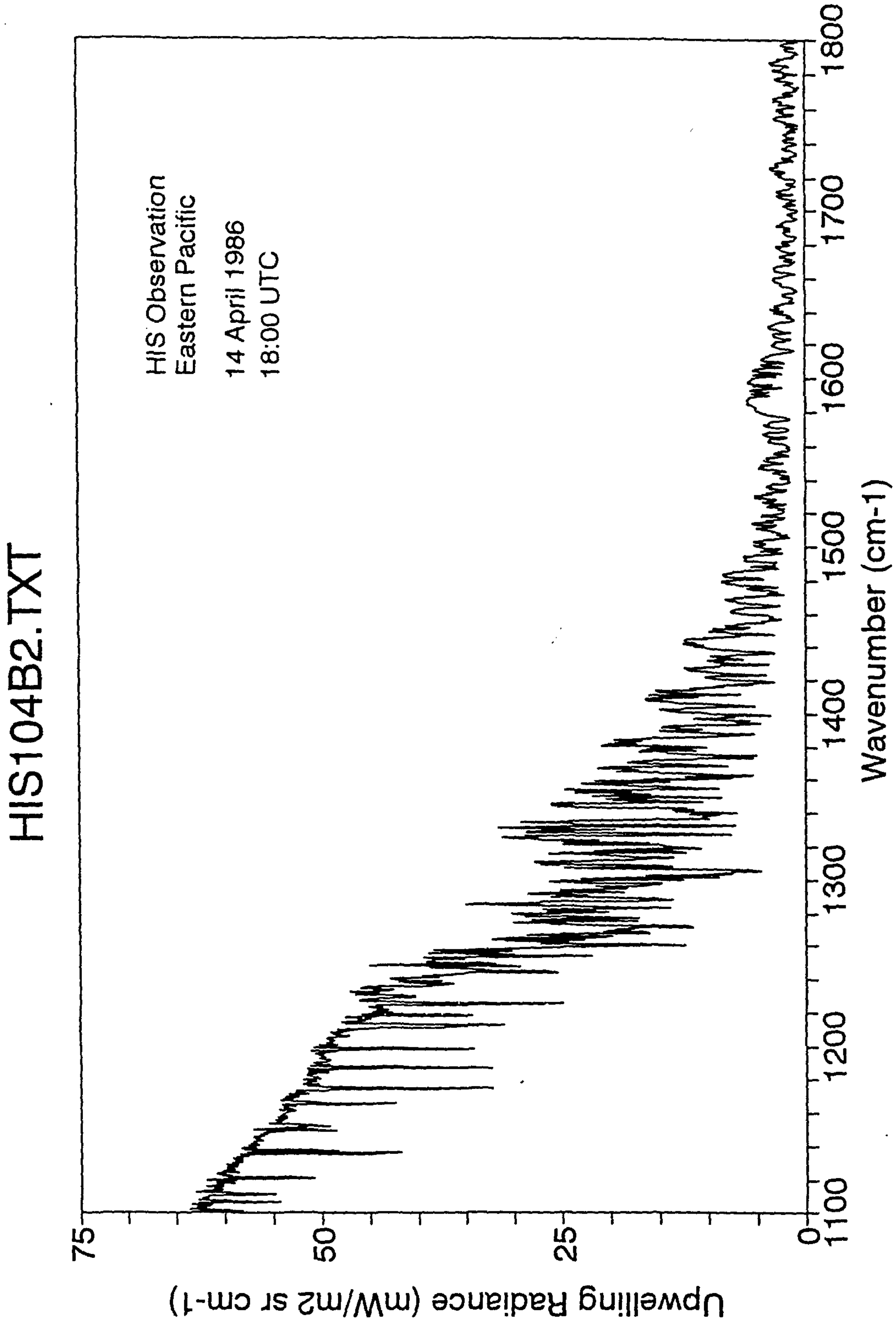


Figure 6b. 14 April 1986 HIS observed radiance data. Band II.

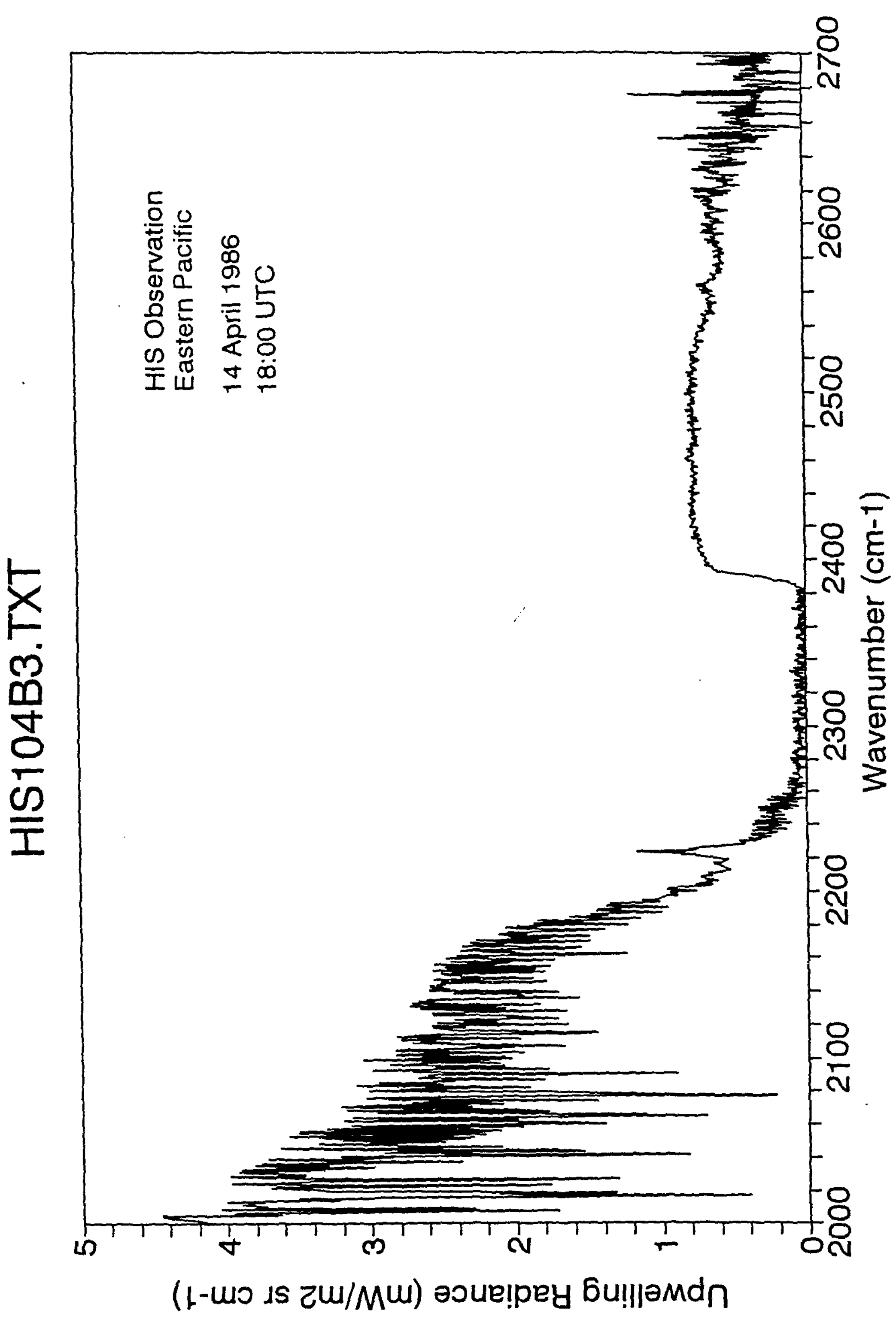


Figure 6c. 14 April 1986 HIS observed radiance data. Band III.

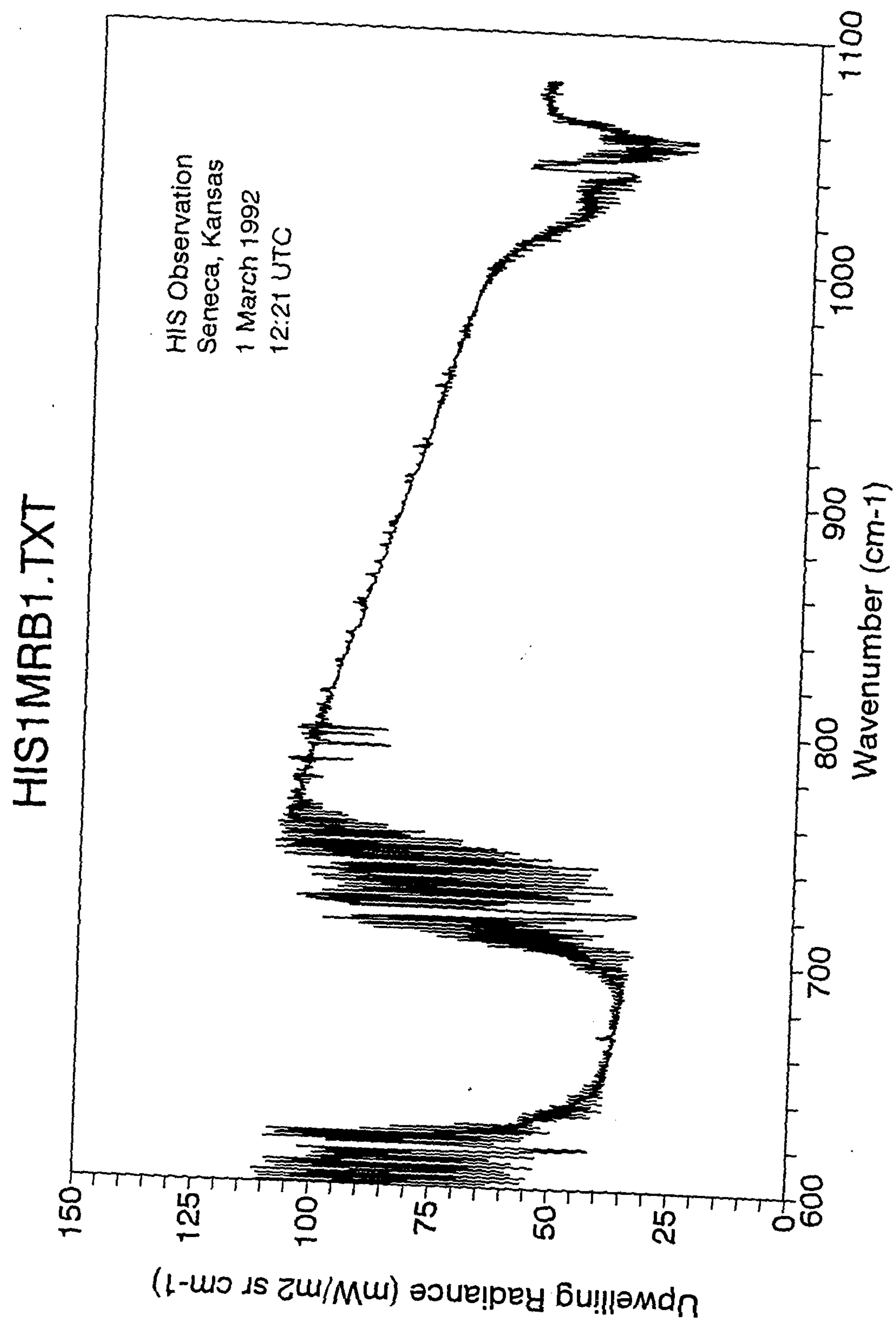


Figure 7a. 1 March 1992 HIS observed radiance data. Band I.

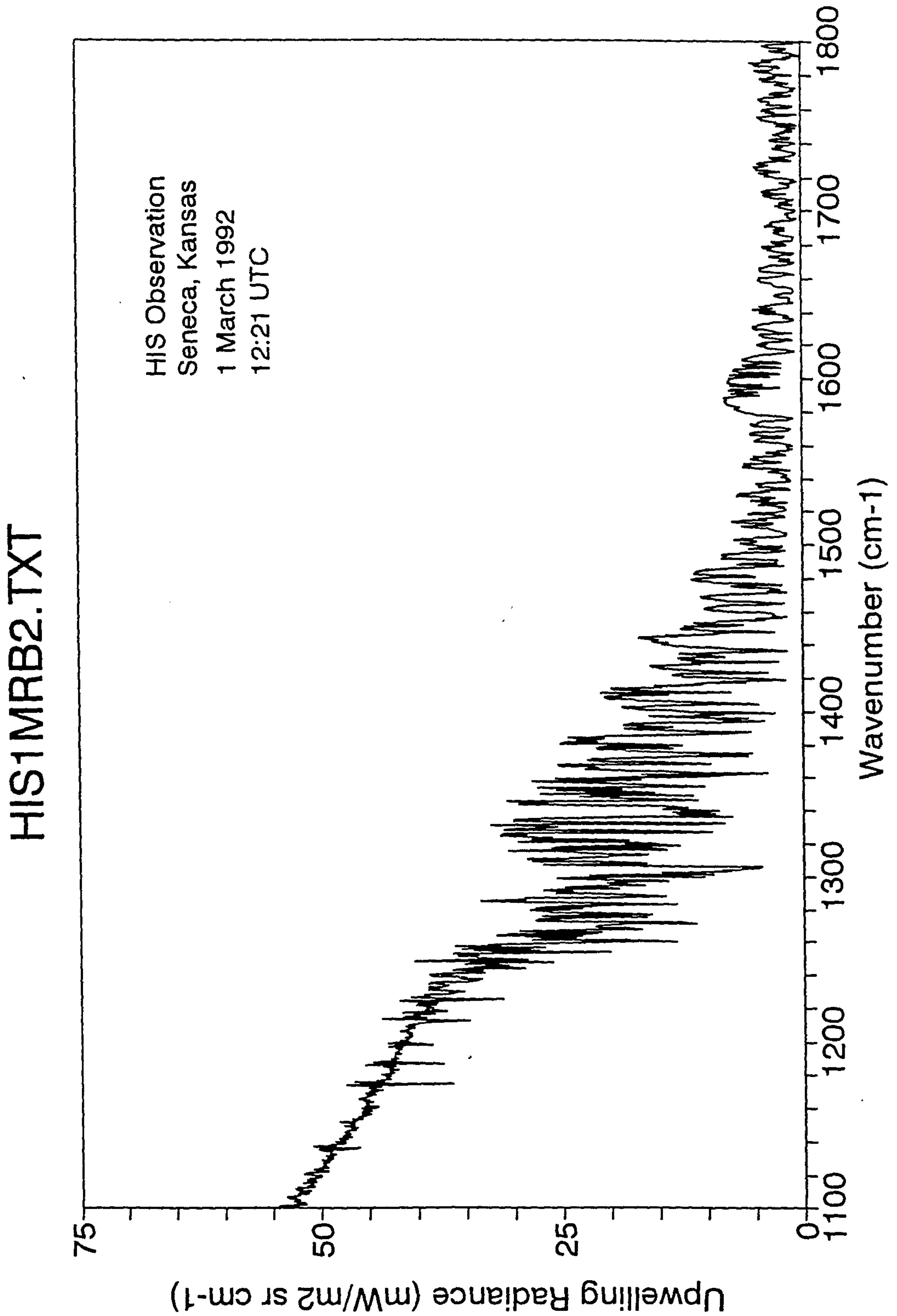


Figure 7b. 1 March 1992 HIS observed radiance data. Band II.

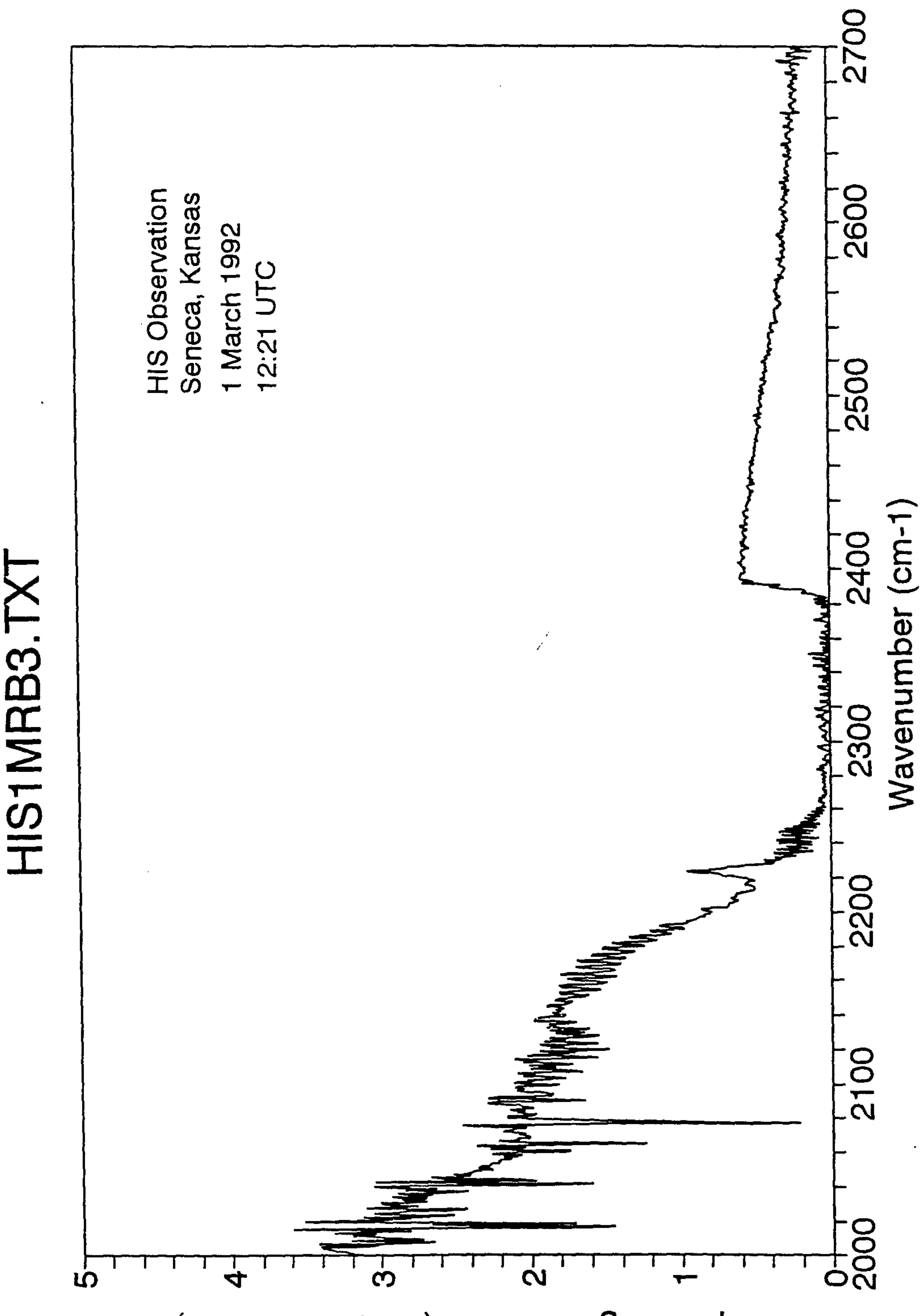


Figure 7c. 1 March 1992 HIS observed radiance data. Band III.

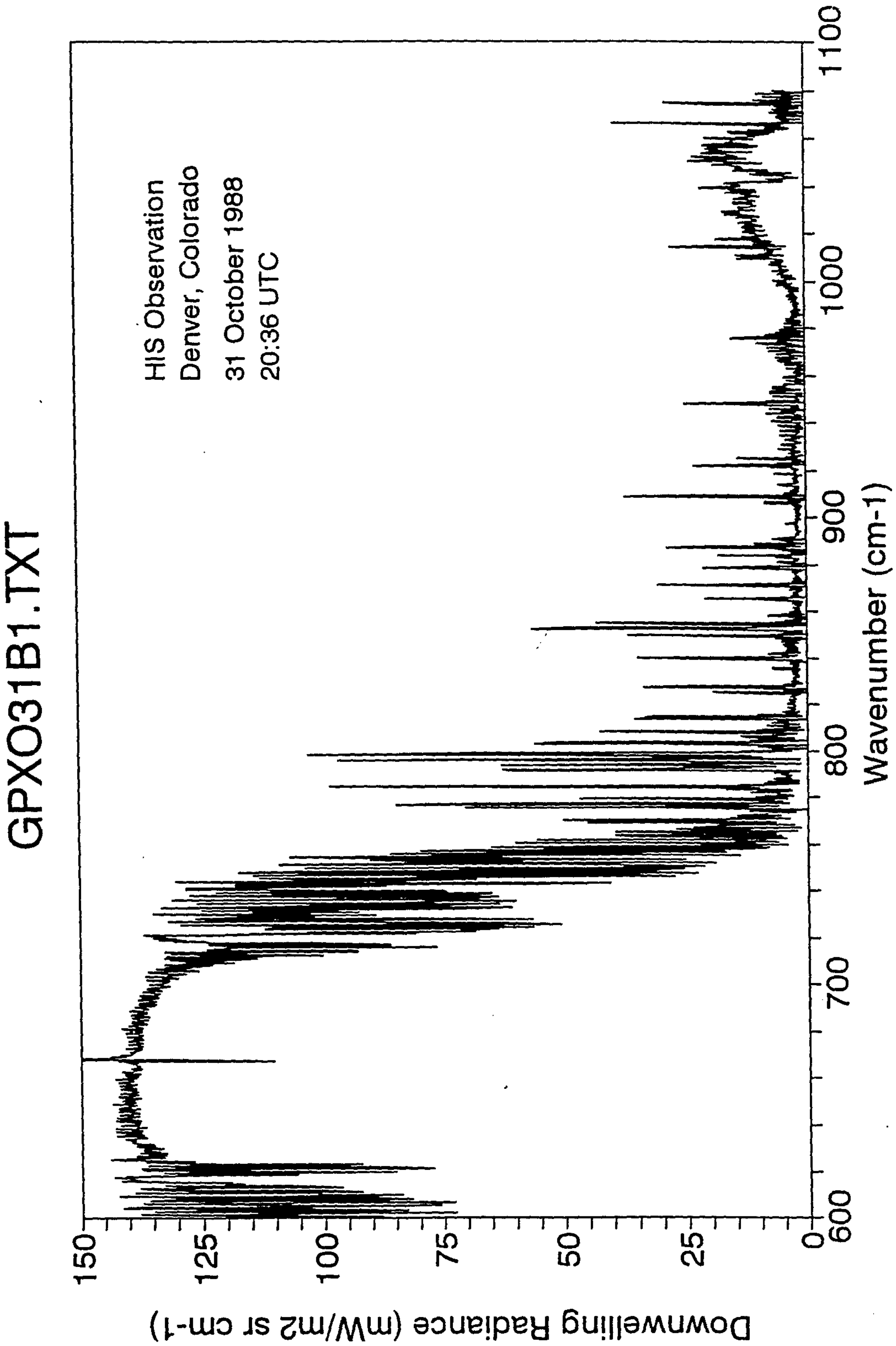


Figure 8a. 31 October 1988 HIS observed radiance data. Band I.

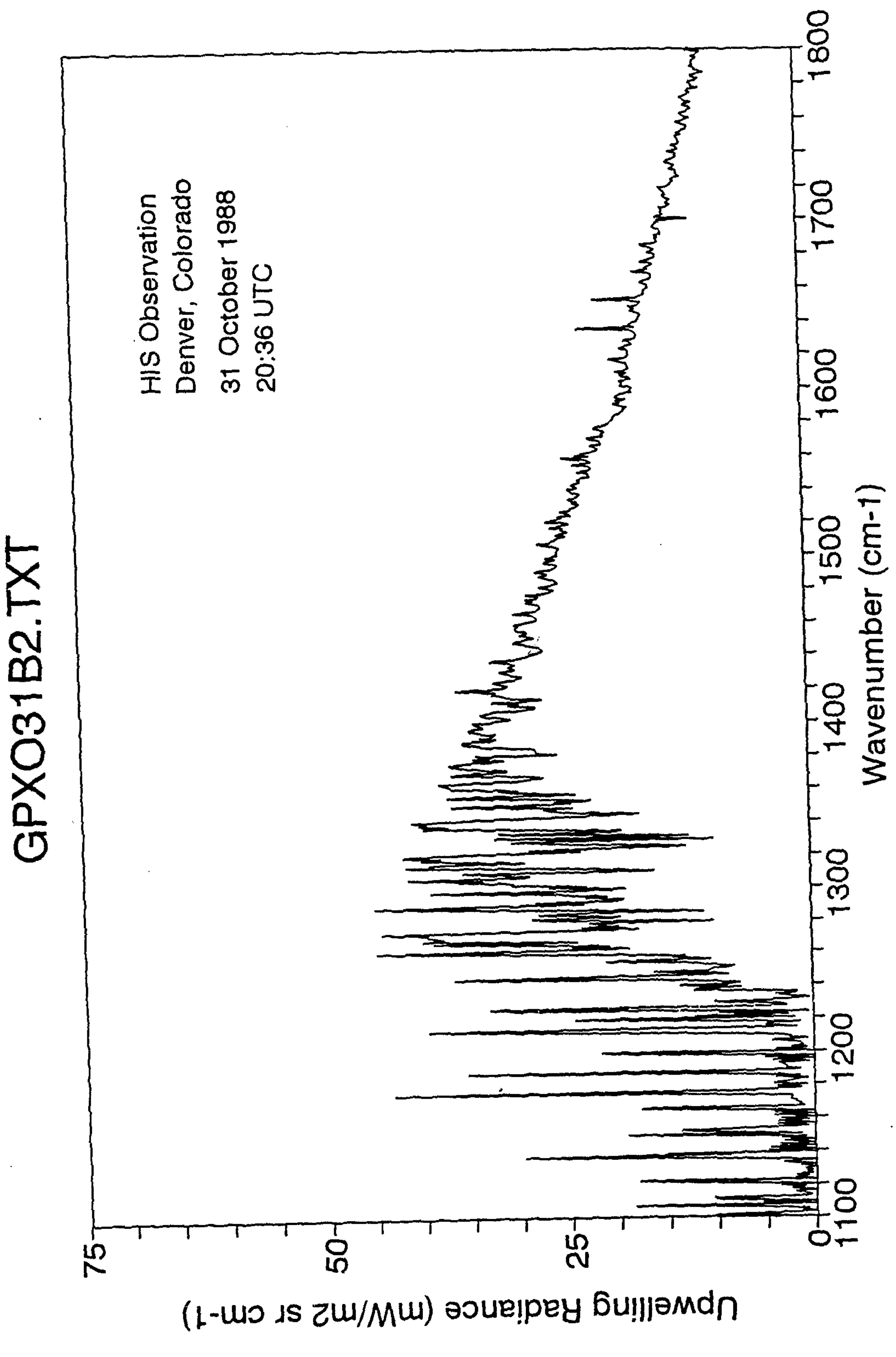


Figure 8b. 31 October 1988 HIS observed radiance data. Band II.

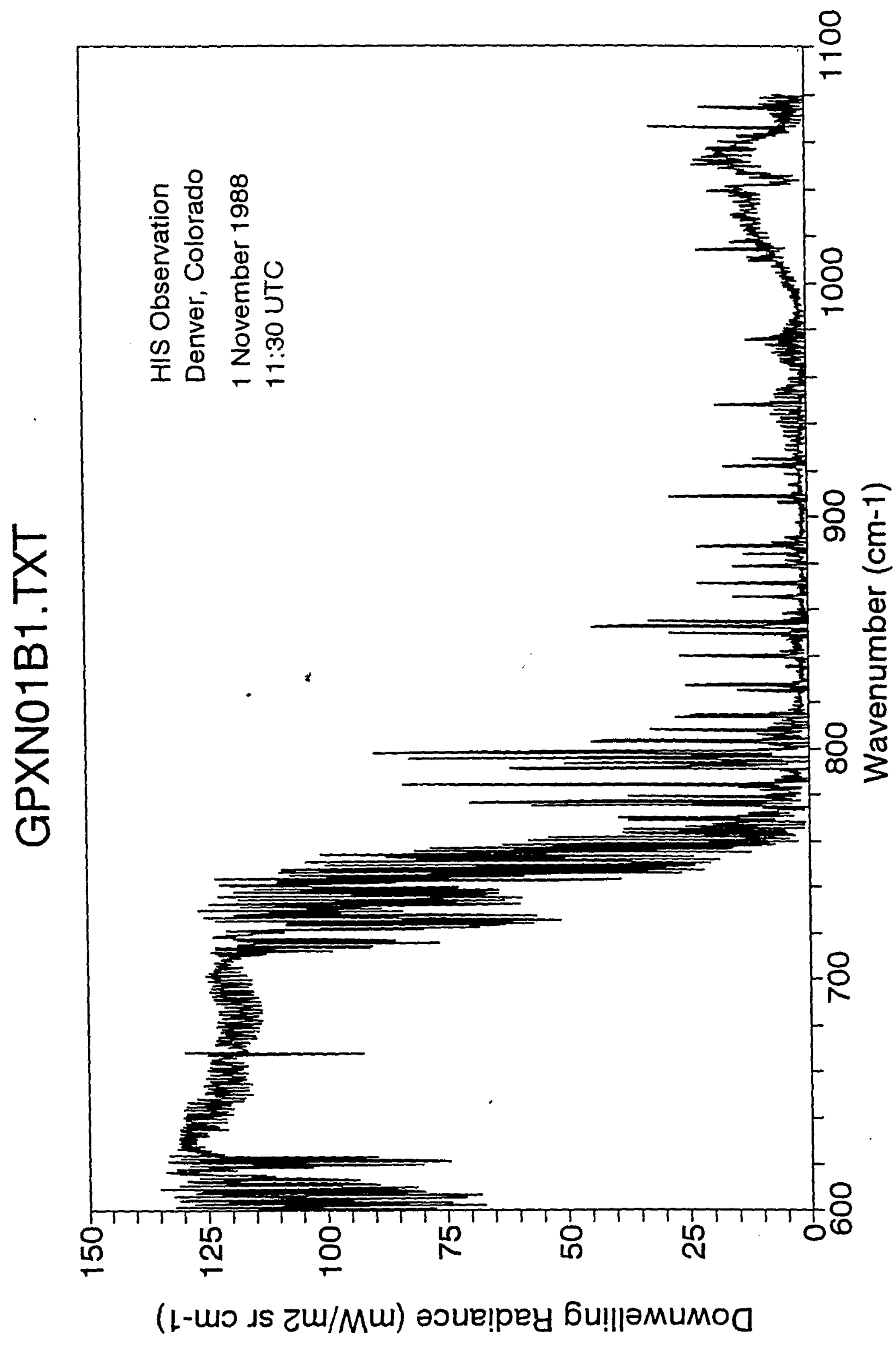


Figure 9a. 1 November 1988 HIS observed radiance data. Band I.

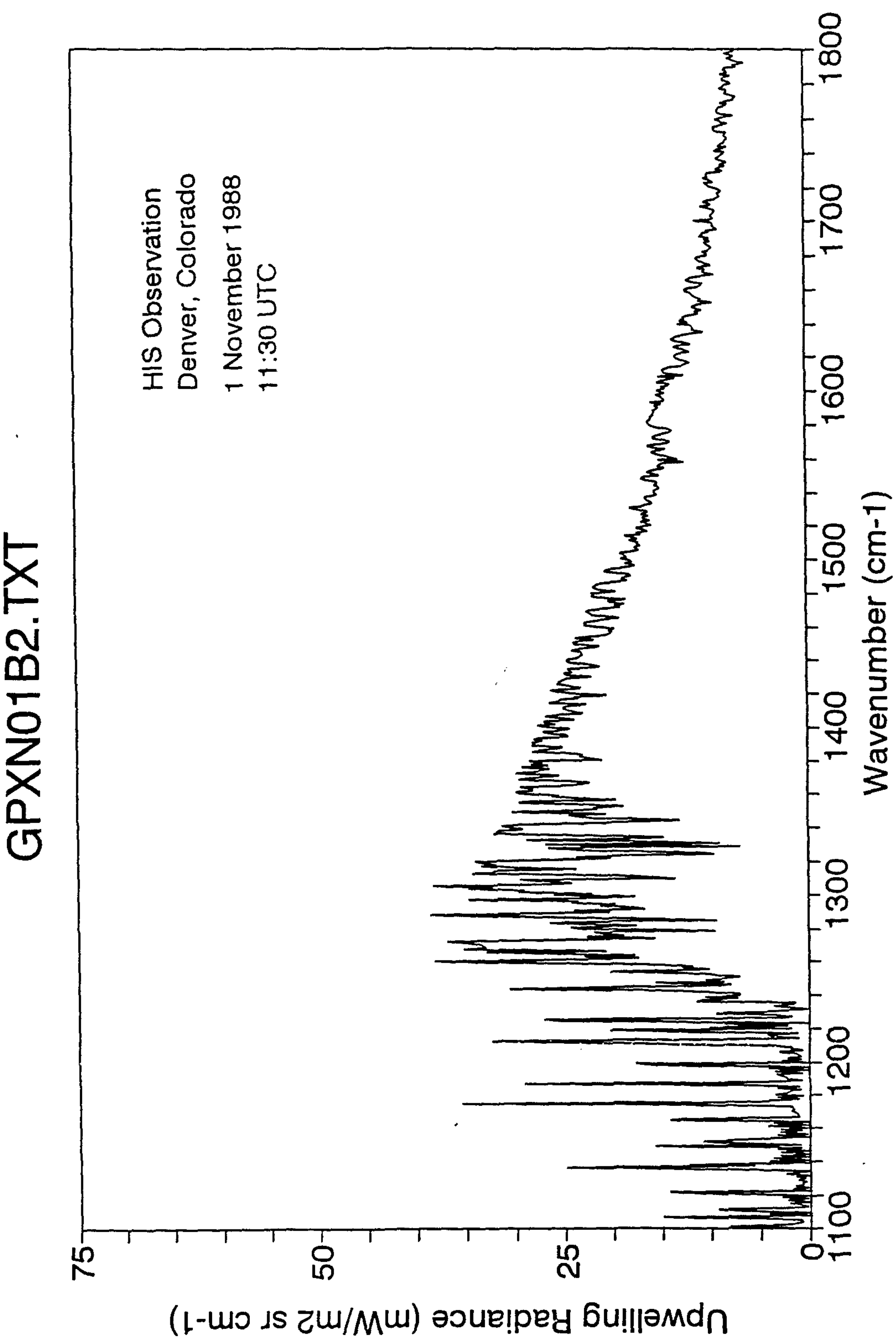


Figure 9b. 1 November 1988 HIS observed radiance data. Band II.

C. Comparison to FASCODE

The line-by-line radiative transfer model developed at the United States Air Force Phillips Laboratory (formerly the Geophysics Laboratory, AFGL) is the Fast Atmospheric Signature CODE (FASCODE). A recent version of the FASCODE model was used to calculate the upwelling (or downwelling) radiance using the atmsopheric state data provided in the UWITRA93 data set. This section contains the preliminary results of comparing the observed radiances to the calculated spectra using the balloon sonde data to define the atmospheric state.

FASCODE version three (FASCOD3P, March 1992) was used on an IBM RS/6000 computer running the IBM unix operating system AIX. The HITRAN92 database was also used as input to the program LNFL92 containing the line mixing parameters to create an input line datafile for use with FASCOD3P. The FASCODE model results, at the very high resolution of the natural atmosphere, were reduced in spectral resolution to carefully match the observation. The method of spectral resolution reduction was to perform a Fast Fourier Transform (FFT) upon the spectral data then truncate the resulting interferogram at the resolution of the instrument data and transform back into the spectral domain. This resolution reduction process accurately matches the calculated spectral resolution to the observed data and samples the atmospheric spectrum at the same points sampled by the HIS instrument.

The observed-minus-calculated differences were formed for both the measured temperature and moisture profiles and for the case where the measured moisture profile was replaced by a retrieved moisture profile above 500 mb. The resulting differences, given in Figures 10-13, are a preliminary result. The FASCOD3P runs are subject to review and possible revision, however the principal features shown are consistent with previous results.

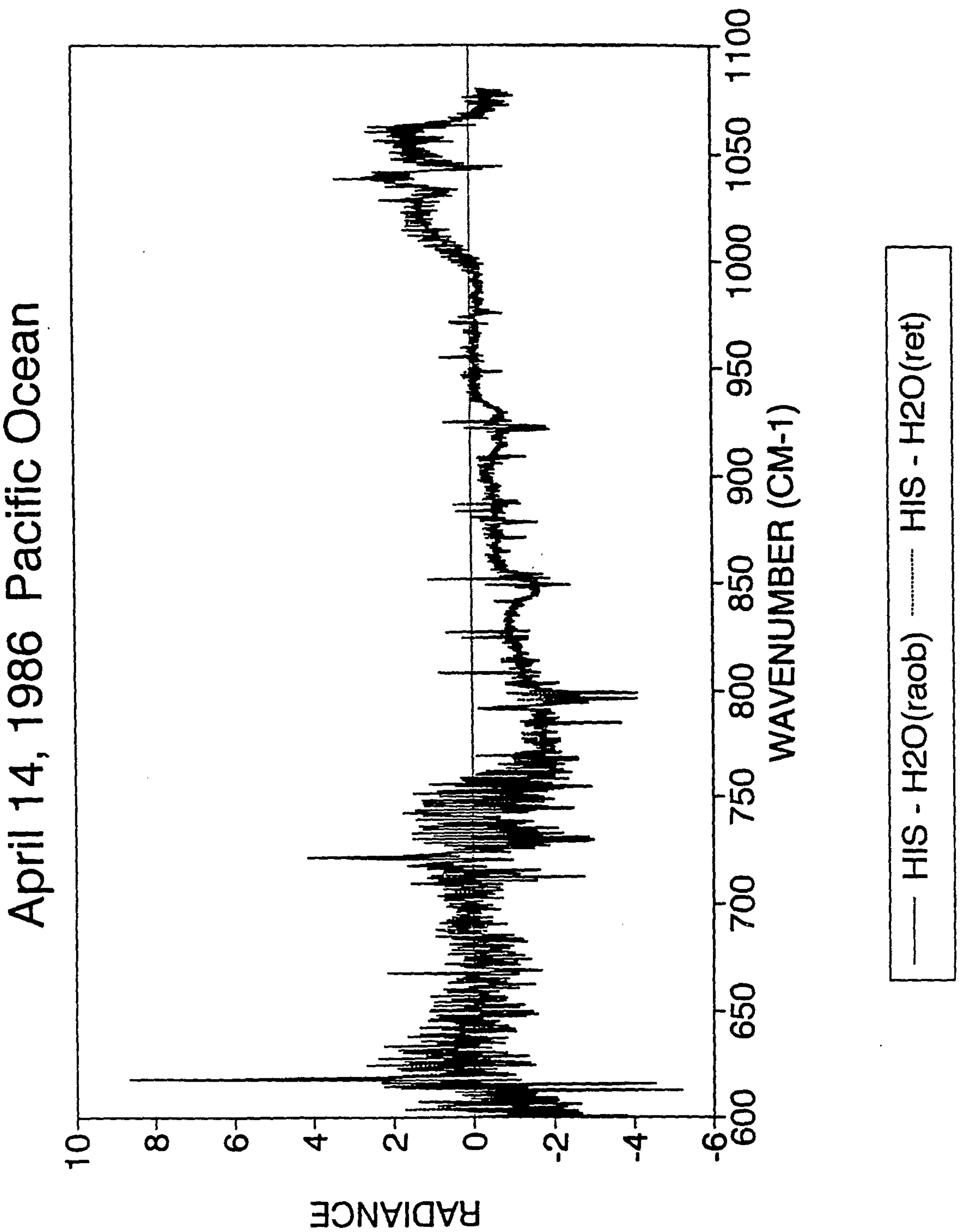


Figure 10a. 14 April 1986 HIS observed minus FASCOD3P calculation. Band I.

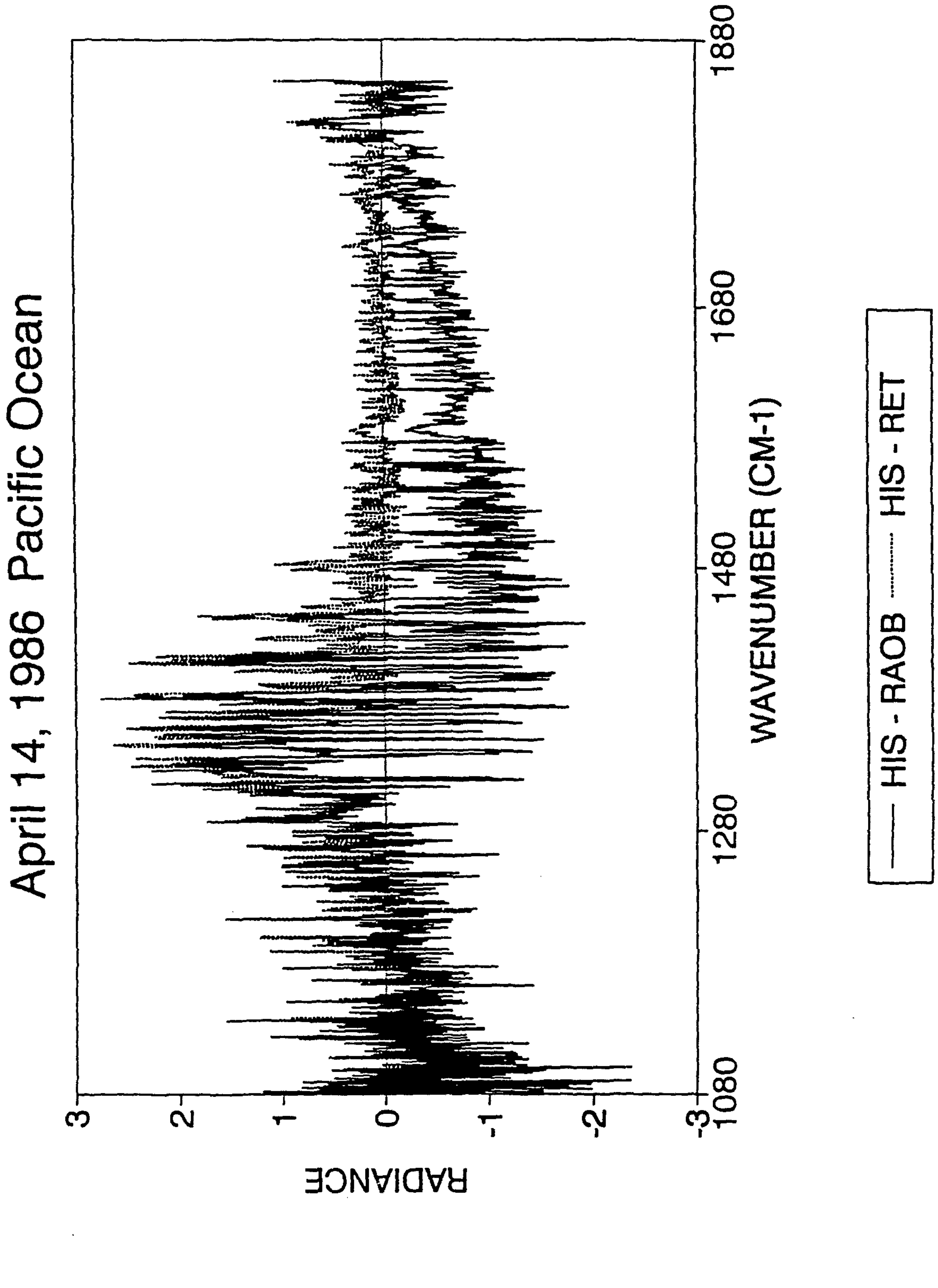


Figure 10b. 14 April 1986 HIS observed minus FASCOD3P calculation. Band II.

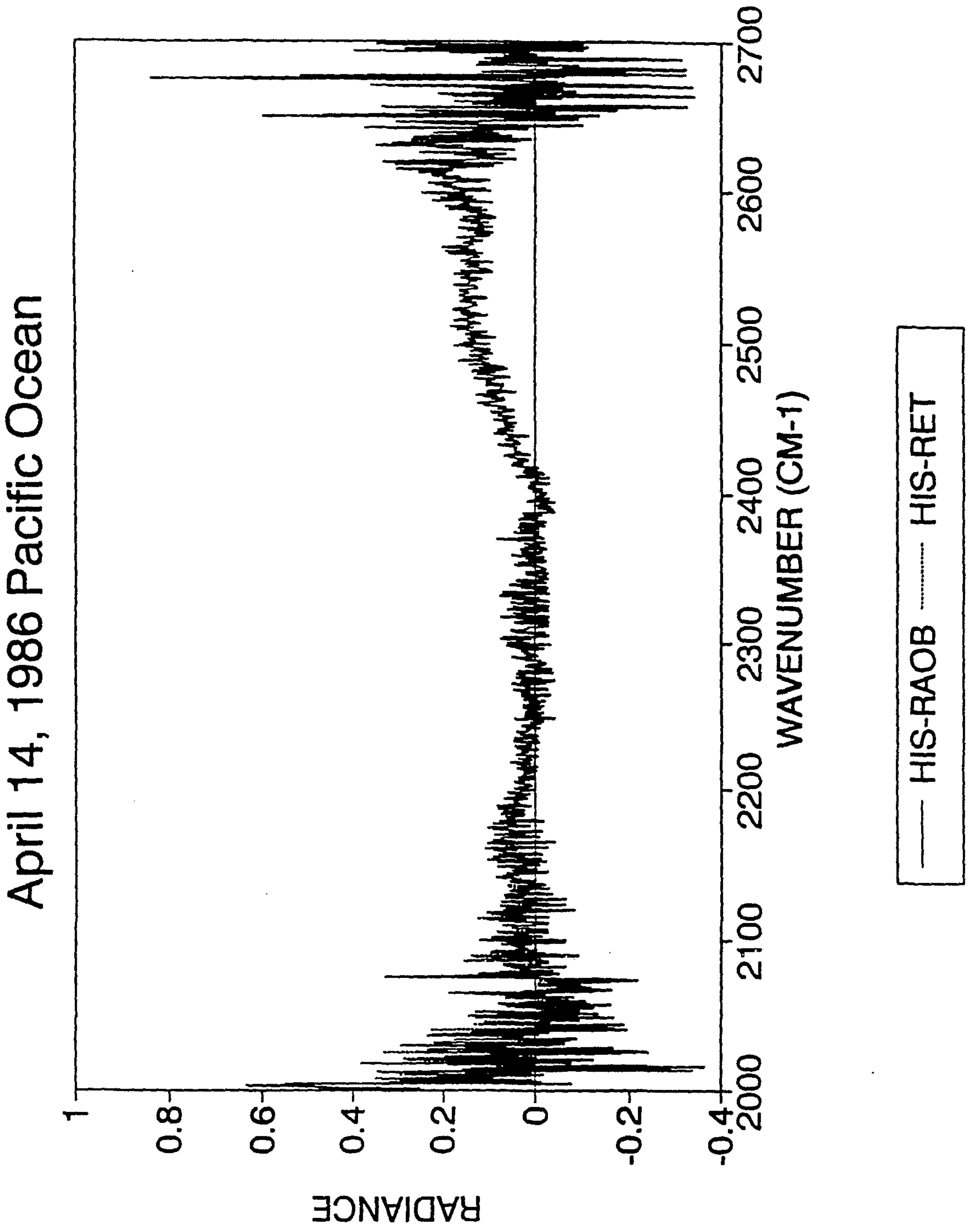


Figure 10c. 14 April 1986 HIS observed minus FASCOD3P calculation. Band III.

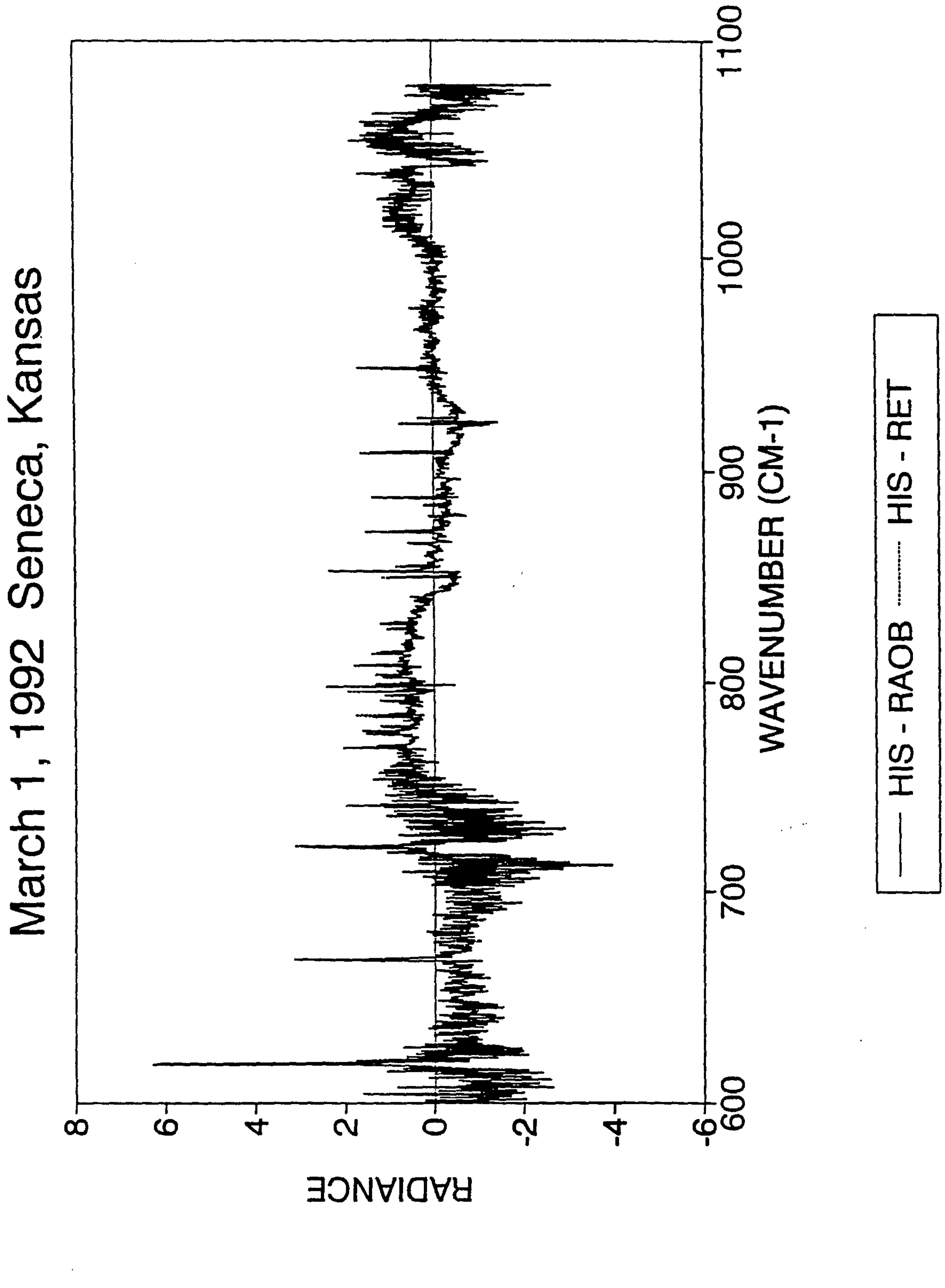


Figure 11a. 1 March 1992 HIS observed minus FASCOD3P calculation. Band I.

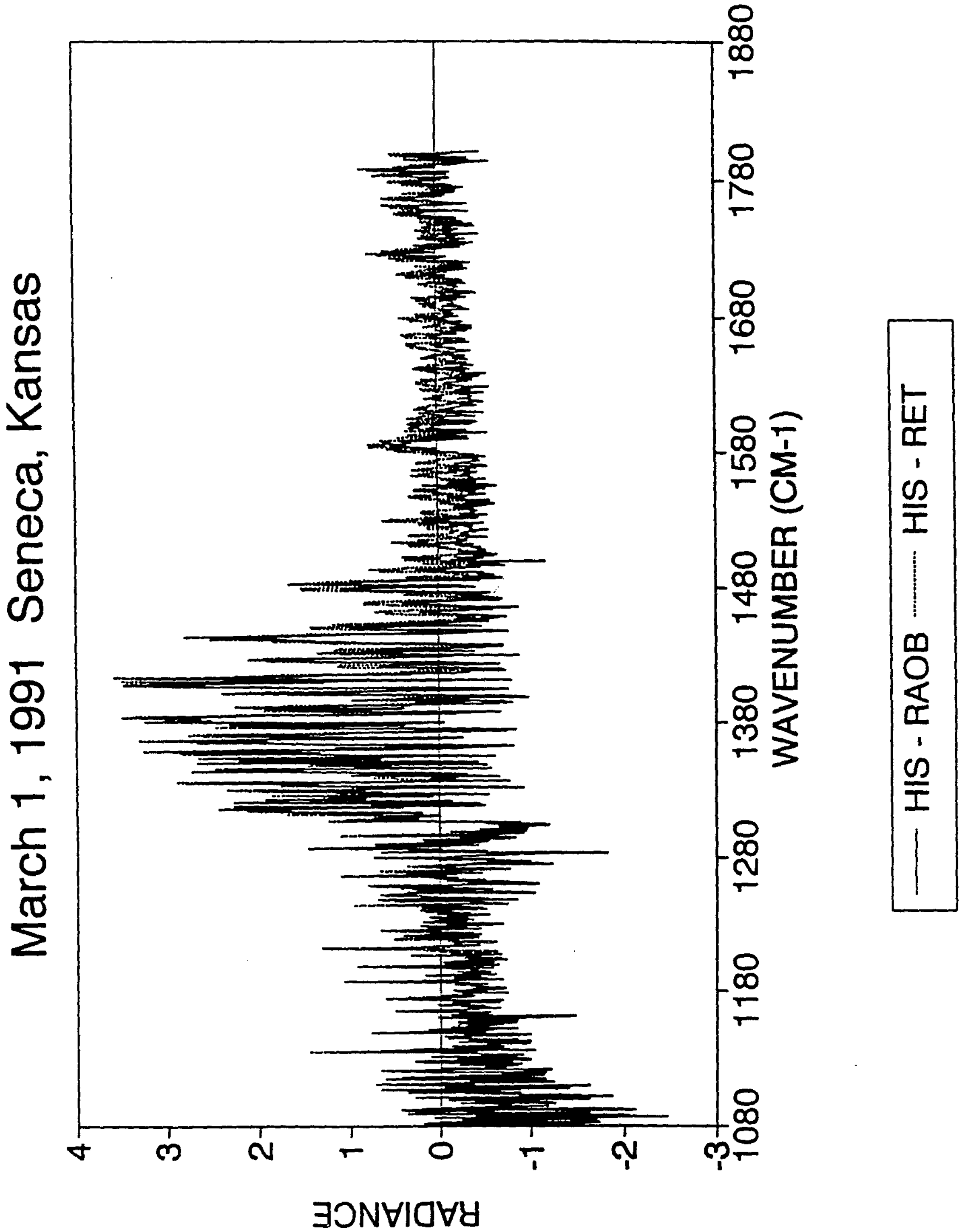


Figure 11b. 1 March 1992 HIS observed minus FASCOD3P calculation. Band II.

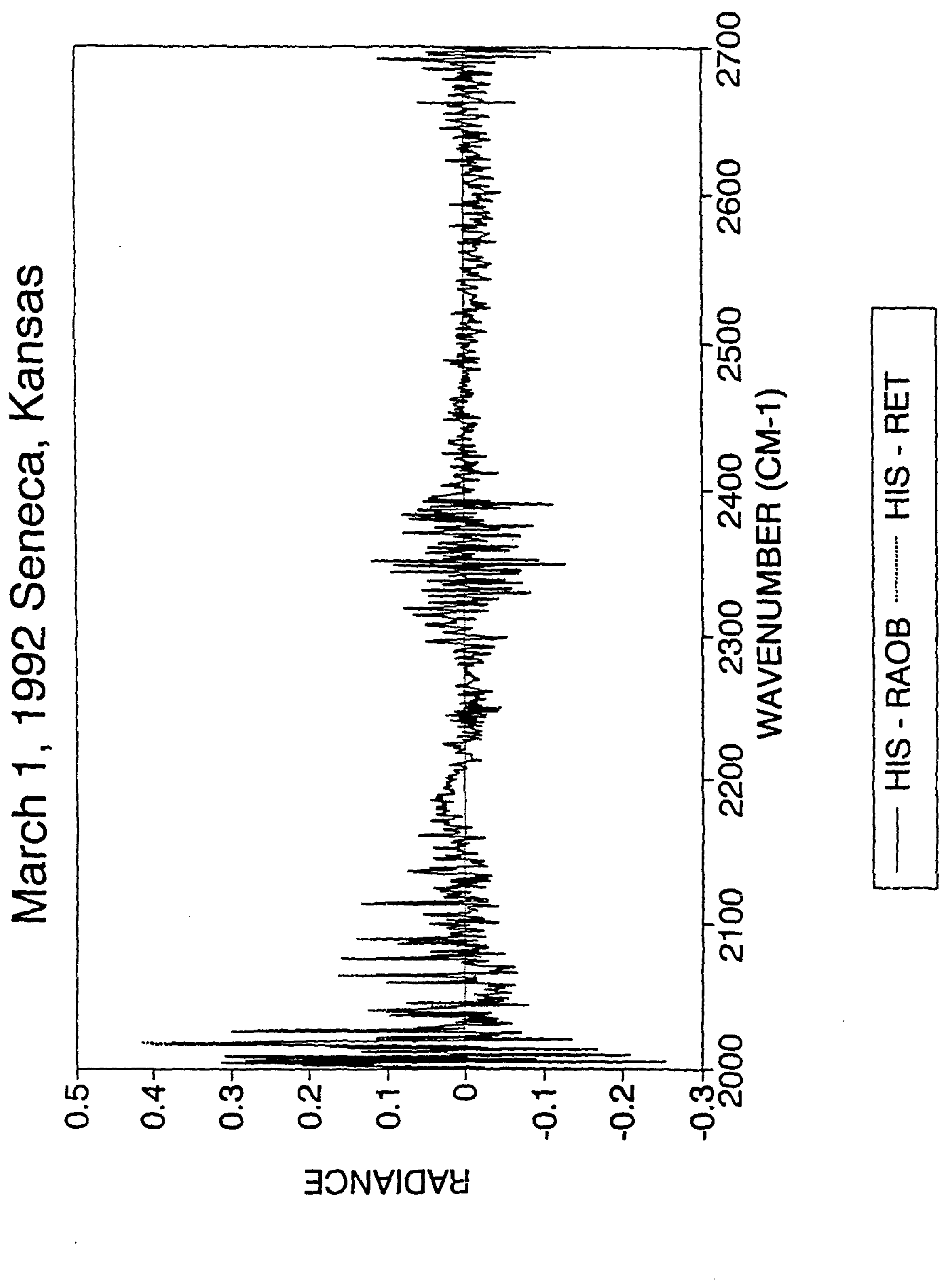


Figure 11c. 1 March 1992 HIS observed minus FASCOD3P calculation. Band III.

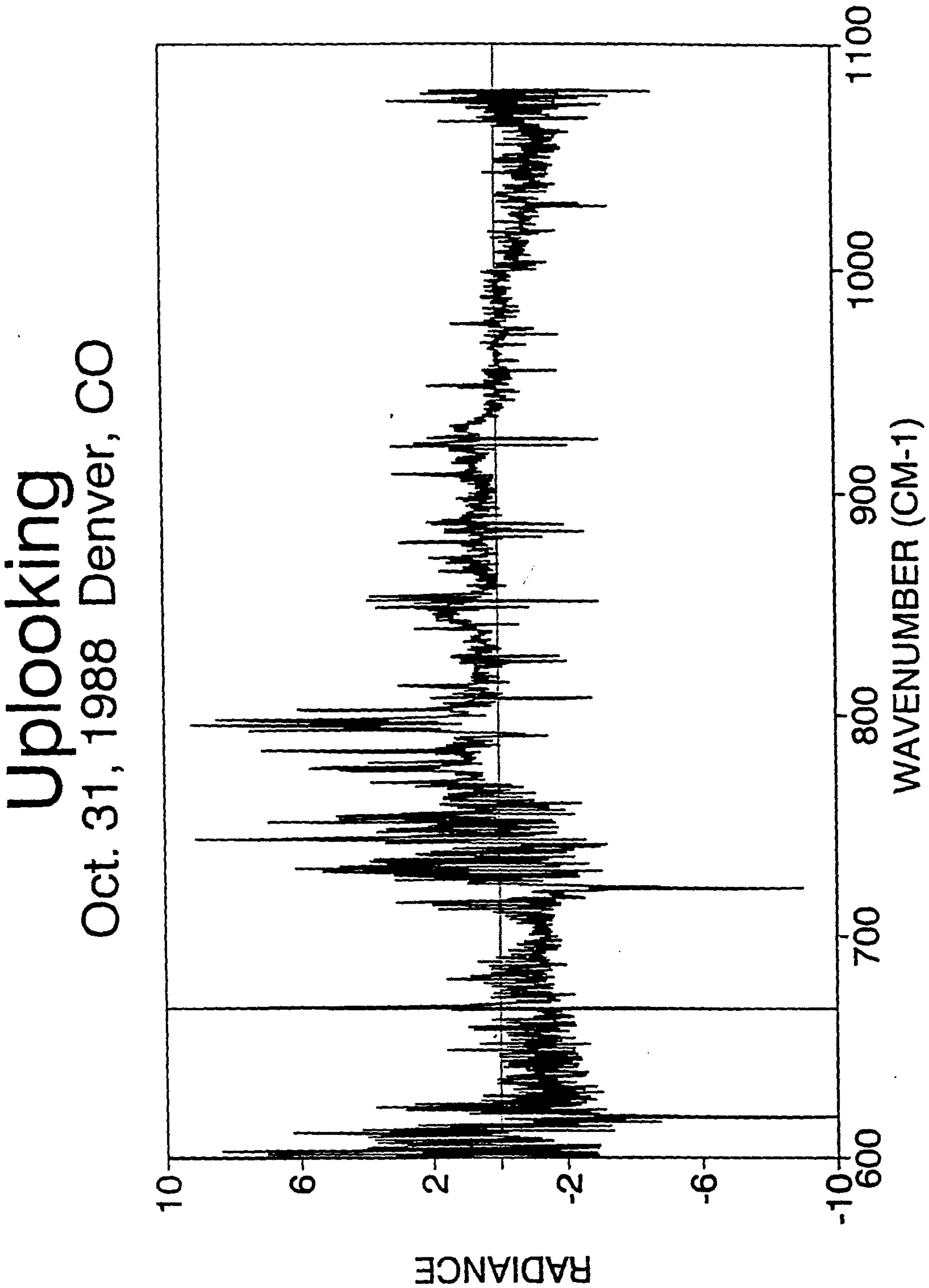


Figure 12a. 31 October 1988 HIS observed minus FASCOD3P calculation. Band I.

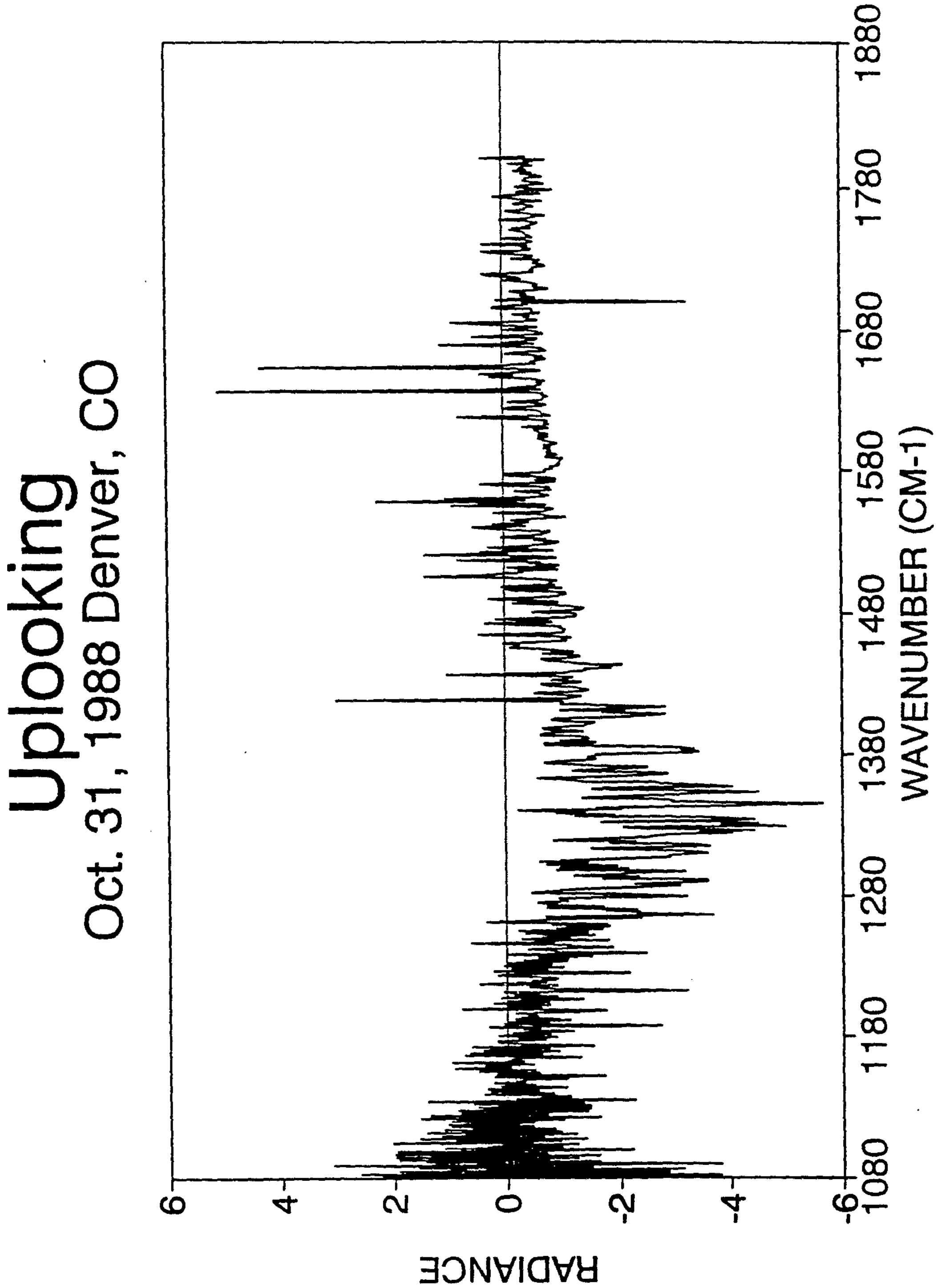


Figure 12b. 31 October 1988 HIS observed minus FASCOD3P calculation. Band II.

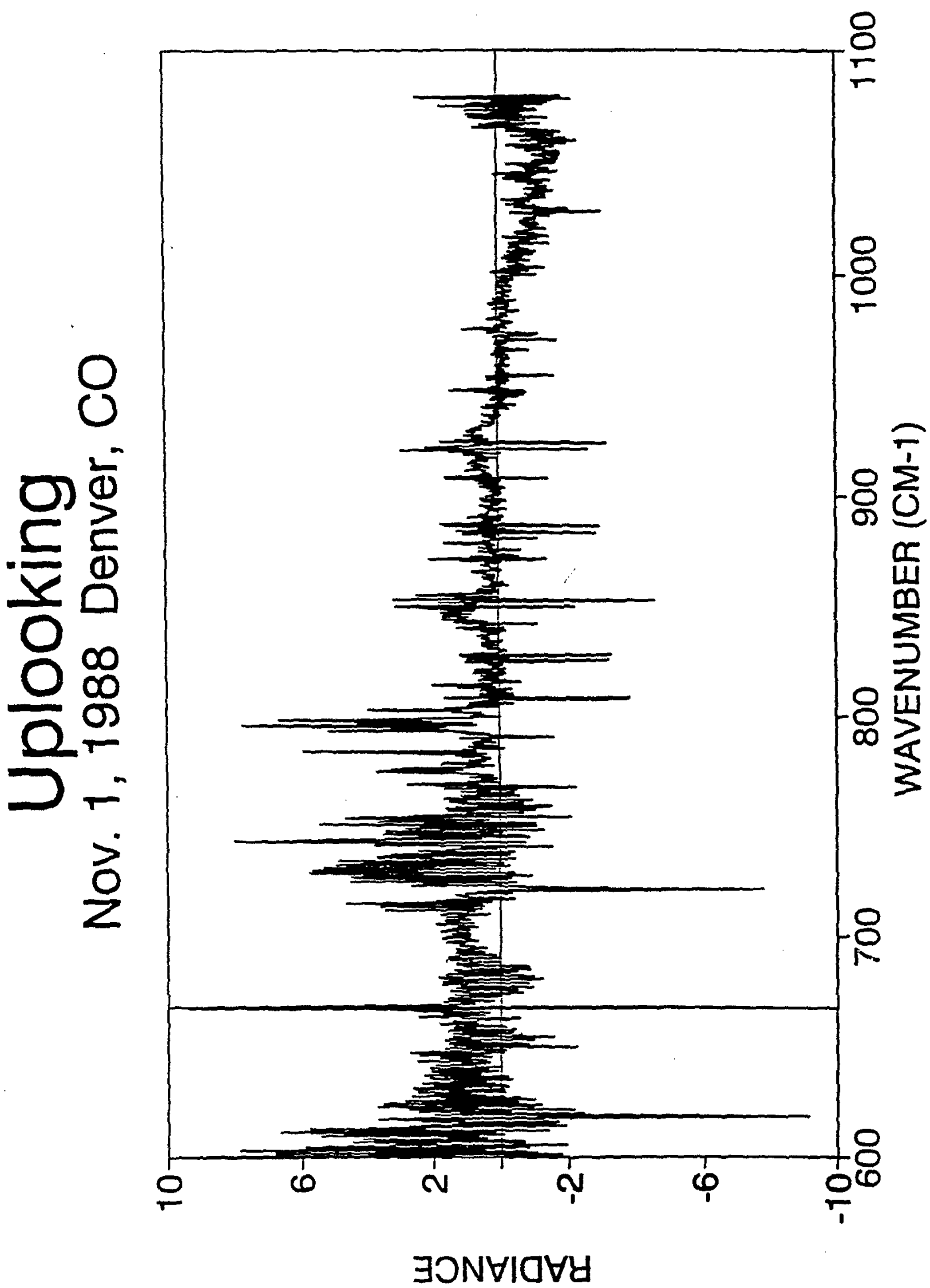


Figure 13a. 1 November 1988 HIS observed minus FASCOD3P calculation. Band I.

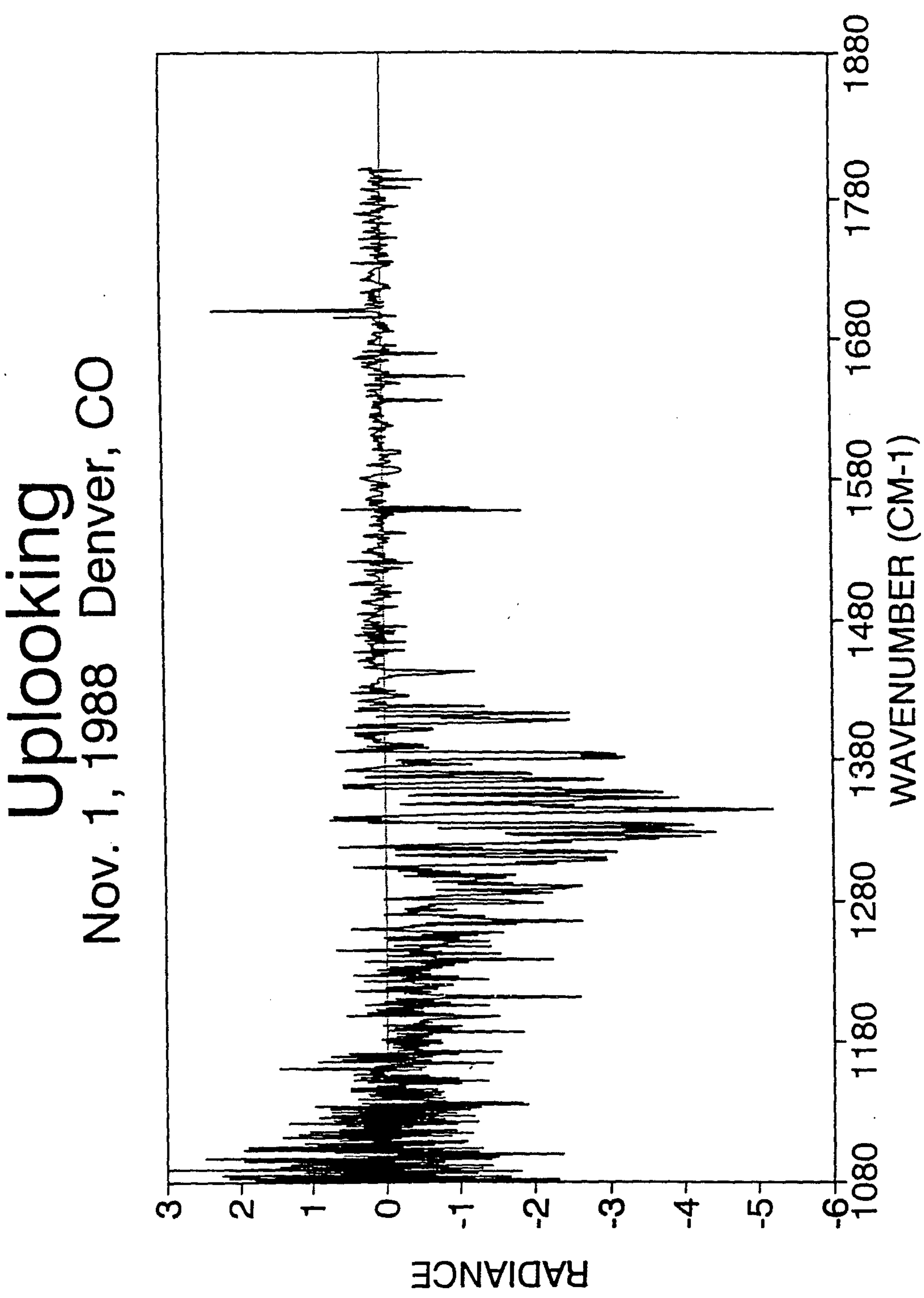


Figure 13b. 1 November 1988 HIS observed minus FASCOD3P calculation. Band II.

The detailed comparison of HIS observations with FASCOD3P calculations given in Figures 10-13 needs some interpretation. There are three possible sources of error in the comparisons: (1) HIS instrumental error whether random or systematic, (2) uncertainty in the characterization of the atmospheric state, and (3) model errors either in the HITRAN92 database or the FASCOD3P program. The possible additional error caused through improper matching of spectral resolutions or spectral point sampling is believed to be negligible because of the extreme care taken to match the calculation to the observation.

The random instrumental error has been minimized through the use of temporal averaging of spectra, however, due to the nature of the measurement, the noise near the band edges is enhanced relative to the remainder of the band. Since the data has been corrected for the instrument finite field of view, no *known* systematic bias is present in the HIS data contained within UWITRA93.

The characterization of the atmospheric state depends on 1) the random and systematic errors in the sondes used, 2) the time and space coincidence of the in situ sonde measurement compared to the remotely sensed radiance measurement, 3) the number and choice of atmospheric levels used to define the atmosphere, and 4) the presence or absence of aerosols and cloud. All cases are nominally clear, but the 14 April 1986 is suspected of containing some cirrus contribution. There was no lidar data available for any of these cases. The 14 April 1986 case is also the only one which uses National Weather Sonde (NWS) data, in addition, it is an area average of four sondes launched from coastal radiosonde stations. In all other cases the balloon data is from spatially coincident NCAR CLASS launch sites using state-of-the-art Vaisala sonde packages. The 14 April 1986 case is also reported only at "significant levels" whereas the CLASS data have been edited through manual selection to reduce the 10 second data (>400 levels) to about fifty atmospheric levels.

The objective of this work is, of course, to minimize the effects of the first two error sources in order to allow the validation of line-by-line radiative transfer models, such as FASCODE. Model dependent errors can often be readily identified through a process of varying the model parameters and noting the effect on observed minus calculated difference spectra. Some of the issues that HIS data can be used to study are 1) the CO2 line strengths and widths, 2) CO2 line mixing, 3) H2O line strengths throughout the infrared spectrum, 4) H2O continuum contributions and to some extent their temperature dependence, and 5) ozone band strengths. The single largest modeling error currently identified is the H2O foreign broadened continuum in the region 1200-2000 cm-1. The HIS data included in UWITRA93 is most useful for studying this effect in the region 1200-1800 cm-1 as is evident by inspection of figures 10b, 11b, 12b, and 13b. An empirical correction to the H2O foreign continuum has been obtained from these and other FTS measurements.

III. H2O CONTINUUM VALIDATION

Another of the major tasks performed under this contract was the preliminary determination of a correction factor for the foreign-broadened water vapor continuum as implemented in FASCOD3P (March 1992 release) based on available atmospheric measurements using instrumentation developed at the University of Wisconsin.

A. Background

The continuum contribution of H2O is divided into a "self"-broadened (i.e. H2O-H2O collision induced) and a "foreign"-broadened (i.e. N2-H2O collision induced) portion with varying strengths in different spectral regions. The total water vapor absorption (or emission) spectrum is a superposition of both line and continuum contributions at each wavelength in the infrared.

The water vapor continuum as implemented in FASCOD3P (and FASCOD2) is divided into three parts; the self-broadened cross-section at both 296K and 260K and the foreign-broadened cross-section at 296K. Thus the self-broadened continuum is implemented as a temperature dependent function whereas the foreign-broadened continuum implementation does not have temperature dependence. Each of these cross-sections is defined (using data statements) at 1 cm-1 intervals from zero to 5000 cm-1 using a definition proposed by Clough, Kneizys, and Davies based upon laboratory measurements.

The absorption and emission of radiation by the water vapor molecule at infrared wavelengths plays a very important role in the radiation balance of the earth-atmosphere system. In certain relatively transparent spectral regions the water vapor continuum has the dominant contribution to the greenhouse trapping of heat emitted by the earth's surface, thus indirectly influencing the earth's average temperature. In addition to climate applications, accurate knowledge of the water vapor continuum is important for remote sensing of the atmosphere. In particular, the retrieval of water vapor profiles from infrared data is strongly biased by the foreign broadened continuum error which impacts strongly the radiation from the 6.3 micron water vapor band.

B. Review of Spectroscopy in the Water Vapor Band

Four cases were used in the determination of a correction to the water vapor foreign continuum, three of these are included in the UWITRA93 data set; 14 April 1986 (downlooking), 1 March 1992 (downlooking), and 31 October 1988 (uplooking). The fourth case (uplooking) was from the SPECTral Radiance Experiment in Coffeyville, Kansas obtained using the Atmospheric Emitted Radiance Interferometer (AERI) on 18 November 1991. The AERI data is particularly useful for analysis in the 1850 - 2000 cm-1 spectral region where HIS data is not available. The AERI was developed at the University of Wisconsin as a groundbased observing system of downwelling radiance for use in the Department of Energy Atmospheric Radiance Measurement program.

The spectroscopic details relevant to the middle infrared region are summarized in figures 14-17 below. Figure 14 shows a portion of the HIS spectrum obtained 31 October 1988 as an apodized radiance (BEER apodization). Figure 15 shows a difference spectrum obtained using FASCOD3P and the HITRAN92 database illustrating a feature near 1350 cm-1 which has been identified as the foreign-broadened water vapor continuum. Figure 16 compares graphically the foreign continuum residual for three distinct atmospheres. Note that the wavenumbers which are sensitive to this effect appear to change depending upon air mass and also are different for the uplooking from the surface and the downlooking from 20 km altitude cases. Figure 17 shows the effect dividing the foreign continuum cross-section by a factor of four at all wavenumbers. This indicates that a wavenumber dependent reduction factor is required to fit the data properly.

C. Preliminary Foreign-broadened Correction Function

In order to make a "first cut" estimate of the wavenumber dependent function required to correct the foreign-broadened water vapor continuum, a modification to FASCOD3P was made to allow for a constant factor to multiple the foreign-broadened cross-section contained in data statements in the FASCOD3P program. A series of FASCODE runs were made with various reduction factors for each of the four cases indicated and the radiance difference plots compared. For each case a set of wavenumbers was selected which appeared to provide significant information on the continuum contribution and an estimate of the continuum reduction factor required to minimize the observed minus calculated difference was obtained. Figure 18 shows the data points obtained from this process as well as an approximate model of the data. The function used to model the data points is given as

$$R(\nu) = a * (1 - b * (\nu_0/\nu)^c * \sin(2\pi(\nu-\nu_0)/ d)^2)^{-1},$$

and

$$C_F^{new} (\nu) = C_F (\nu) / R(\nu),$$

where a, b, c, and d are parameters of the model and ν refers to wavenumber. Through a process of manual adjustment of parameters and allowing for variability in the estimation of each of the HIS/FASCODE data points the following set of parameters was determined to provide a best estimate of the foreign-broadened water vapor continuum correction:

$a = 1.15$, $b = 0.74$, $c = 0.6$, $d = 1000$, and $\nu_0 = 1610$ cm-1, for
1100 cm-1 $< \nu <$ 2100 cm-1

As is clear from the scatter of points in figure 18, the magnitude of the water vapor foreign continuum correction is somewhat uncertain from this initial estimate from HIS/AERI data. However, the importance of the spectral region affected to climate and remote sensing research is such that it is imperative that this initial estimate be refined and/or verified by more sophisticated analysis techniques and with additional quality measurement comparisons. One of the tasks for which future funding is desired is the implementation of this functional correction into a modified version of FASCODE and the validation of the functional form of the correction against both historical and recent HIS/AERI radiance measurements.

Furthermore, a comparison of this correction function to another independent functional form found by Jean-Marc Theriaux of the Canada Defense Institute of Quebec, Canada is shown in figure 19. This figure shows that the two estimates, one using radiance data and the other using transmission measurements, are in quite reasonable agreement in the overall size and shape of the required correction. The differences between the estimated corrections in the 1800-2000 cm-1 region are of considerable interest and further analysis to understand the reasons for the differences would be appropriate.

Finally, a comparison of the corrected foreign-broadened cross-section derived from HIS data with the original FASCOD3P continuum cross-section is given in Figure 20.

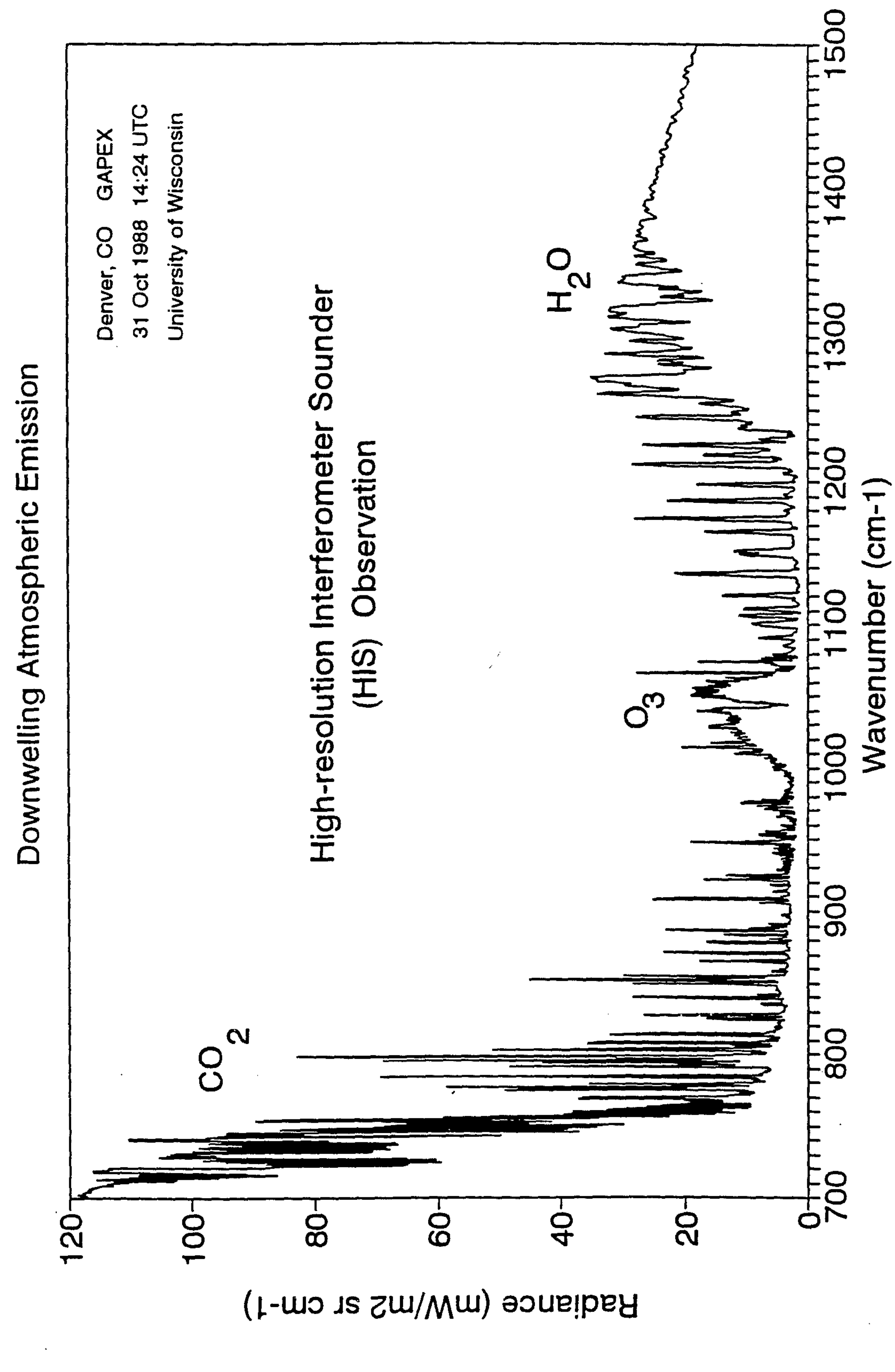


Figure 14. HIS observation from 31 October 1988 used in continuum analysis.

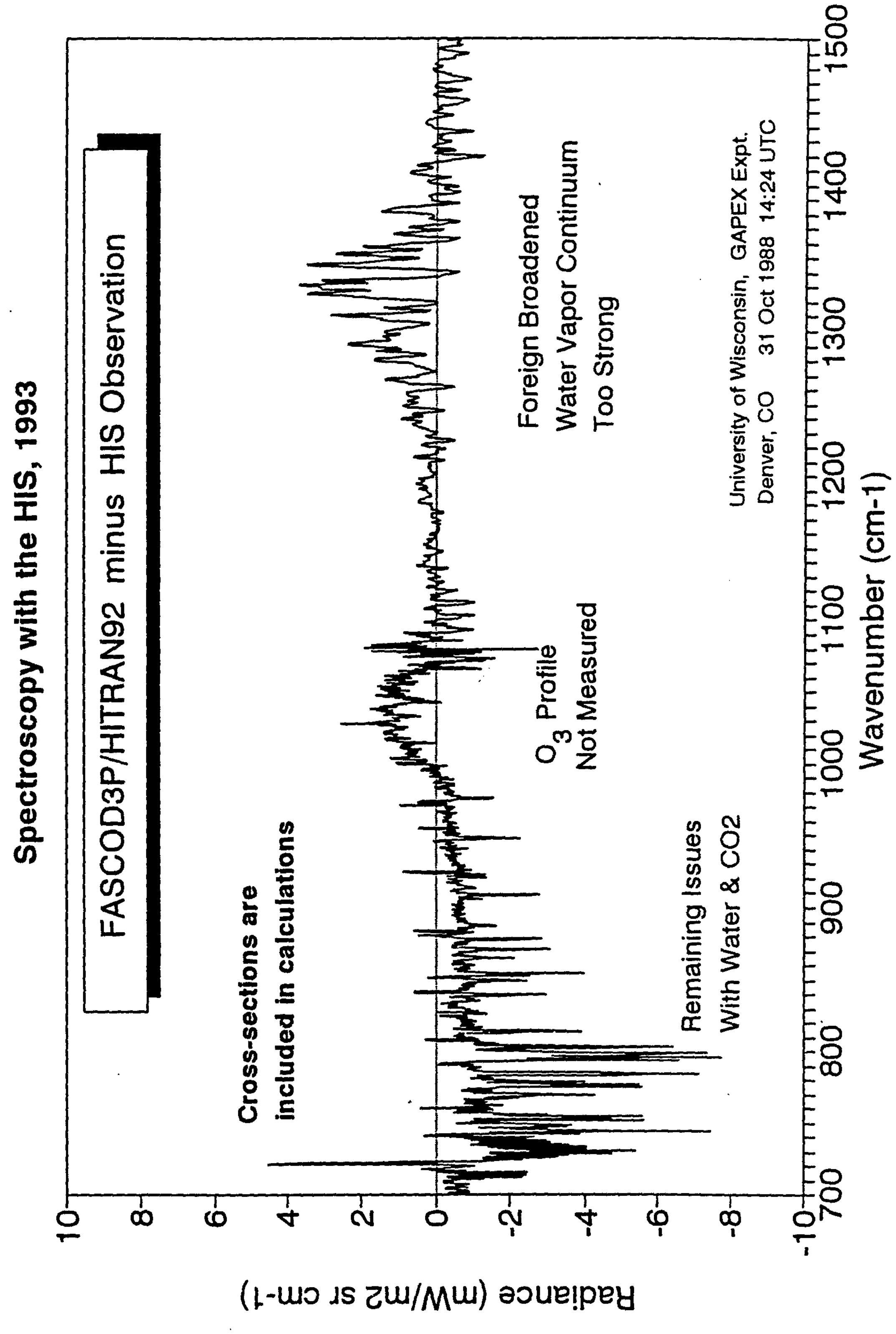


Figure 15. Calculated minus observed difference showing remaining spectroscopic issues.

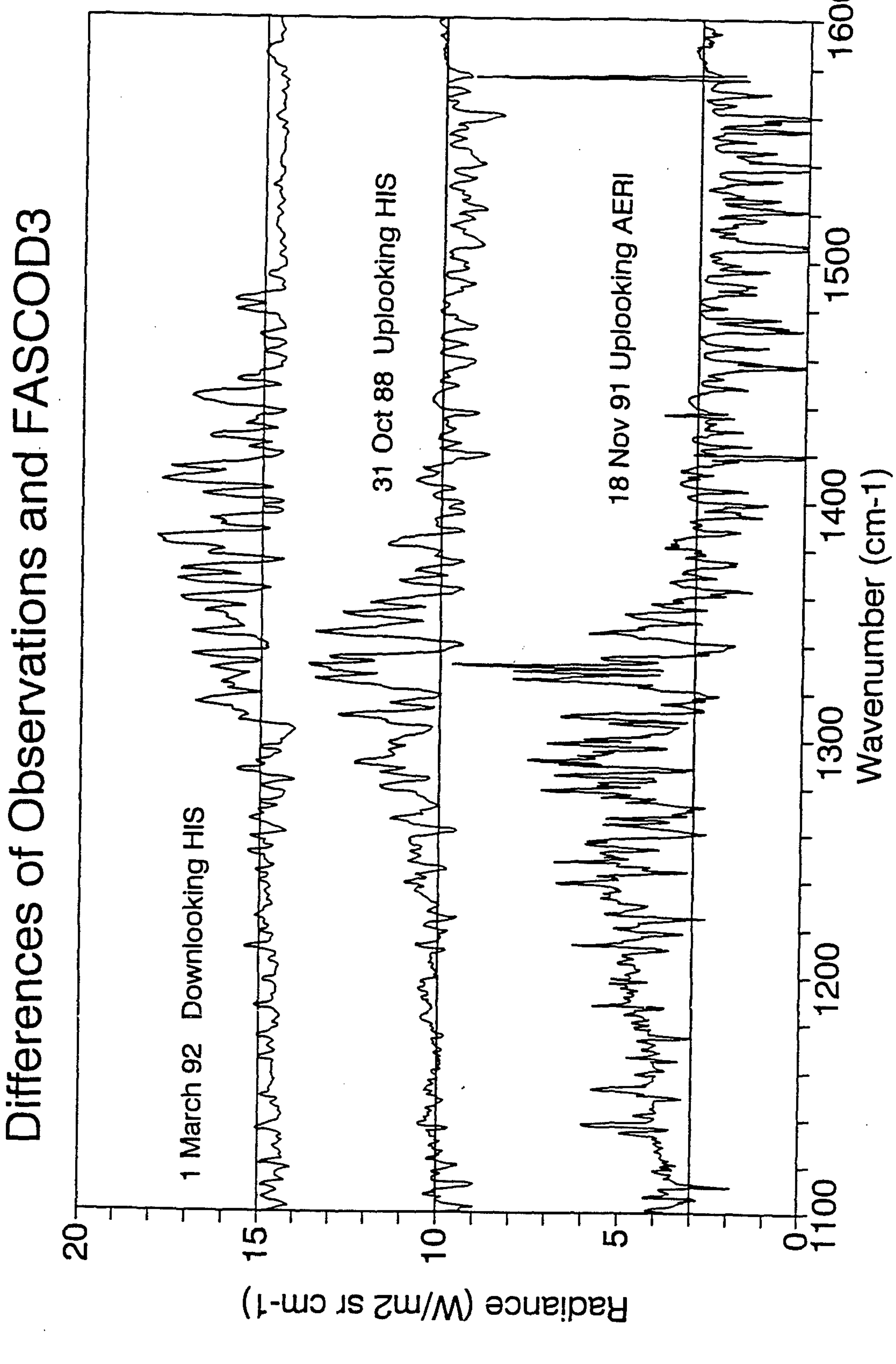


Figure 16. Summary of foreign continuum induced errors shown as apodized radiance.

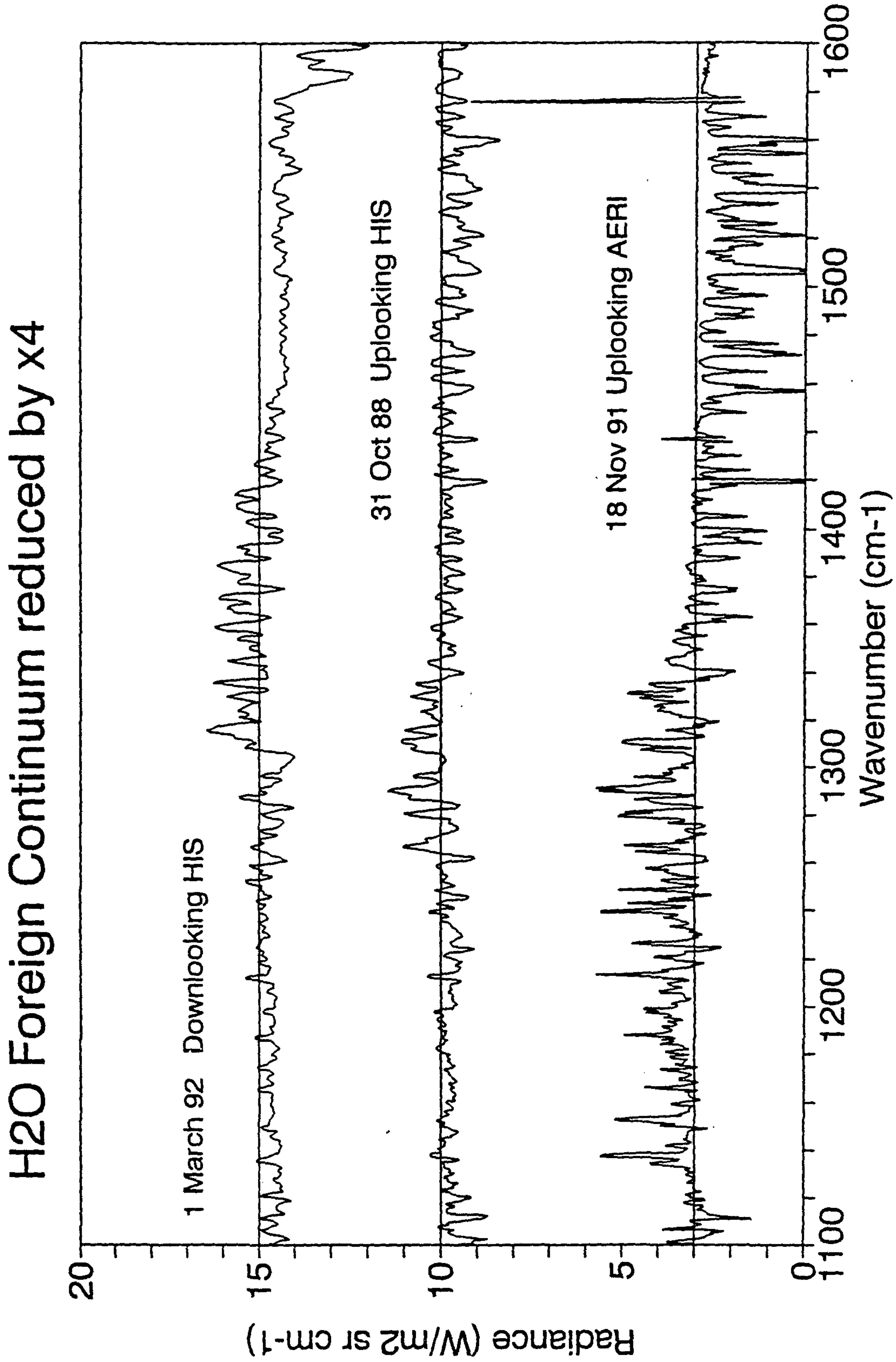


Figure 17. Summary of foreign continuum reduced by a constant factor of four.

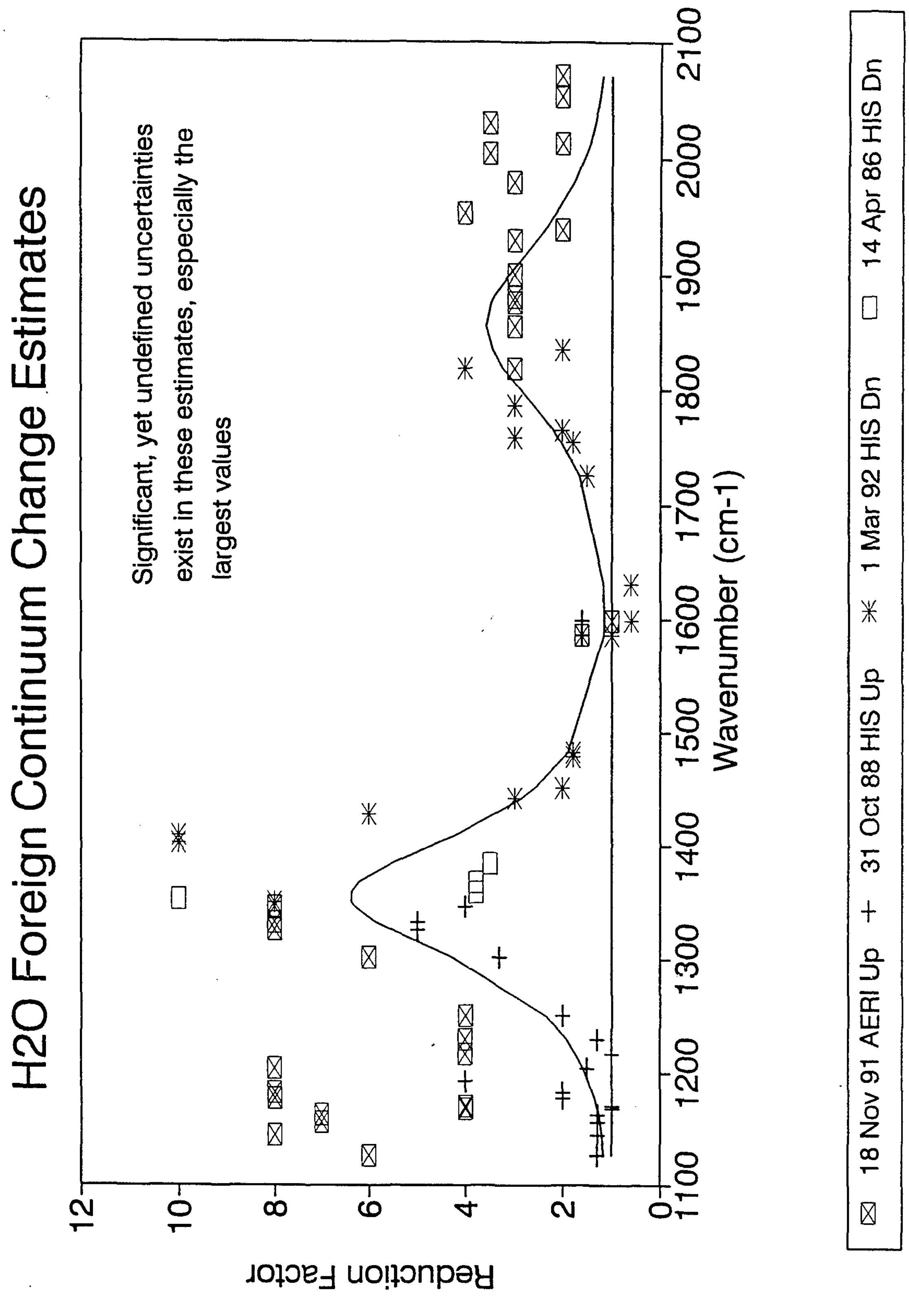


Figure 18. Water vapor foreign continuum correction factor compared to AERI/HIS data.

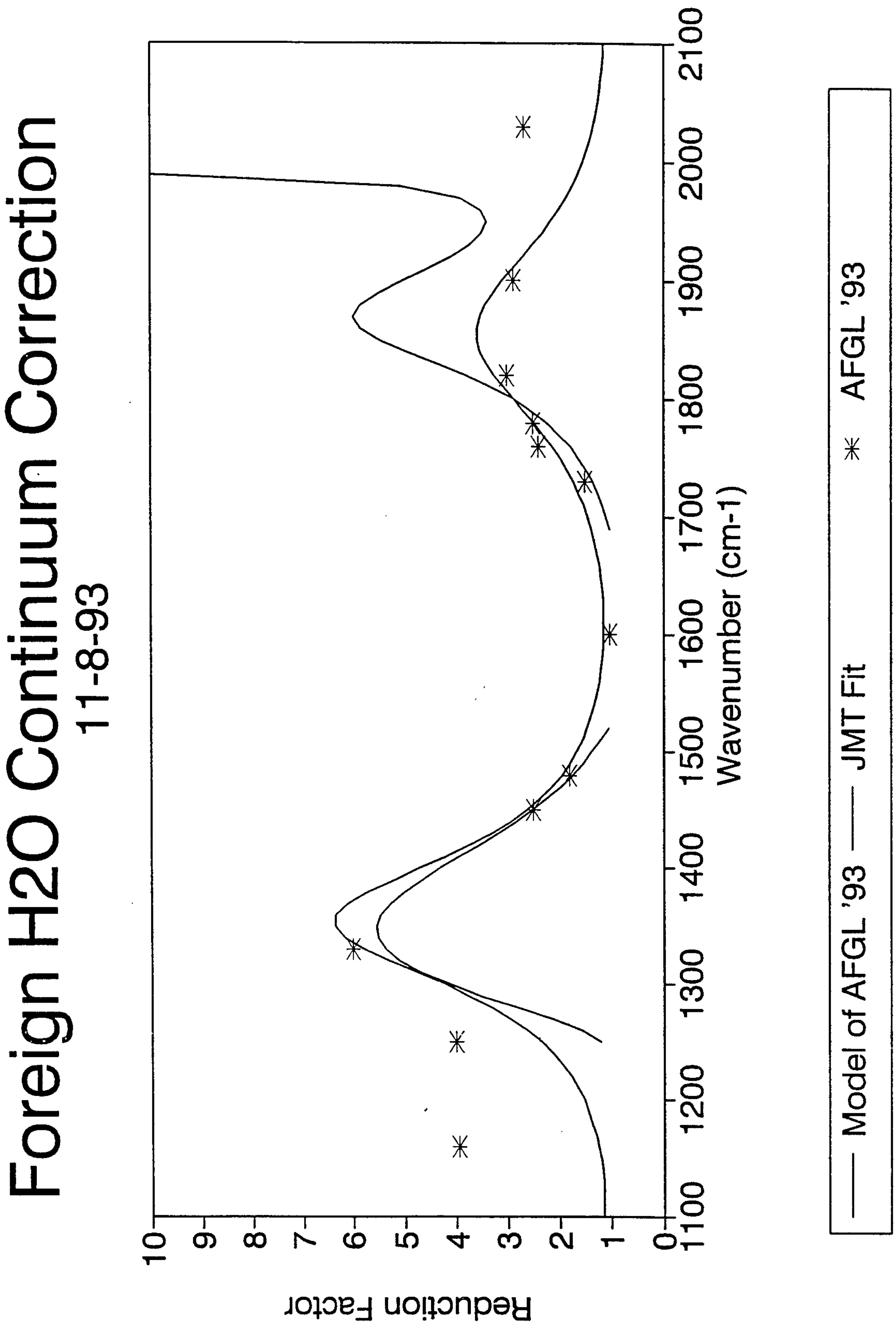


Figure 19. Comparison of two independent determinations of required foreign-broadened water vapor continuum correction.

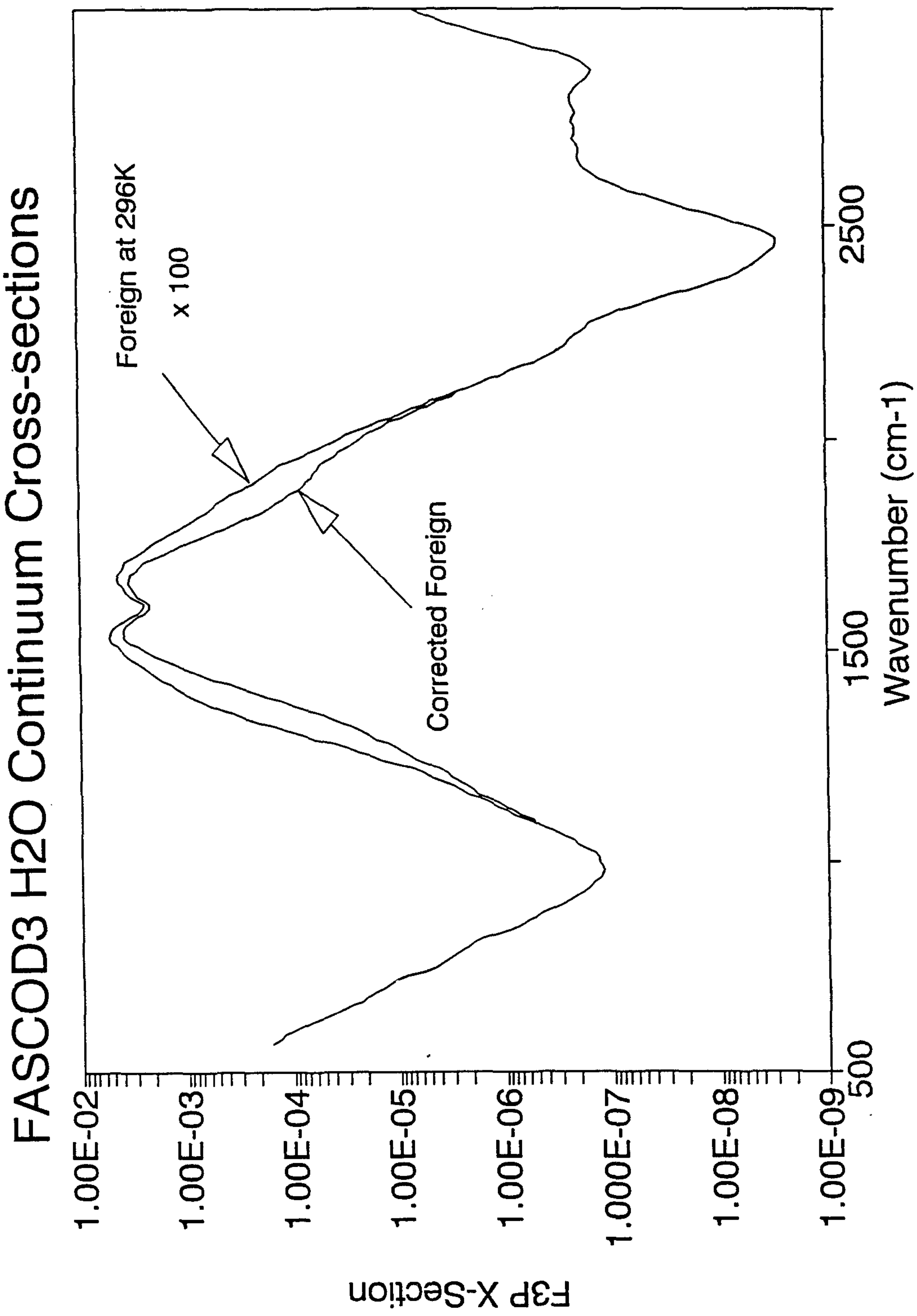


Figure 20. Original and corrected foreign-broadened water vapor continuum cross-sections.

IV. SUMMARY AND FUTURE WORK

As described in the text of the report, the main tasks performed under this contract were the preparation of a data set of observed radiances and associated atmospheric state observations for use in the validation of line-by-line radiative transfer models, and the deduction of a correction function for the foreign-broadened water vapor continuum contribution as defined in the March 1992 release of FASCOD3. In addition, the above mentioned data set (UWITRA93) was delivered to the chairperson of the ITRA working group for further distribution and the preliminary water vapor continuum results were presented at the annual review conference at Phillips laboratory.

Future work would include refinement of the parameters of the water vapor foreign-broadened continuum correction function through incorporation of the function into the FASCOD3P program and performing new calculations for the original cases. Also the number of cases studied would be increased, in particular, to include recent data from the Convection and Moisture Experiment (CAMEX, Wallops Island, VA, Sept-Oct 1993). CAMEX has an exceptional amount of ground truth with multiple coincident temperature and moisture radiosondes, ozone soundings, and raman lidar data. CAMEX also has coincident downlooking aircraft data from the HIS and uplooking data from the surface based AERI instrument which will provide additional useful constraints on the radiative transfer validation.