AD779 726

AFCRL-TR-74-0003
ENVIRONMENTAL RESEARCH PAPERS, NO. 460

Atmospheric Attenuation of Laser Radiation From 0.76 to 31.25 μm

ROBERT A. McCLATCHEY
JOHN E.A. SELBY

3 January 1974

Approved for public release; distribution unlimited.

OPTICAL PHYSICS LABORATORY PROJECT 7670, 8603
AIR FORCE CAMBRIDGE RESEARCH LABORATORIES
L. G. HANSCOM FIELD, BEDFORD, MASSACHUSETTS 01730

AIR FORCE SYSTEMS COMMAND, USAF

AIR FORCE (2) APRIL 22, 1974--1728

Unclassified

Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Air Force Cambridge Research Laboratories (OP) L. G. Hanscom Field Bedford, Massachusetts 01730	2a. REPORT SECURITY CLASSIFICATION Unclassified 2b. GROUP

3. REPORT TITLE

ATMOSPHERIC ATTENUATION OF LASER RADIATION FROM 0.76 to 31.25 μm

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*

Robert A. McClatchey
John E. A. Selby

6. REPORT DATE 3 January 1974	7a. TOTAL NO. OF PAGES 176	7b. NO. OF REFS 20

8a. CONTRACT OR GRANT NO. b. PROJECT, TASK, WORK UNIT NOS. 76700901 86030301 c. DOD ELEMENT 62101F 61102F d. DOD SUBELEMENT 681000 681310	9a. ORIGINATOR'S REPORT NUMBER(S) AFCRL-TR-74-0003 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)* ERP No. 460

10. DISTRIBUTION STATEMENT

Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES TECH, OTHER	12. SPONSORING MILITARY ACTIVITY Air Force Cambridge Research Laboratories (OP) L. G. Hanscom Field Bedford, Massachusetts 01730

13. ABSTRACT

High resolution atmospheric transmittance curves are presented for the spectral region 320 to 13,200 cm^{-1} (0.7576 to 31.25 μm). These spectra are useful as a guide for selecting laser wavelengths for atmospheric propagation studies in this spectral region. In addition, this report provides attenuation coefficients for those lines of the CO, HF, DF, and CO_2 laser systems which suffer the least atmospheric attenuation. A new aerosol model is introduced here, taking into account recent measurements of the complex index of refraction of aerosol particles.

DD FORM 1 NOV 65 1473

Unclassified

Security Classification

Unclassified

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Laser Transmittance Attenuation						

Unclassified

Security Classification

Unclassified
Security Classification

DOCUMENT CONTROL DATA - R&D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)*
Air Force Cambridge Research Laboratories (OP)
L. G. Hanscom Field
Bedford, Massachusetts 01730

2a. REPORT SECURITY CLASSIFICATION
Unclassified

2b. GROUP
AD-779 726

3. REPORT TITLE
ATMOSPHERIC ATTENUATION OF LASER RADIATION FROM 0.76 to 31.25 μm

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Scientific. Interim.

5. AUTHOR(S) *(First name, middle initial, last name)*
Robert A. McClatchey
John E. A. Selby

6. REPORT DATE
3 January 1974

7a. TOTAL NO. OF PAGES
176

7b. NO. OF REFS
20

8a. CONTRACT OR GRANT NO.

b. PROJECT, TASK, WORK UNIT NOS. 76700901 86030301

c. DOD ELEMENT 62101F 61102F

d. DOD SUBELEMENT 681000 681310

9a. ORIGINATOR'S REPORT NUMBER(S)
AFCRL-TR-74-0003

9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
ERP No. 460

10. DISTRIBUTION STATEMENT
Approved for public release; distribution unlimited.

11. SUPPLEMENTARY NOTES
TECH, OTHER

12. SPONSORING MILITARY ACTIVITY
Air Force Cambridge Research Laboratories (OP)
L. G. Hanscom Field
Bedford, Massachusetts 01730

13. ABSTRACT

High resolution atmospheric transmittance curves are presented for the spectral region 320 to 13,200 cm^{-1} (0.7576 to 31.25 μm). These spectra are useful as a guide for selecting laser wavelengths for atmospheric propagation studies in this spectral region. In addition, this report provides attenuation coefficients for those lines of the CO, HF, DF, and CO_2 laser systems which suffer the least atmospheric attenuation. A new aerosol model is introduced here, taking into account recent measurements of the complex index of refraction of aerosol particles.

DD FORM 1 NOV 65 1473

Unclassified
Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Laser						
Transmittance						
Attenuation						

Preface

This work was undertaken to provide extremely high resolution spectra as an aid to systems planning requiring a knowledge of laser propagation through the atmosphere. We have specifically addressed the problem of CO, HF, DF, and CO_2 laser systems and we have incorporated a new aerosol model.

We wish to acknowledge the Mie calculations performed by Dr. E. Shettle and the consultation with Dr. F. Volz and Dr. R. Fenn in the definition of the aerosol models described in this report. In addition, we acknowledge the efforts of Mr. J. Chetwynd in running computer programs and otherwise organizing the synthetic spectral plots.

Contents

Illustrations

Illustrations

Tables

Atmospheric Attenuation of Laser Radiation from 0.76 to 31.25 μm

1. INTRODUCTION

Theoretical investigations of the attenuation of laser emission through the atmosphere require a knowledge of the molecular absorption of the atmosphere at very high spectral resolution. Absorption line widths of atmospheric molecules are typically of the order of 0.1 cm^{-1} at one atmosphere pressure and decrease with decreasing pressure. Thus, considerations of laser propagation in the atmosphere require a knowledge of atmospheric transmittance with a spectral resolution of better than 0.1 cm^{-1}. In previous reports, calculations of synthetic atmospheric spectra were made for a spectral resolution of 0.01 cm^{-1}. The resulting spectra can thus be considered as representing an infinite resolution spectrum, limited only by the real width of the atmospheric absorption lines. One of the previous reports[1] provided spectra covering the region of CO emission - 1400 to 2120^{-1}. A second report[2] provided spectra covering the region of HF and DF emission from 2120 to 3740 cm^{-1}, and a third report[3] provided spectra covering the region of CO_2 emission and beyond from 320 to 1400 cm^{-1}.

(Received for publication 3 January 1974)

1. McClatchey, R.A. (1970) Atmospheric Attenuation of CO Laser Radiation, AFCRL-71-0370, ERP 359.
2. McClatchey, R.A. and Selby, J.E.A. (1972a) Atmospheric Attenuation of HF and DF Laser Radiation, AFCRL-72-0312, ERP 400.
3. McClatchey, R.A. and Selby, J.E.A. (1972b) Atmospheric Transmittance, 7-30 μm: Attenuation of CO_2 Laser Radiation, AFCRL-72-0611, ERP 419.

In addition to the "infinite" resolution spectra provided in these reports, specific laser attenuation charts have been provided for a great number of laser wavelengths in the CO, HF, DF and CO_2 systems. Although it is useful to have these laser attenuation coefficients immediately available, we have found the "infinite" resolution spectra of great value for a large number of purposes. For example, these spectra can be used directly as a guide to selecting other lasers which have lines that lie in the spectral interval in question.

Because of the growing interest in finding relatively transparent atmospheric windows for propagating new laser emission lines through the atmosphere, it was decided to extend the calculations reported earlier to shorter wavelengths and to provide in one report synthetic spectra for the entire spectral region from 320 to 13,200 cm^{-1} (0.7576 to 31.25 μm). The generation of accurate synthetic spectra requires a detailed knowledge of the spectroscopic parameters for each of the many thousands of molecular absorption features appearing in the infrared atmospheric spectrum. We are now in a position to perform these calculations due to the development of the AFCRL Compilation of Atmospheric Absorption Line Parameters described by McClatchey, et al.[4]

In addition to the absorption lines associated with water vapor, carbon dioxide, ozone, nitrous oxide, methane, carbon monoxide and oxygen, at low levels in the atmosphere there is the important water vapor continuum of particular importance in the 9- to 13-μm region and between 16 μm and 30 μm.[5,6] The pressure induced band at nitrogen in the region near 4.3 μm has also been included.[7,8] Absorption by each of the molecules mentioned here has been included in the calculation of synthetic spectra provided below.

For consistency with earlier reports on the problem of laser propagation in the atmosphere, synthetic spectra based only on molecular absorption have in all cases been provided for two different atmospheric paths: (1) A 10-km horizontal path at sea level, and (2) a 10-km horizontal path at an altitude of 12 km.

---

4. McClatchey, R.A., Benedict, W.S., Clough, S.A., Burch, D.E., Calfee, R.F., Fox, K., Rothman, L.S., and Garing, J.A. (1973) AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-0096.

5. Burch, D.E. (1970) Semiannual Technical Report, Investigation of the Absorption of Infrared Radiation by Atmospheric Gases U-4784, Jan. 1970.

6. Bignell, K.J. (1970) Q.J.R.M.S., **96**:409.

7. Burch, D.E., Gryvnak, D.A., and Pembrook, J.D. (1971) Philco-Ford Corporation, Aeronutronic Division, Contract No. F19628-69-C-0263, U-4897, ASTIA AD882876.

8. Shapiro, M.M. and Gush, H.P. (1966) Canad, J. Phys. **44**:949.

In addition to molecular absorption, three other sources of attenuation should be considered:[9] molecular (or Rayleigh) scattering, aerosol scattering, and aerosol absorption. Quantitative data are also provided below on the basis of which aerosol attenuation can be estimated. It should be noted that aerosol attenuation and molecular scattering are very slowly varying functions of frequency and, therefore, provide a quasi-continuum attenuation over the whole spectral range of interest, whereas the molecular absorption is highly frequency-dependent. Thus, molecular absorption dominates in the determination of the relative "windows" where the transmittance of a laser beam is greatest.

2. ATMOSPHERIC MODELS

The atmospheric models used in the laser computations have been fully described,[9] and so only a brief sketch will be provided here. Three model atmospheres for pressure, temperature, H_2O, and O_3 distributions have been used here and are referred to as Tropical, Midlatitude Winter, and Subarctic Winter. They refer to models of the same names defined in the Handbook of Geophysics and Space Environment.[10] The major effect which these three different models have on the computations in this report is due to the differences in water vapor distribution. Table 1 provides the water vapor amounts in a 10-km sea level path, a 10-km horizontal path at 12-km altitude, and in a vertical path through the entire atmosphere for the three models. The water vapor distribution in all models is identical above 11-km altitude. The ozone abundances have been included in Table 1 as ozone is the only other molecular species which is not assumed to be uniformly mixed in the atmosphere. All other absorbing gases were assumed uniformly mixed according to the mixing ratios indicated in Table 2.

In addition to the three models described above, computations were made for two aerosol models described as a "clear" and "hazy" atmosphere corresponding to a ground level visibility of 23 km and 5 km, respectively. The aerosol size distribution function for both models is the same at all altitudes and similar to one suggested by Deirmendjian[11] for continental haze. It differs from Deirmendjian's model "C" (and also from the model used by McClatchey et al[7] in that the

9. McClatchey, R.A., Fenn, R.W., Selby, J.E.A., Volz, F.E., and Garing, J.W. (1972) Optical Properties of the Atmosphere (Third Edition), AFCRL-72-0497, August 1972.

10. Valley, S.L., Ed., (1965) Handbook of Geophysics and Space Environments, AFCRL.

11. Deirmendjian, D. (1963) Scattering and Polarization Properties of Polydispersed Suspensions with Partial Absorption, Proc. of the Interdisciplinary Conf. on Electromagnetic Scattering, Potsdam, NY, Milton Kerker, Ed., Pergamon Press.

Table 1. Amount of Water Vapor and Ozone (molecules per square centimeter) in the Three Model Atmospheres for which Calculations Have Been Made

Type at Path		Tropical	Midlatitude Winter	Subarctic Winter
10-km horizontal path at sea level	H_2O O_3	6.36×10^{23} 6.70×10^{17}	1.17×10^{23} 6.7×10^{17}	4.01×10^{22} 6.7×10^{17}
10-km horizontal path at 12-km altitude	H_2O O_3	2.00×10^{20} 5.40×10^{17}	2.00×10^{20} 3.23×10^{18}	2.00×10^{20} 5.4×10^{18}
vertical path from sea level to space	H_2O O_3	1.38×10^{23} 6.62×10^{18}	2.85×10^{22} 1.07×10^{19}	1.40×10^{22} 1.29×10^{19}

Table 2. Concentrations of Uniformly Mixed Gases

		Molecules/cm^2		
		Midlatitude Winter Model		
Constituent	ppm by Volume	10-km Sea Level	10-km Path at 12-km Altitude	Vertical Path From Sea Level
N_2	7.808×10^5	2.10×10^{25}	4.87×10^{24}	1.69×10^{25}
O_2	2.095×10^5	5.63×10^{25}	1.31×10^{24}	4.52×10^{24}
CO_2	330	8.87×10^{21}	2.05×10^{21}	7.12×10^{21}
CO	0.075	2.03×10^{18}	4.67×10^{17}	1.62×10^{18}
N_2O	0.28	7.28×10^{18}	1.68×10^{18}	6.04×10^{18}
CH_4	1.6	4.30×10^{19}	9.92×10^{18}	3.45×10^{19}

large particle cut-off has been extended from 5 μm to 100 μm as indicated in Figure 1. The refractive index for the aerosol particles (Table 3) is based on experimental data published by Volz.[12] The attenuation coefficients were then determined as composites of 70 percent water soluble aerosol material and 30 percent dust-like substances which can be assumed representative of continental aerosol. The total numbers of aerosol particles per unit volume (Table 4) for the "clear" atmosphere have been adjusted to give an extinction coefficient at λ = 0.55 μm identical to the attenuation model of Elterman[13, 14] at each altitude. The

12. Volz, F. E. (1972) Appl. Opt. **11**:755.
13. Elterman, L. (1968) UV Visible, and IR Attenuation for Altitudes up to 50 km, 1968, AFCRL, Environmental Res. Paper No. 285, AFCRL-68-0153.
14. Elterman, L. (1970) Vertical-Attenuation Model with Eight Surface Meteorological Ranges 2 to 13 Kilometers, 1970, AFCRL, Environmental Research Paper No. 310, AFCRL-70-0200.

"clear" and "hazy" models are identical above 5 km. Below 5-km altitude, the number of aerosol particles in the "hazy" model increases exponentially to a value corresponding to a ground visibility of 5 km.

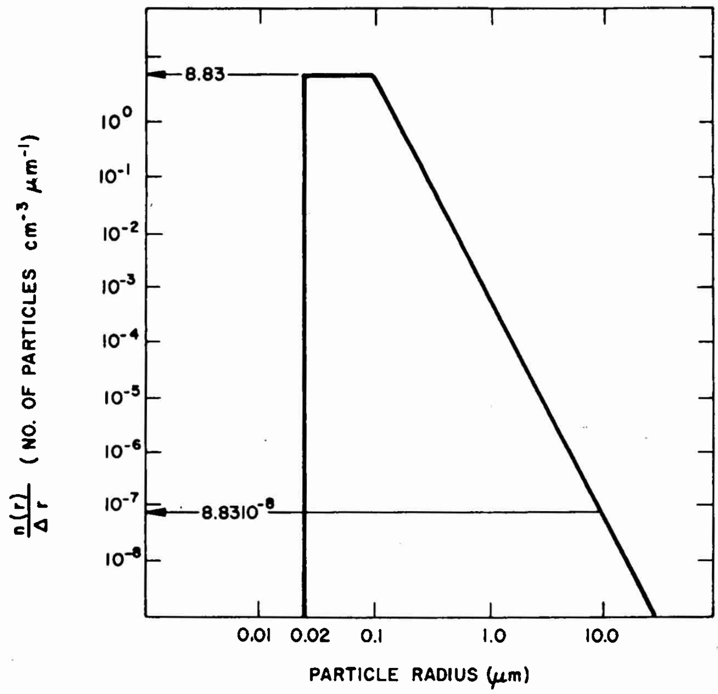


Figure 1. Aerosol Size Distribution Used in Computing Attenuation Coefficients

Table 3. Aerosol Complex Index of Refraction (n-n'i): n = real (Scattering Part and n' = imaginary (absorption) Part

Wavelength	Water Soluble Refractive Index	Dust-Like Refractive Index
.20000	1.530 -.070*I	1.530 -.070*I
.25000	1.530 -.030*I	1.530 -.030*I
.30000	1.530 -.008*I	1.530 -.008*I
.33710	1.530 -.005*I	1.530 -.008*I
.48800	1.530 -.005*I	1.530 -.008*I
.51450	1.530 -.005*I	1.530 -.008*I
.63280	1.530 -.006*I	1.530 -.008*I
.69430	1.530 -.007*I	1.530 -.008*I
.86000	1.520 -.012*I	1.520 -.008*I
1.06000	1.520 -.017*I	1.520 -.008*I
1.53600	1.510 -.023*I	1.400 -.008*I
2.00000	1.420 -.008*I	1.260 -.008*I
2.50000	1.420 -.012*I	1.180 -.009*I
2.70000	1.400 -.055*I	1.180 -.013*I
3.00000	1.420 -.022*I	1.160 -.012*I
3.20000	1.430 -.008*I	1.220 -.010*I
3.39230	1.430 -.007*I	1.260 -.013*I
3.50000	1.450 -.005*I	1.280 -.011*I
3.75000	1.452 -.004*I	1.270 -.011*I
4.00000	1.455 -.005*I	1.260 -.012*I
4.50000	1.460 -.013*I	1.260 -.014*I
5.50000	1.440 -.018*I	1.220 -.021*I
6.00000	1.410 -.023*I	1.150 -.037*I
6.50000	1.460 -.033*I	1.130 -.042*I
7.20000	1.400 -.070*I	1.400 -.055*I
7.90000	1.200 -.065*I	1.150 -.040*I
8.20000	1.010 -.100*I	1.130 -.074*I
8.50000	1.300 -.215*I	1.300 -.090*I
8.70000	2.400 -.290*I	1.400 -.100*I
9.00000	2.560 -.370*I	1.700 -.140*I
9.20000	2.200 -.420*I	1.720 -.150*I
9.50000	1.950 -.160*I	1.730 -.162*I
10.00000	1.820 -.030*I	1.750 -.162*I
10.59100	1.760 -.070*I	1.620 -.120*I
11.00000	1.720 -.050*I	1.620 -.105*I
13.00000	1.620 -.055*I	1.470 -.100*I
14.80000	1.400 -.100*I	1.570 -.100*I
15.00000	1.420 -.200*I	1.570 -.100*I
17.20000	2.080 -.240*I	1.630 0.100*I
18.50000	1.850 -.170*I	1.648 -.120*I
20.00000	2.120 -.220*I	1.680 -.220*I
25.00000	1.880 -.280*I	1.970 -.248*I
27.90000	1.840 -.290*I	1.890 -.320*I
30.00000	1.820 -.300*I	1.800 -.420*I
35.00000	1.920 -.400*I	1.900 -.500*I
40.00000	1.860 -.500*I	2.100 -.600*I

Table 4. Aerosol Models - Vertical Distributions for a "Clear" and "Hazy" Atmosphere

Altitude (km)	PARTICLE DENSITY N (PARTICLES PER cm^3)	
	23-km Visibility Clear	5-km Visibility Hazy
0	2.828E+03	1.378E+04
1	1.244E+03	5.030E+03
2	5.371E+02	1.844E+03
3	2.256E+02	6.731E+02
4	1.192E+02	2.453E+02
5	8.987E+01	8.987E+01
6	6.337E+01	6.337E+01
7	5.890E+01	5.890E+01
8	6.069E+01	6.069E+01
9	5.818E+01	5.818E+01
10	5.675E+01	5.675E+01
11	5.317E+01	5.317E+01
12	5.585E+01	5.585E+01
13	5.156E+01	5.156E+01
14	5.048E+01	5.048E+01
15	4.744E+01	4.744E+01
16	4.511E+01	4.511E+01
17	4.458E+01	4.458E+01
18	4.313E+01	4.313E+01
19	3.634E+01	3.634E+01
20	2.667E+01	2.667E+01
21	1.933E+01	1.933E+01
22	1.455E+01	1.455E+01
23	1.113E+01	1.113E+01
24	8.826E+00	8.826E+00
25	7.429E+00	7.429E+00
30	2.238E+00	2.238E+00
35	5.890E-01	5.890E-01
40	1.550E-01	1.550E-01
45	4.082E-02	4.082E-02
50	1.078E-02	1.078E-02
70	5.550E-05	5.550E-05
100	1.969E-08	1.969E-08

Through application of Mie scattering theory, attenuation coefficients were then extended to both longer and shorter wavelengths. The results of this extrapolation are contained in Figure 2 in which attenuation coefficients per kilometer are provided separately for absorption and total extinction (absorption plus scattering). The attenuation coefficients for molecular (Rayleigh) scattering is also given in Figure 2. The scale on the right hand side of Figure 2 is intended for use with some auxiliary curves provided in the report by McClatchey et al.[9] The curve provided here is intended to be used as a replacement (containing more recent information) for the curve contained in the earlier report. Using these attenuation coefficients, Figures 3a and 3b were constructed, providing the transmittance over a 10-km path at sea level and 12 km respectively, resulting from both the clear and hazy models. The transmittance due to Rayleigh scattering has also been included.

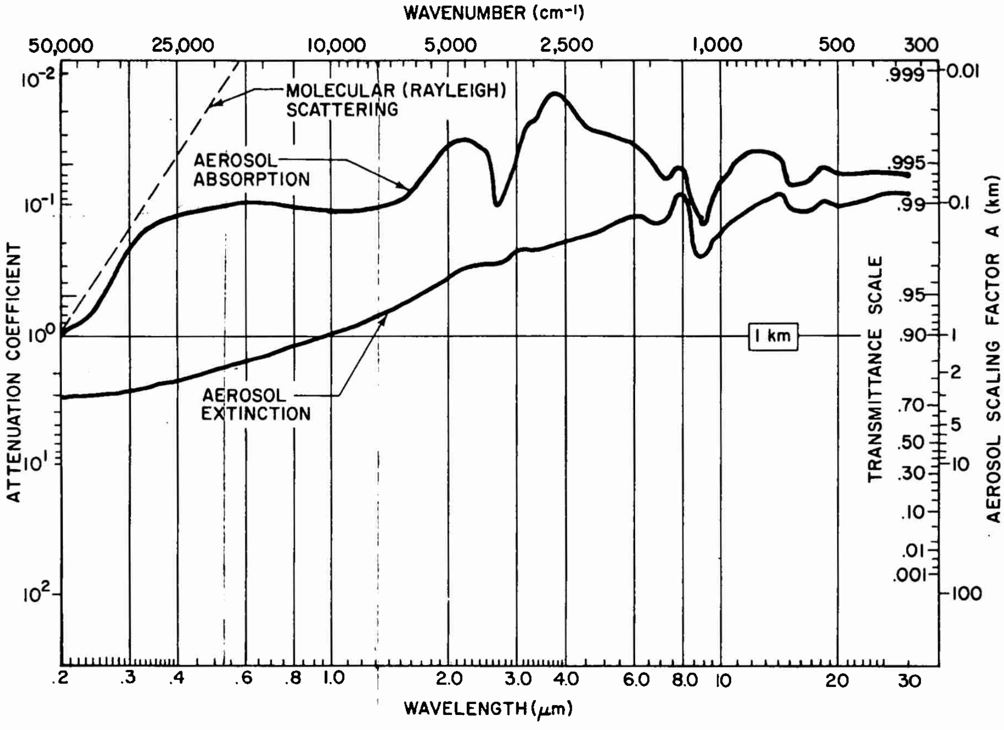


Figure 2. Attenuation Coefficients for Aerosol Transmittance (Absorption and Total Extinction)

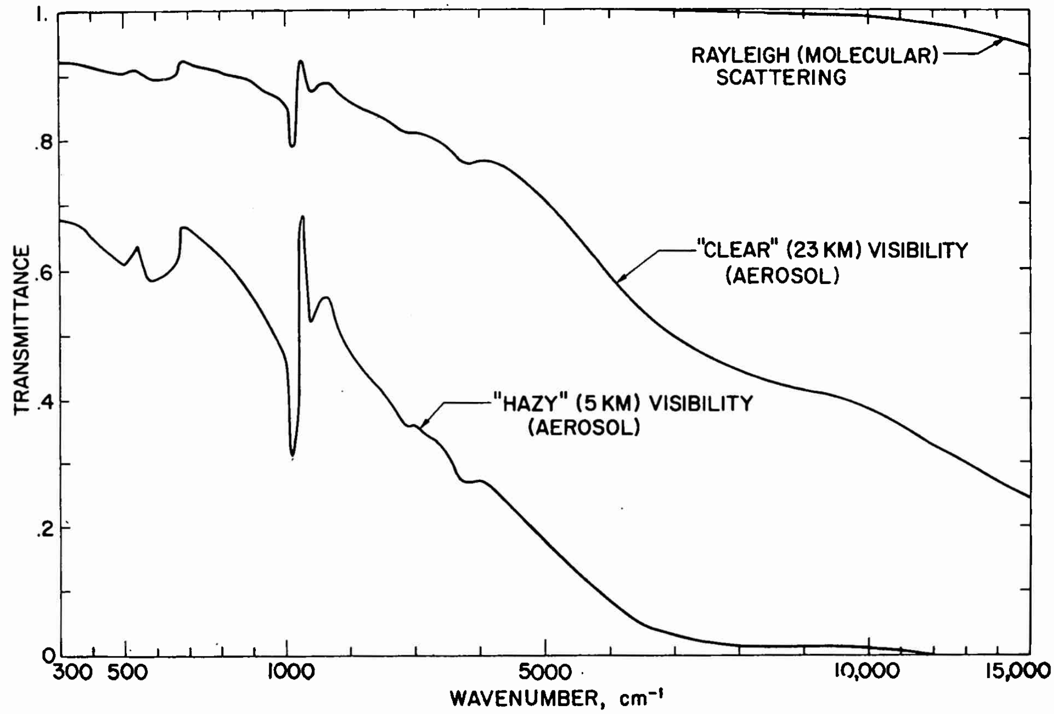


Figure 3a. Atmospheric Transmittance due to Aerosols and Rayleigh Scattering Through a 10-km Horizontal Path at Sea Level in a "Clear" and a "Hazy Atmosphere

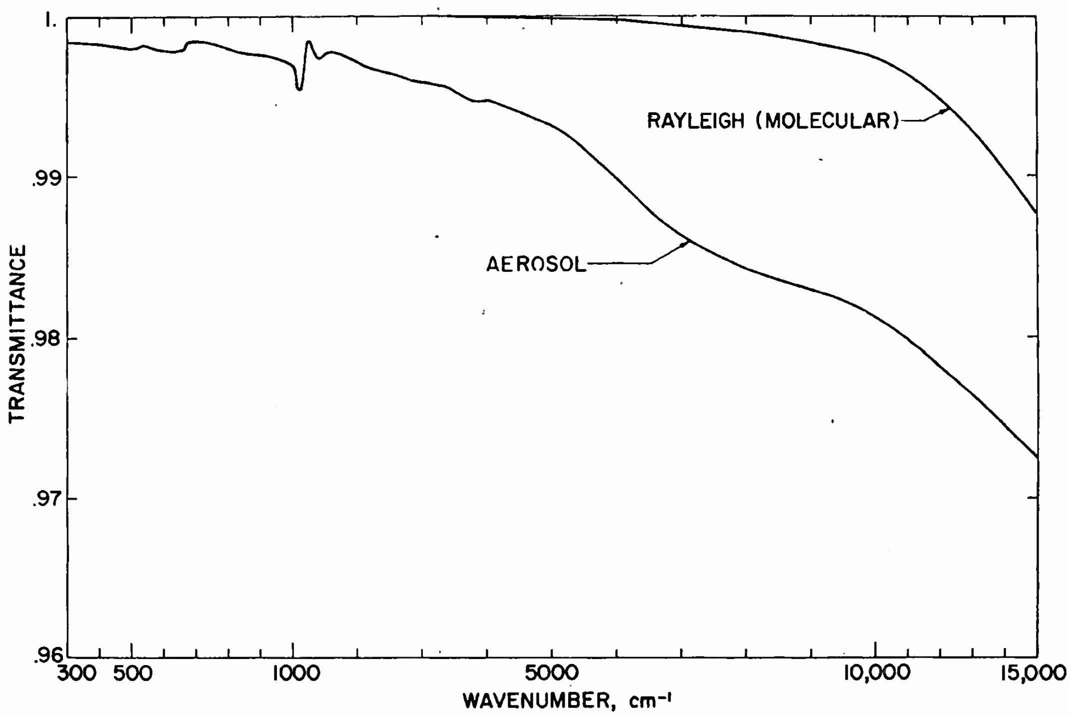


Figure 3b. Atmospheric Transmittance due to Aerosols and Rayleigh Scattering Through a 10-km Horizontal Path at an Elevation of 12 km

3. COMPUTATIONAL TECHNIQUES FOR MOLECULAR ABSORPTION

A Lorentz line shape as given in Eq. (1) was assumed for each line.

$$k_m = \frac{S\alpha}{\pi[(\nu - \nu_o)^2 + \alpha^2]} \tag{1}$$

in which S is the line intensity, α is the half-width, ν_o is the central line frequency, and ν is the laser frequency. For pressures less than 10 mb, a Voigt profile was used in the calculations.[15] The laser frequency (ν) was assumed monochromatic for the purposes of this calculation. In general, a large number of absorption lines belonging to different molecules contribute to the attenuation at any specific laser frequency, so the total optical depth (O. D.) must be evaluated and is given by Eq. (2):

$$\text{O. D.} = \sum_j \sum_i \frac{S_{ij}\alpha_{ij}m_j}{\pi[(\nu - \nu_{ij})^2 + \alpha^2_{ij}]} \tag{2}$$

where m_j represents the amount of the j^{th} absorbing gas.

Pressure broadening enters through the α_{ij} values in Eq. (2). The Lorentz line width is given by $\alpha = \alpha_o \, P/P_o \sqrt{To/T}$. The monochromatic transmittance, τ_ν is thus given by

$$\tau_\nu = e^{-(\text{O. D.})}.$$

The line intensity (S) is also temperature dependent through the population of the lower state of the transition and through the partition functions. These pressure and temperature effects have been included for all lines. The wings of all lines within $\pm$ 20 cm^{-1} of frequency, ν, were considered to contribute to the absorption coefficient at frequency ν.

In addition to this, absorption due to the water vapor continuum has been included based on the measurements of Burch et al[7] and Bignell[6] between 1250 and 320 cm^{-1}. Absorption due to the pressure-induced band of nitrogen was included in the 4-μm region.[7,8]

15. Young, C. (1965) J. Q. S. R. T. 5:549-552.

4. RESULTS

Figures 4 a through 4cl provide a high resolution (infinite resolution) transmittance spectrum for a 10-km horizontal path at sea level corresponding to the Midlatitude Winter model atmosphere. These curves cover the entire spectral region from 320 to 13,200 wavenumbers (0.76 to 31.25 μm). Figures 5a through 5cl provide similar high resolution transmittance spectra for a 10-km horizontal path at a 12-km (approximately 40,000 ft) altitude for the same Midlatitude Winter model. The resulting curves in some portions of this spectral range were entirely opaque ($\tau_\nu \leq 10^{-3}$) and in portions were entirely transparent ($\tau_\nu \geq 0.999$). In these cases the spectra were omitted and are not included in Figures 4 or 5. However, the lettering sequence accounts for all plots whether or not they are included. This allows for an easy comparison between equivalent spectra at sea level (Figure 4) and at 12 km (Figure 5).

Table 5 indicates which curves have been omitted with the notation "opaque" or "transparent" as appropriate.

Table 5. Spectral Plots Omitted as Being Completely Opaque ($\tau_\nu \leq 10^{-3}$) or Transparent ($\tau_\nu \geq 0.999$)

Figure No.	Spectral Range (cm^{-1})		Figure No.	Spectral Range (cm^{-1})	
4a	320-400	opaque	5ah	4220-4340	transparent
4b	400-560	opaque	5ai	4340-4460	transparent
4c	560-680	opaque	5aj	4460-4580	transparent
4j	✓1400-1520	opaque	5ak	4580-4700	transparent
4k	✓1520-1640	opaque	5au	5780-5900	transparent
4l	✓1640-1760	opaque	5av	5900-6020	transparent
4m	✓1760-1880	opaque	5bn	8068-8180	transparent
4q	✓2240-2360	opaque	5bx	9260-9368	transparent
4ab	3560-3680	opaque	5by	9380-9500	transparent
4ac	3680-3740	opaque	5bz	9500-9620	transparent
4ad	3740-3860	opaque	5ca	9620-9740	transparent
4ap	5180-5300	opaque	5cb	9740-9860	transparent
4aq	5300-5420	opaque	5cc	9860-9980	transparent
4bf	7100-7220	opaque	5cd	9980-10040	transparent
4bg	7220-7340	opaque	5ci	11200-11500	transparent
			5cj	11500-11800	transparent
			5ck	11800-12100	transparent

In previous reports on laser propagation in the atmosphere, we have provided a large number of attenuation coefficient charts for specific laser lines of the CO, HF, DF, and CO_2 systems. These charts provided attenuation coefficients as a function of altitude for several different atmospheric models. Our intent here is to provide the high spectral resolution curves described above and contained in Figures 4 and 5. However, during the last two or three years, some improvements in the molecular spectroscopic data have allowed us to make improved calculations for some of the laser wavelengths previously tabulated. In addition, interest has been indicated in the low vibration bands of CO and also in a number of additional DF lines. Consequently, we have compiled in Table 5 a large number of attenuation coefficients for laser emission lines belonging to these four molecular systems for which the attenuation coefficients per kilometer are the lowest. Although the laser frequencies are quoted to 0.001 cm^{-1} in Table 5, in most cases the probable accuracy is within $\pm$ 0.01 cm^{-1} due to uncertainties in the molecular constants. Entries have been included in this table if the attenuation coefficients per kilometer for the Midlatitude Winter model are less than 0.25. In addition to these values, we have included attenuation coefficients per kilometer at sea level for the Tropical and the Subarctic Winter models and also for the Midlatitude Winter model at 12-km altitude. Table 6 contains attenuation coefficients for molecular absorption only. The effects of molecular (Rayleigh) scattering and of aerosol scattering and absorption would have to be added to these values if the total atmospheric attenuation is to be estimated. This can be accomplished by using Figure 2 as described above.

Table 6. Attenuation Coefficients for Laser Frequencies

CO LASER PARAMETERS			ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
			H = 0 km SEA LEVEL			H = 12 km
BAND	Rot. ID	$\nu(cm^{-1})$	k_{trop}	k_{mw}	k_{sw}	k_{mw}
* 1 - 0	P2	2135.549	.661	.249	.224	.266
	P14	2086.325	.409	.202	.176	.141
	P17	2073.267	.608	.159	.104	.0511
	P18	2068.849	.268	.101	.0792	.0352
	P21	2055.402	.141	.0750	.0654	.0112
	P22	2050.856	.152	.0522	.0392	.00630
	P25	2037.027	.441	.0765	.0369	.00574
	P26	2032.354	.178	.0292	.0124	.000813
	P27	2027.651	.757	.137	.0477	.000650
	P30	2013.353	.548	.0784	.0230	.000077
* 2 - 1	P1	2112.977	.0935	.0144	.00665	.00035
	P2	2109.132	.0525	.0168	.0126	.00902
	P3	2105.256	.120	.0264	.0125	.0038
	P4	2101.342	.122	.0246	.0127	.0055
	P7	2089.393	1.52	.191	.0527	.00671
	P8	2085.343	.186	.0346	.0218	.00196
	P9	2081.258	.151	.0276	.0140	.00109
	P11	2072.987	.366	.0733	.0332	.00268
	P12	2068.802	.240	.0761	.0563	.00427
	P15	2056.046	.144	.0218	.0118	.000605
	P16	2051.729	1.09	.0846	.0283	.000769
	P17	2047.379	.350	.0718	.0413	.00118
	P19	2038.582	.365	.0542	.0190	.000178
	P21	2029.656	.213	.0314	.00956	.000032
	P22	2025.145	.537	.0746	.0221	.000079
	P25	2011.423	.407	.0577	.0167	.000014
	P26	2006.786	.801	.108	.0300	.000020
	P27	2002.118	.320	.0504	.0156	.000016
	P28	1997.419	.938	.157	.0501	.000045
3 - 2	P1	2086.594	.479	.0565	.0263	.00305
	P2	2082.784	.114	.0181	.00920	.00084
	P3	2078.940	.630	.171	.125	.045
	P4	2075.061	.333	.0558	.0216	.0064
	P5	2071.148	.123	.0235	.0125	.000861
	P6	2067.200	.679	.112	.0508	.00181
	P7	2063.218	.801	.130	.0561	.00152
	P8	2059.203	.571	.0937	.0365	.000655
	P10	2051.071	.414	.0581	.0236	.000598
	P11	2046.954	.851	.104	.0292	.000119
	P12	2042.804	1.49	.225	.0735	.000429
	P13	2038.621	.367	.0525	.0174	.000122

*Laser frequencies calculated using molecular constants of Young[16].

16. Young, L.A. (1968) J. Quant, Spectrosc. Rad. Transfer **8**:693.

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

CO LASER PARAMETERS			ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
			H = O km SEA LEVEL			H = 12 km
BAND	Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
* 3 - 2 (Cont)	P14	2034.405	.882	.0896	.0217	.000239
	P15	2030.157	.317	.0406	.0116	.000073
	P16	2025.875	1.13	.166	.0513	.000365
	P17	2021.561	.734	.098	.0277	.000066
	P19	2012.835	.739	.102	.0290	.000077
	P20	2008.424	1.68	.231	.0654	.000044
	P21	2003.981	.299	.0416	.0127	.000117
	P25	1985.891	1.06	.155	.0455	.000030
	P26	1981.290	.843	.0773	.0188	.000011
	P27	1976.658	1.15	.214	.0735	.000094
	P28	1971.995	.607	.0944	.0290	.000040
	P30	1962.577	1.37	.216	.0660	.000058
* 4 - 3	P2	2056.506	.127	.0568	.0497	.00233
	P3	2052.697	.0955	.0198	.0114	.000392
	P4	2048.853	.283	.0616	.0406	.00151
	P5	2044.975	.779	.125	.0407	.000133
	P7	2037.116	.568	.0802	.0305	.00110
	P8	2033.135	.172	.0215	.00596	.000012
	P9	2029.121	.180	.0284	.00939	.000049
	P10	2025.074	.503	.0708	.0214	.000069
	P11	2020.993	.859	.119	.0338	.000050
	P13	2012.731	.581	.0816	.0234	.000022
	P14	2008.550	1.43	.203	.0590	.000053
	P15	2004.337	.302	.0406	.0117	.000001
	P17	1995.812	1.12	.170	.0513	.000039
	P20	1982.783	.507	.0753	.0225	.000017
	P21	1978.375	.281	.0446	.0141	.000048
	P22	1973.936	.386	.0607	.0187	.000016
* 5 - 4	P2	2030.297	.186	0.0236	.00682	.000011
	P6	2014.993	1.62	0.229	.0666	.000117
	P7	2011.082	1.02	0.138	.0392	.000120
	P8	2007.137	1.70	0.225	.0623	.000219
	P9	2003.158	.373	0.0502	.0144	.000018
	P11	1995.100	1.61	.243	.0731	.000075
	P14	1982.764	.496	.0730	.0217	.000017
	P15	1978.586	.266	.0416	.0129	.000016
	P16	1974.376	.412	.0631	.0194	.000016
	P21	1952.838	.900	.145	.0453	.000046
	P25	1935.035	1.29	.205	.0681	.001500
	P26	1930.506	1.13	.180	.0563	.000071
* 6 - 5	P2	2004.155	.588	.0587	.0151	.000026
	P3	2000.415	.783	.134	.0434	.000040
	P4	1996.641	1.089	.155	.0464	.00039
	P7	1985.115	.738	.108	.0319	.000024
	P8	1981.205	1.55	.119	.0257	.000013

*Laser frequencies calculated using molecular constants of Young.[16]

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

	CO LASER PARAMETERS			ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
				H = 0 km SEA LEVEL			H = 12 km
	BAND	Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
*	6 - 5 (Cont)	P9	1977.261	.437	.0737	.0238	.000023
		P10	1973.284	.432	.0669	.0205	.000022
		P15	1952.901	.917	.147	.0459	.000044
		P19	1936.007	1.23	.195	.0617	.000157
a	7 - 6	P3	1974.409	.424	.0641	.0196	.000016
		P4	1970.670	1.16	.176	.0529	.000042
		P6	1963.089	1.26	.195	.0594	.000052
		P7	1959.247	.969	.152	.0469	.000048
		P14	1931.380	1.36	.212	.0653	.000106

a Laser frequencies calculated using molecular constants of Mantz.[17]
* Laser frequencies calculated using molecular constants of Young.[16]

17. Mantz, A.W., Nichols, E.R., Alpert, B.D. and Rao, K.N. (1970) J. Mol Spec. 35:325.

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

	HF LASER PARAMETER			ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
				H = O km SEA LEVEL			H = 12 km
	BAND	Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
b	1 - 0	P11	3436.12	2.21	.221	.0542	.0000287
b		P12	3381.50	.496	.0751	.0231	.000022
b	2 - 1	P8	3435.17	2.01	.209	.0512	.0000267
b	3 - 2	P6	3373.46	.364	.0537	.0168	.000029
c	4 - 3	P8	3130.09	.801	.148	.0554	.000295
		P9	3083.83	1.12	.211	.0808	.000806
c	5 - 4	P4	3150.67	.498	.126	.0736	.00229
c	6 - 5	P6	2921.74	.586	.0453	.0103	.000077
		P7	2880.70	.0430	.00424	.00121	.000006
		P8	2838.59	.369	.0654	.0218	.000044

b Measured frequencies.[18]
c Calculated frequencies.[19]

18. Deutsch, T.F. (1968) Appl. Phys. Letters 10:234.

19. Basov, N.G., Galochkin, V.T., Igoshin, V.I., Kulakov, L.V., Martin, E.P., Nikitin, A.I. and Oraevsky, A.N. (1971) Appl. Optics 10:1814.

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

DF LASER PARAMETER				ATMOSPHERIC ABSORPTION COEFFICIENTS			
				H = O km SEA LEVEL			H - 12 km
	BAND	Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
d	1 - 0	P1	2884.934	.414	.123	.0772	.00316
d		P2	2862.652	.0540	.0115	.00485	.00316
d		P3	2839.779	.0386	.00725	.00266	.000038
d		P4	2816.362	.0837	.0190	.0104	.00108
d		P5	2792.437	.0471	.0106	.00496	.000157
d		P6	2767.914	.0719	.0184	.00952	.000672
d		P7	2743.028	.0352	.00801	.00352	.000043
d		P8	2717.536	.114	.0204	.00718	.000034
d		P9	2691.409	.0248	.00485	.00252	.000053
d		P10	2665.20	.0237	.00752	.00489	.000307
d		P11	2638.396	.337	.0664	.0247	.000187
d		P12	2611.125	.0133	.00394	.00302	.000090
c		P13	2584.91	.0145	.0102	.00981	.00390
c		P14	2557.09	.0176	.0180	.0185	.00335
b		P15	2527.06	.0145	.0155	.0161	.000565
b		P16	2498.02	.0261	.0282	.0295	.00103
b	2 - 1	P3	2750.05	.0401	.00898	.00403	.000074
b		P4	2727.38	.0378	.00653	.00272	.000033
b		P5	2703.98	.00528	.00171	.00118	.0000307
b		P6	2680.28	.0600	.0139	.00611	.000069
b		P7	2655.97	.0535	.0134	.00667	.000733
b		P8	2631.09	.00950	.00348	.00293	.000761
b		P9	2605.87	.0311	.00776	.00455	.000110
b		P10	2580.16	.0282	.0295	.0311	.00180
b		P11	2553.97	.0144	.0163	.0177	.000883
b		P12	2527.47	.0140	.0152	.0158	.000554
b		P13	2500.32	.0240	.0265	.0278	.000972
b		P16	2417.27	.0811	.0901	.0943	.00330
b	3 - 2	P3	2662.17	.0354	.00790	.00361	.000047
b		P4	2640.04	.0437	.00914	.00424	.000075
b		P5	2617.41	.00490	.00276	.00253	.000090
b		P6	2594.23	.0118	.00557	.00480	.000152
b		P7	2570.51	.0507	.0560	.0613	.00557
b		P8	2546.37	.0322	.0356	.0379	.00228
b		P9	2521.81	.0150	.0164	.0171	.00599
b		P10	2496.61	.0319	.0298	.0307	.00107
b		P11	2471.34	.0509	.0491	.0508	.00184
b		P12	2445.29	.0659	.0728	.0756	.00266
b		P13	2419.02	.0797	.0885	.0927	.00325
b		P14	2392.46	.141	.119	.115	.00369
b	4 - 3	P5	2532.50	.0134	.0143	.0148	.000528
b		P6	2509.86	.0199	.0218	.0228	.000795
b		P7	2486.83	.0318	.0349	.0356	.00129
c		P8	2463.25	.0681	.0563	.0571	.00198
c		P9	2439.29	.0686	.0758	.0794	.00279
c		P10	2414.89	.0829	.0921	.0964	.00338
c	5 - 4	P7	2404.63	.0878	.0965	.101	.00354

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

DF LASER PARAMETERS				ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
				H = O km SEA LEVEL			H = 12 km
	BAND	Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
	7 - 6	P8	2222.68	.251	.233	.226	.0102
		P10	2177.99	.123	.0979	.0867	.00297
		P11	2155.03	.186	.0344	.0225	.000846
		P12	2131.68	.272	.187	.195	.0311
c	8 - 7	P7	2165.93	.0698	.0459	.0466	.00258
c		P8	2144.80	1.34	.129	.0349	.000357
c		P9	2123.24	.187	.0296	.0169	.00410
c		P10	2101.27	.144	.0322	.0180	.00599
c		P12	2056.14	.114	.0222	.0131	.000494
c		P13	2033.01	.153	.0198	.00580	.000100
c	9 - 8	P6	2108.48	.0603	.0172	.0119	.00969
c		P7	2088.34	.444	.0567	.0188	.00663
c		P8	2067.76	.791	.112	.0554	.00259
c		P10	2025.36	.646	.0864	.0253	.000025
c		P11	2003.56	.367	.0480	.0138	.000085
c		P12	1981.38	.476	.0557	.0152	.000010

b Measured, Deutsch.[18]
c Calculated, Basov et al.[19]
d Measured, Spanbauer et al.[20]
e Calculated using Spanbauer et al.[20]

20. Spanbauer, R. N., Rao, K. N. and Jones, L. H. (1965) J. Mol. Spec. 16:100.

Table 6. Attenuation Coefficients for Laser Frequencies (Cont)

CO_2 LASER PARAMETERS		ATMOSPHERIC ABSORPTION COEFFICIENTS (km^{-1})			
		H = O km SEA LEVEL			H 12 km
Rot. ID	ν (cm^{-1})	k_{trop}	k_{mw}	k_{sw}	k_{mw}
P40	924.970	.514	0.0359	.0112	.000812
P38	927.004	.521	0.0423	.0154	.00164
P36	929.013	.744	0.0584	.0190	.00211
P34	930.997	.538	0.0536	.0227	.00311
P32	932.956	.557	0.0650	.0302	.00520
P30	934.890	.572	0.0737	.0360	.00677
P28	936.800	.588	0.0852	.0440	.00887
P26	938.684	.583	0.0853	.0447	.00955
P24	940.544	.603	0.0955	.0517	.0118
P22	942.380	.606	0.1021	.0569	.0136
P20	944.190	.609	0.0958	.0521	.0125
P18	945.976	.635	0.1223	.0717	.0186
P16	947.738	.572	0.0747	.0378	.00897
P14	949.476	.607	0.1101	.0642	.0173
P12	951.189	.591	0.1058	.0619	.0171
P10	952.877	.596	0.1008	.0580	.0161
P8	954.541	.553	0.0817	.0452	.0123
P6	956.181	.513	0.0615	.0314	.00810
P4	957.797	.484	0.0498	.0236	.00573
P2	959.388	.978	0.0753	.0282	.00609
R0	961.729	.456	0.0347	.0130	.00234
R2	963.260	.461	0.0401	.0170	.00367
R4	964.765	.478	0.0502	.0241	.00590
R6	966.247	.519	0.0614	.0308	.00783
R8	967.704	.505	0.0663	.0352	.00931
R10	969.136	.510	0.0714	.0389	.0104
R12	970.544	.578	0.0788	.0418	.0109
R14	971.927	.556	0.0796	.0427	.0110
R16	973.285	.554	0.0799	.0425	.0106
R18	974.618	.522	0.0755	.0405	.0101
R20	975.927	.194	0.2140	.0740	.0109
R22	977.210	.674	0.0871	.0398	.00803
R24	978.468	.503	0.0641	.0318	.00699
R26	979.701	.484	0.0579	.0280	.00585
R28	980.909	.474	0.0529	.0245	.00471
R30	982.091	.552	0.0587	.0240	.00378
R32	983.248	.454	0.0436	.0183	.00324
R34	984.379	.455	0.0439	.0158	.00229
R36	985.484	.436	0.0357	.0133	.00176
R38	986.563	.428	0.0328	.0114	.00138
R40	987.616	.423	0.0306	.0102	.00121

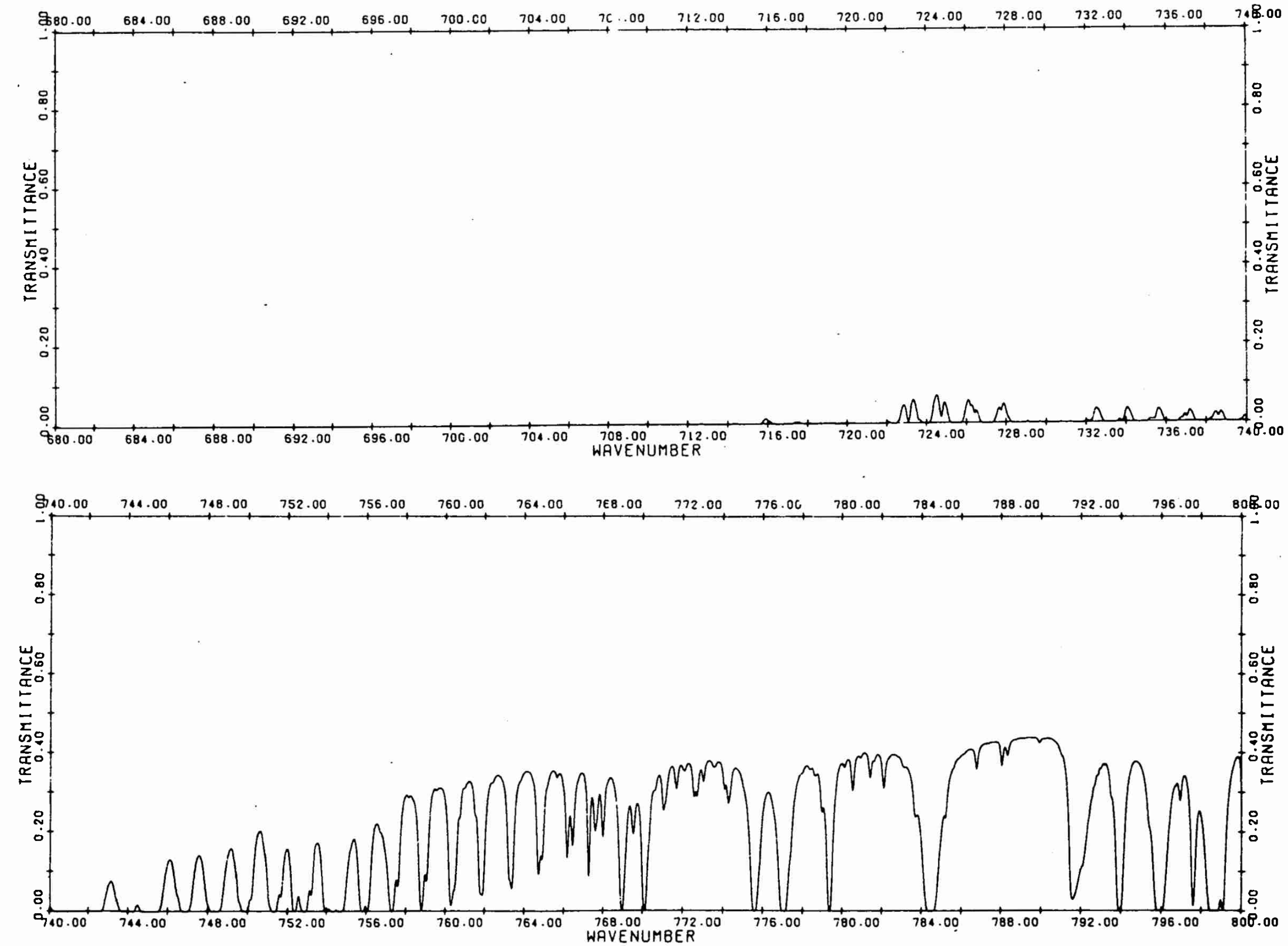


Figure 4d. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

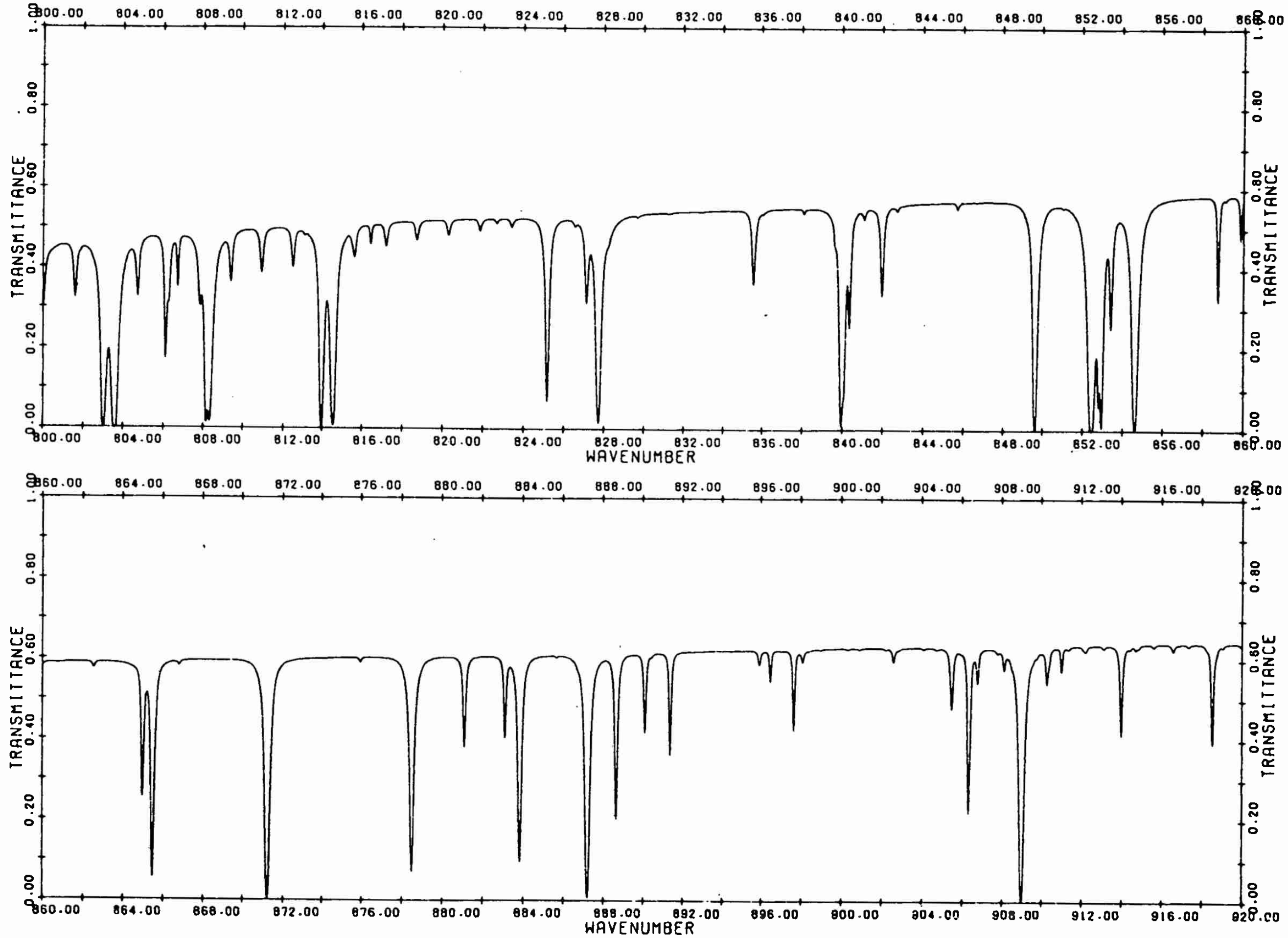


Figure 4e. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

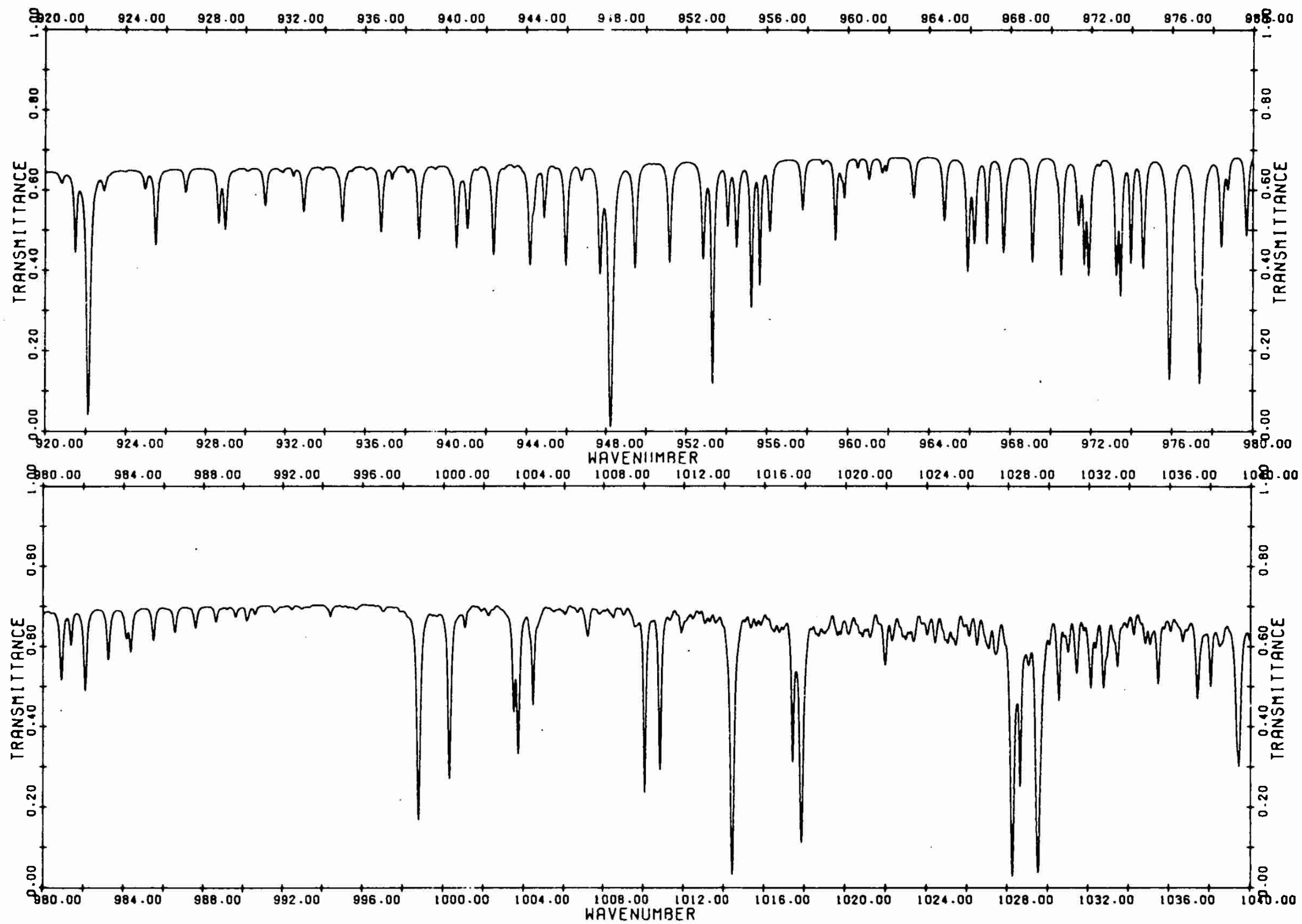


Figure 4f. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

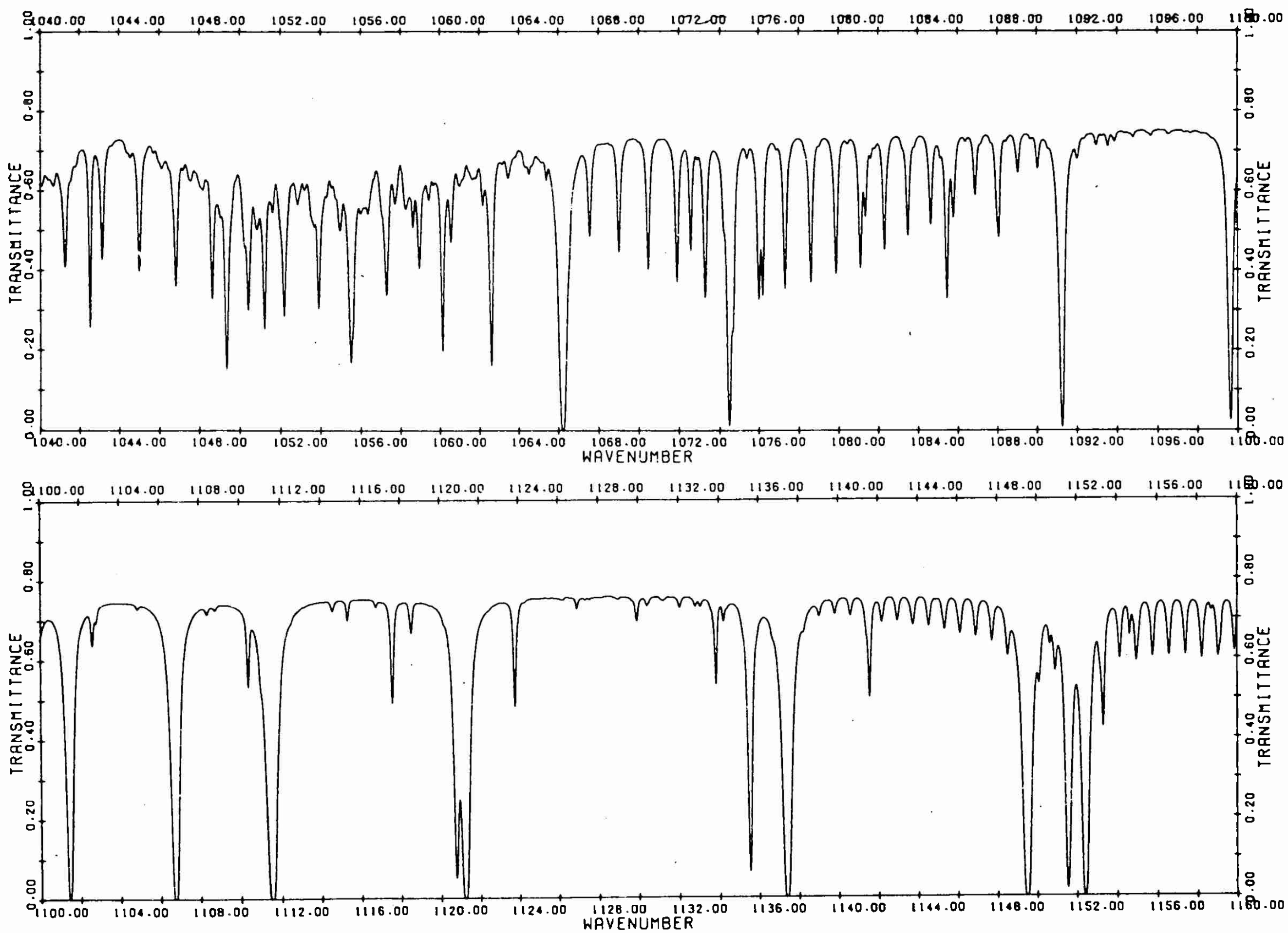


Figure 4g. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

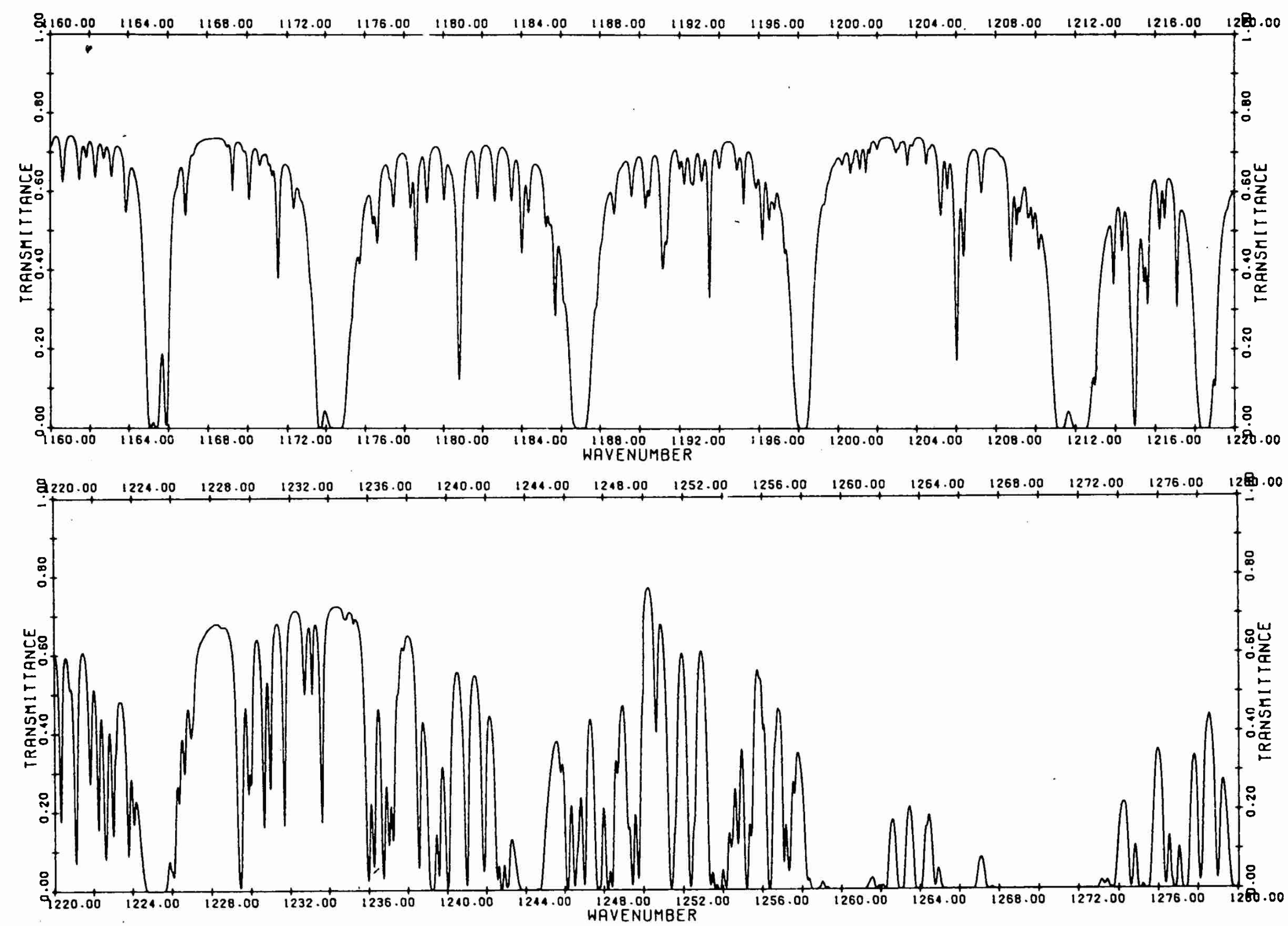


Figure 4h. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

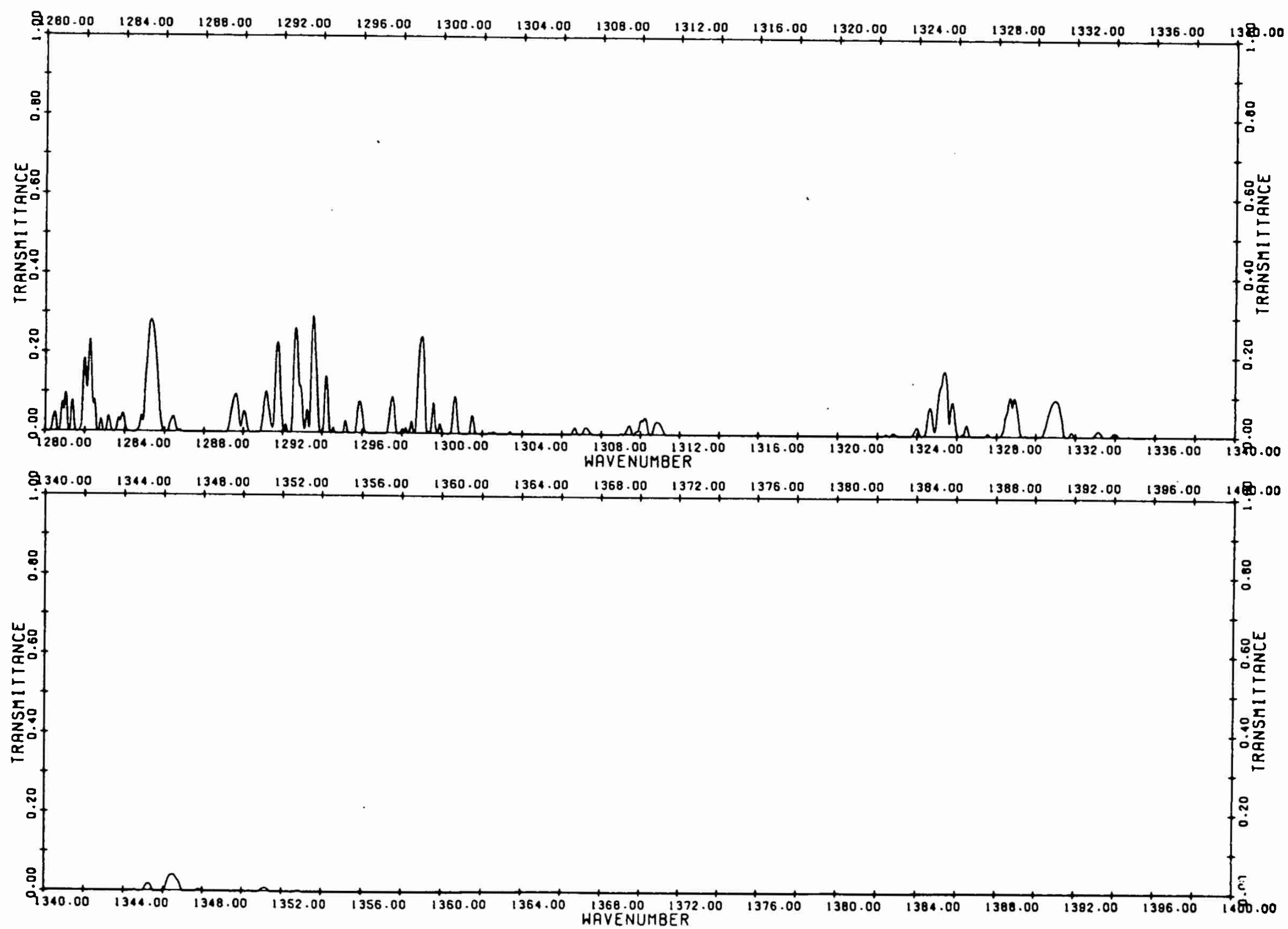


Figure 4i. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

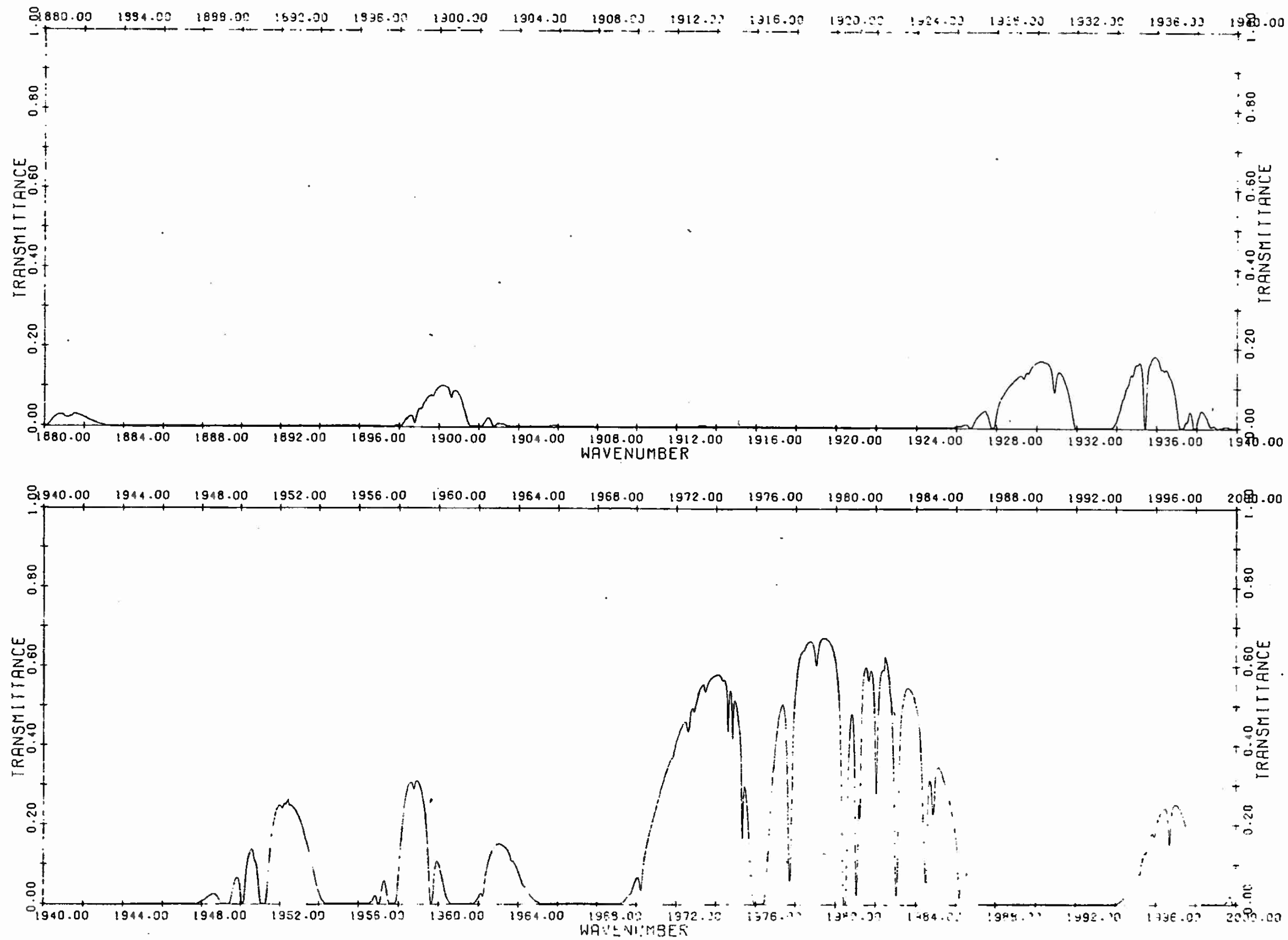


Figure 4n. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

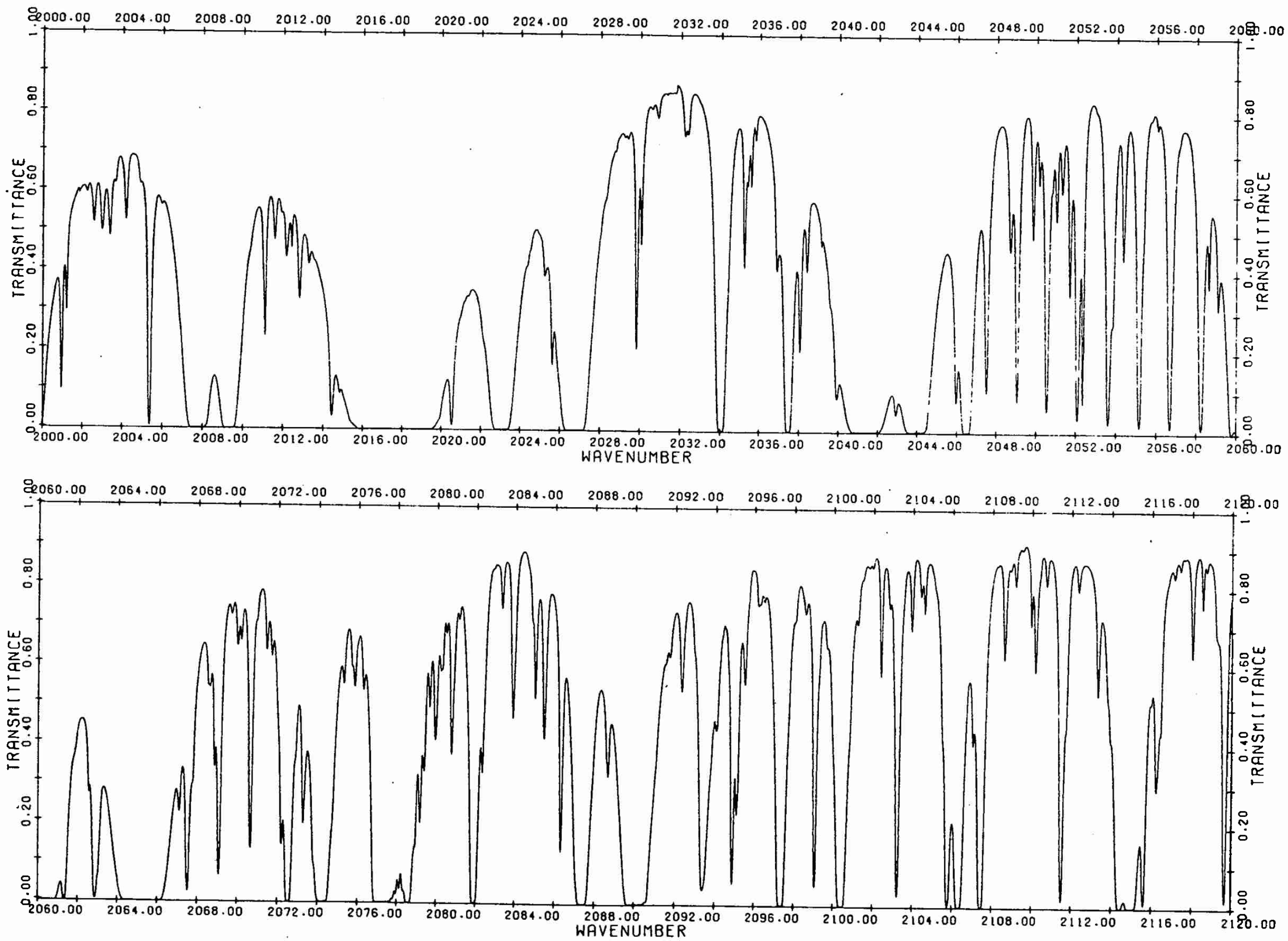


Figure 4o. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

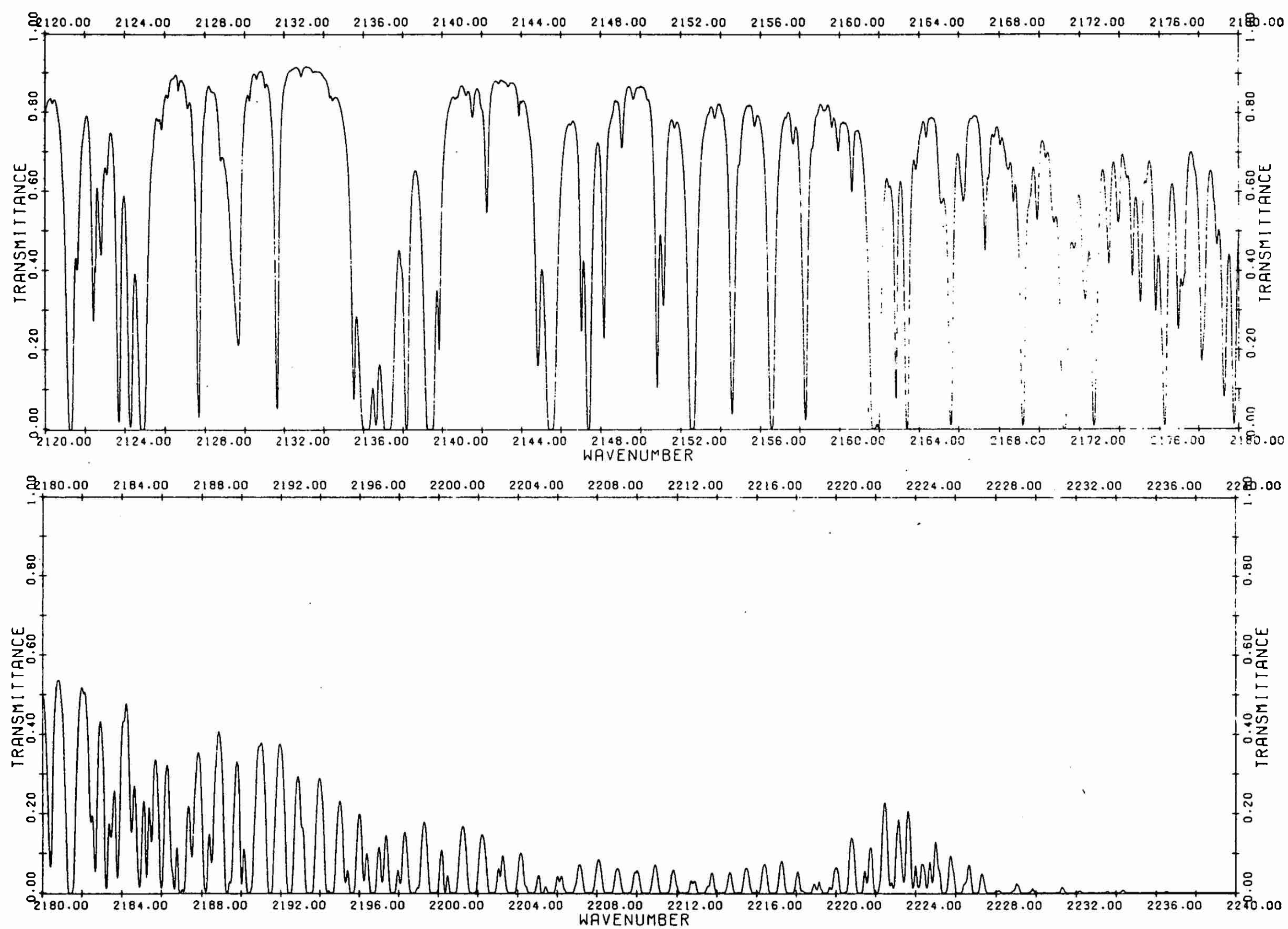


Figure 4p. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

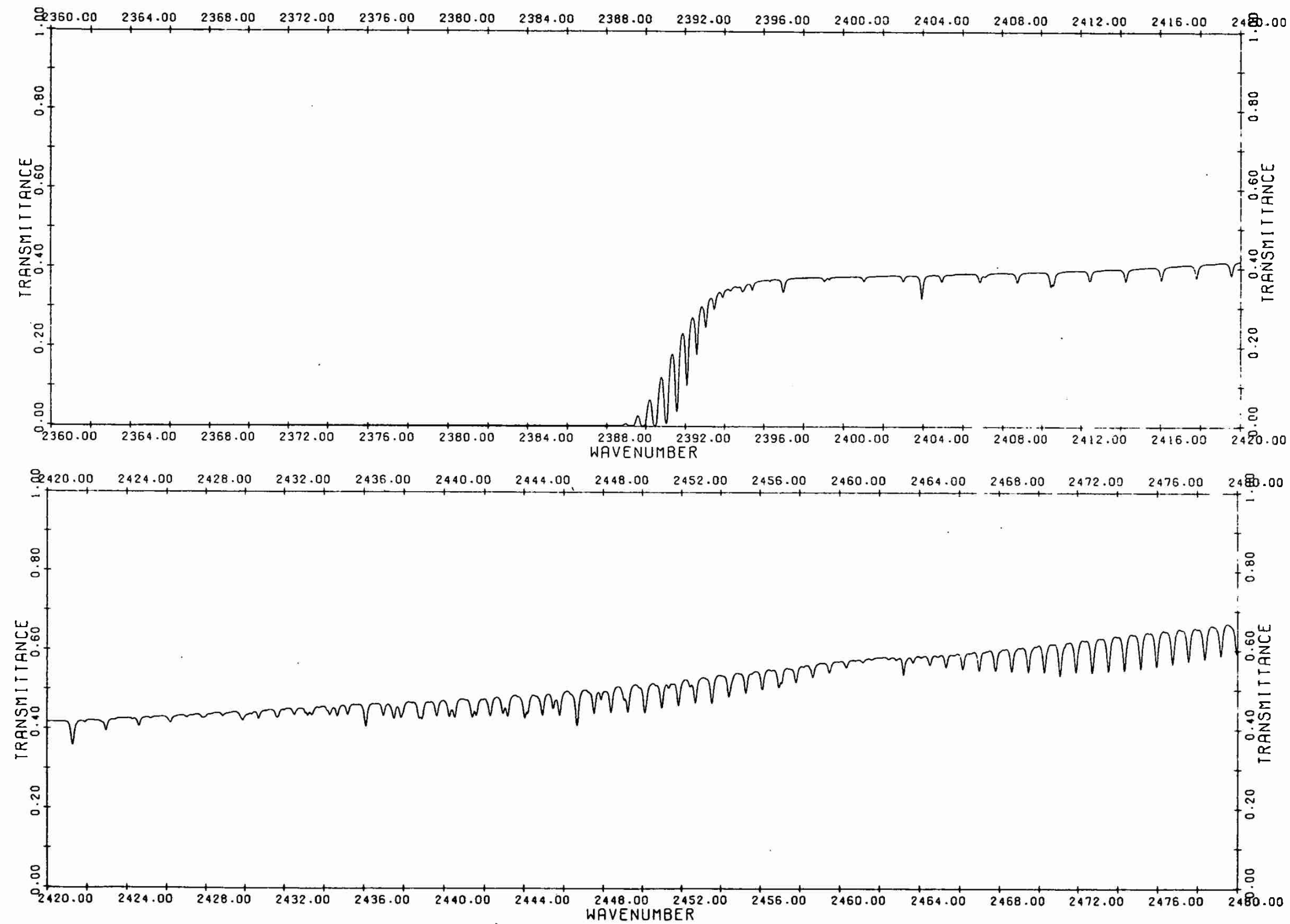


Figure 4r. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

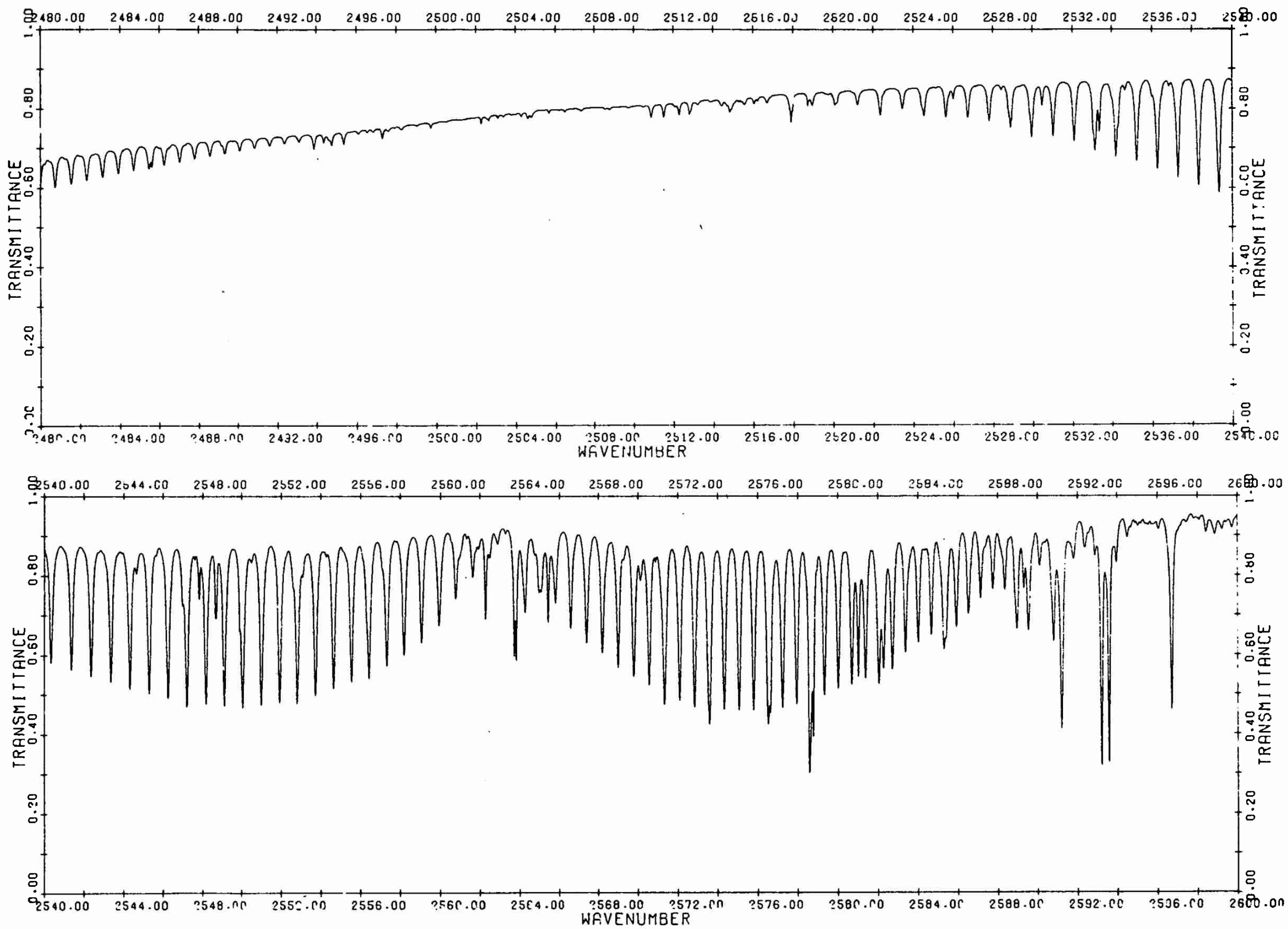


Figure 4s. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

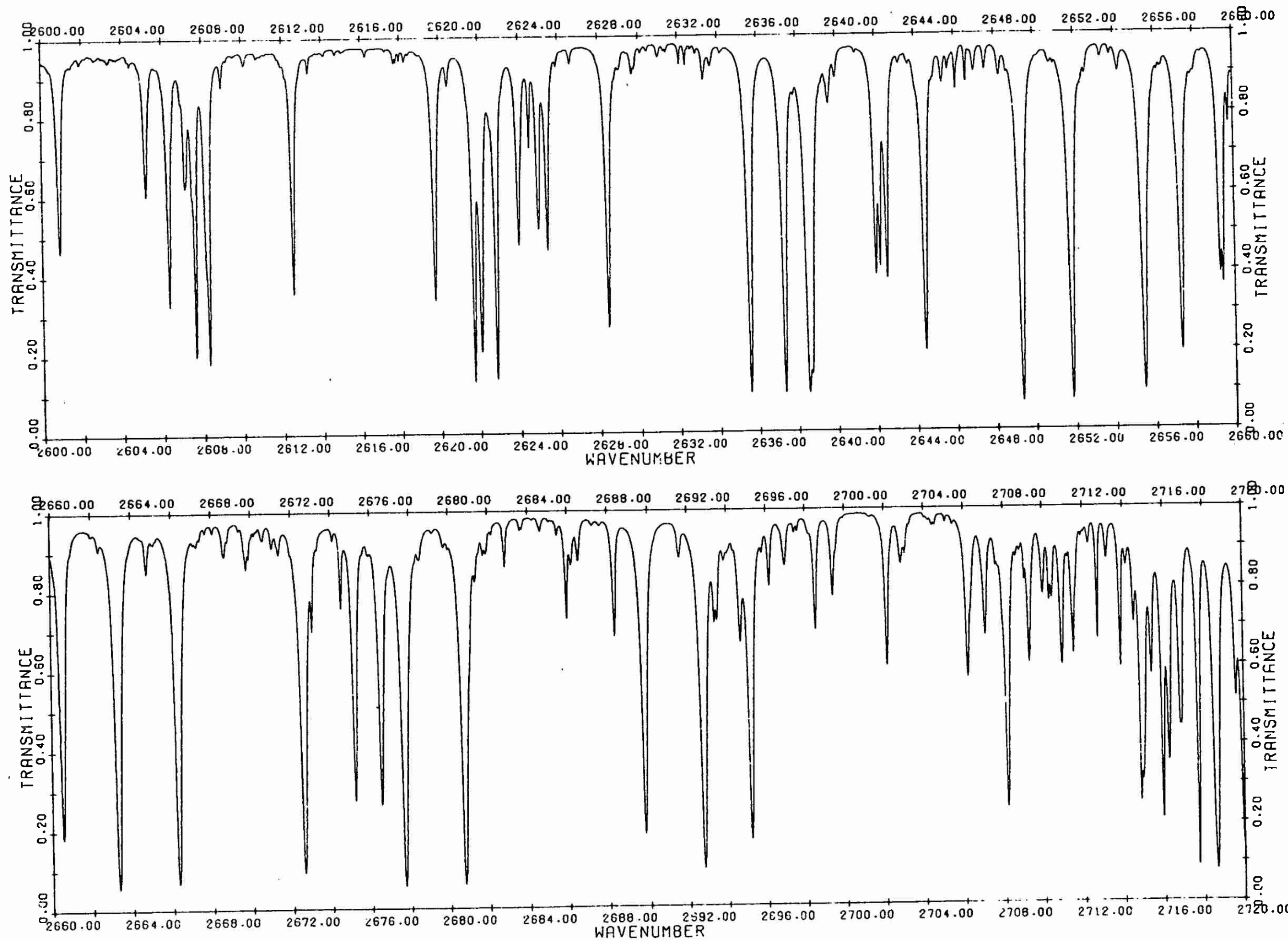


Figure 4t. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

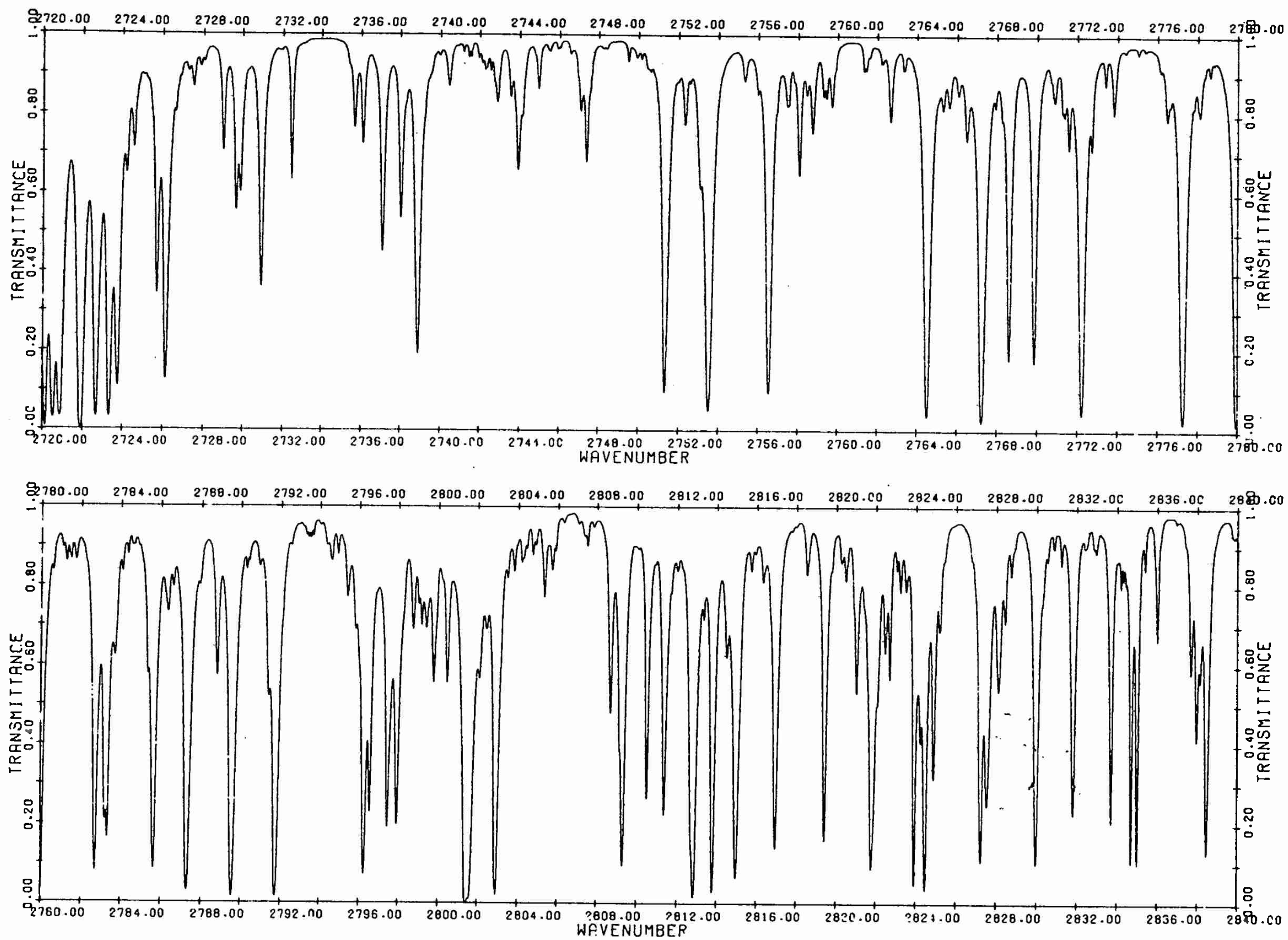


Figure 4u. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

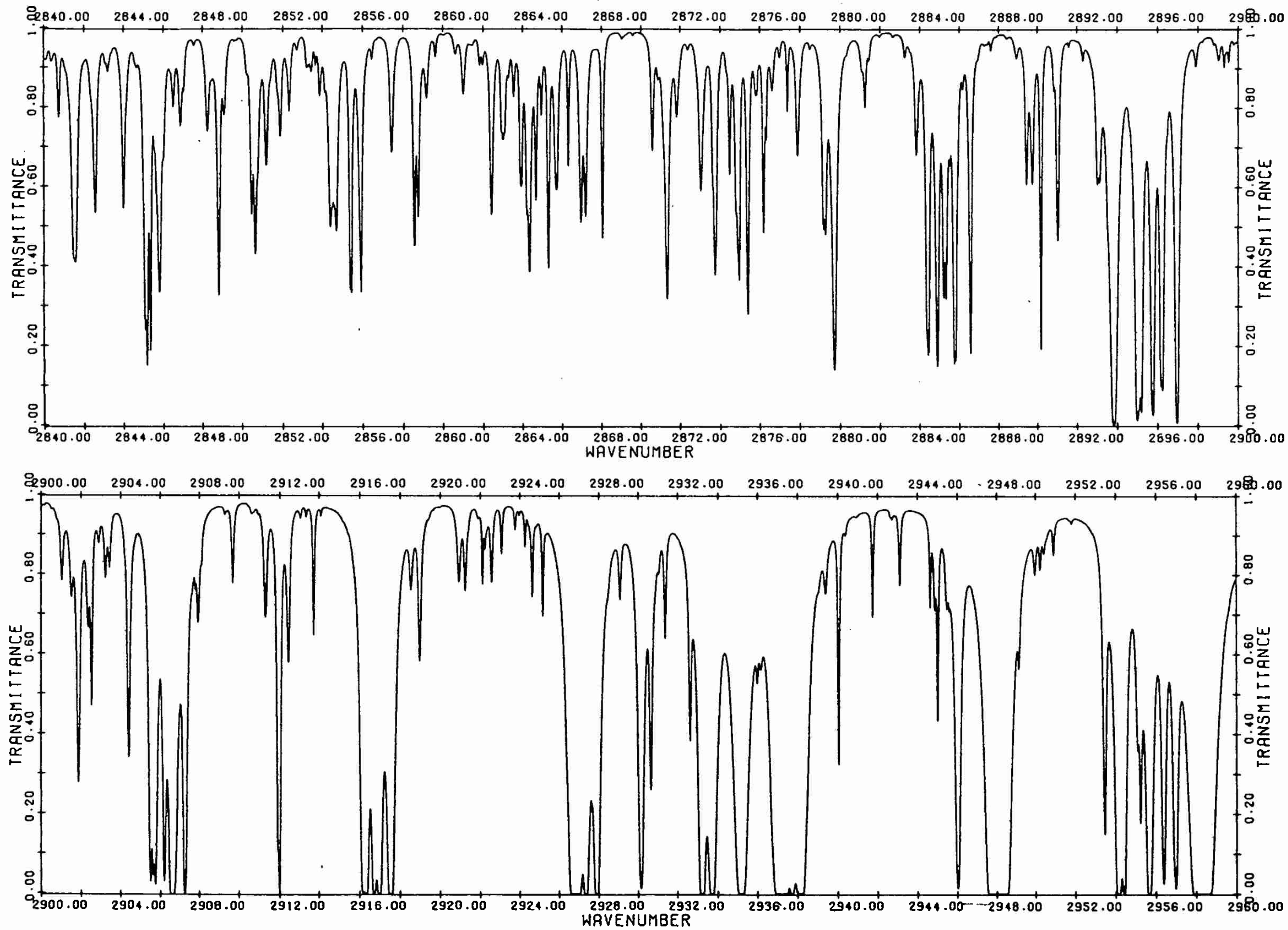


Figure 4v. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

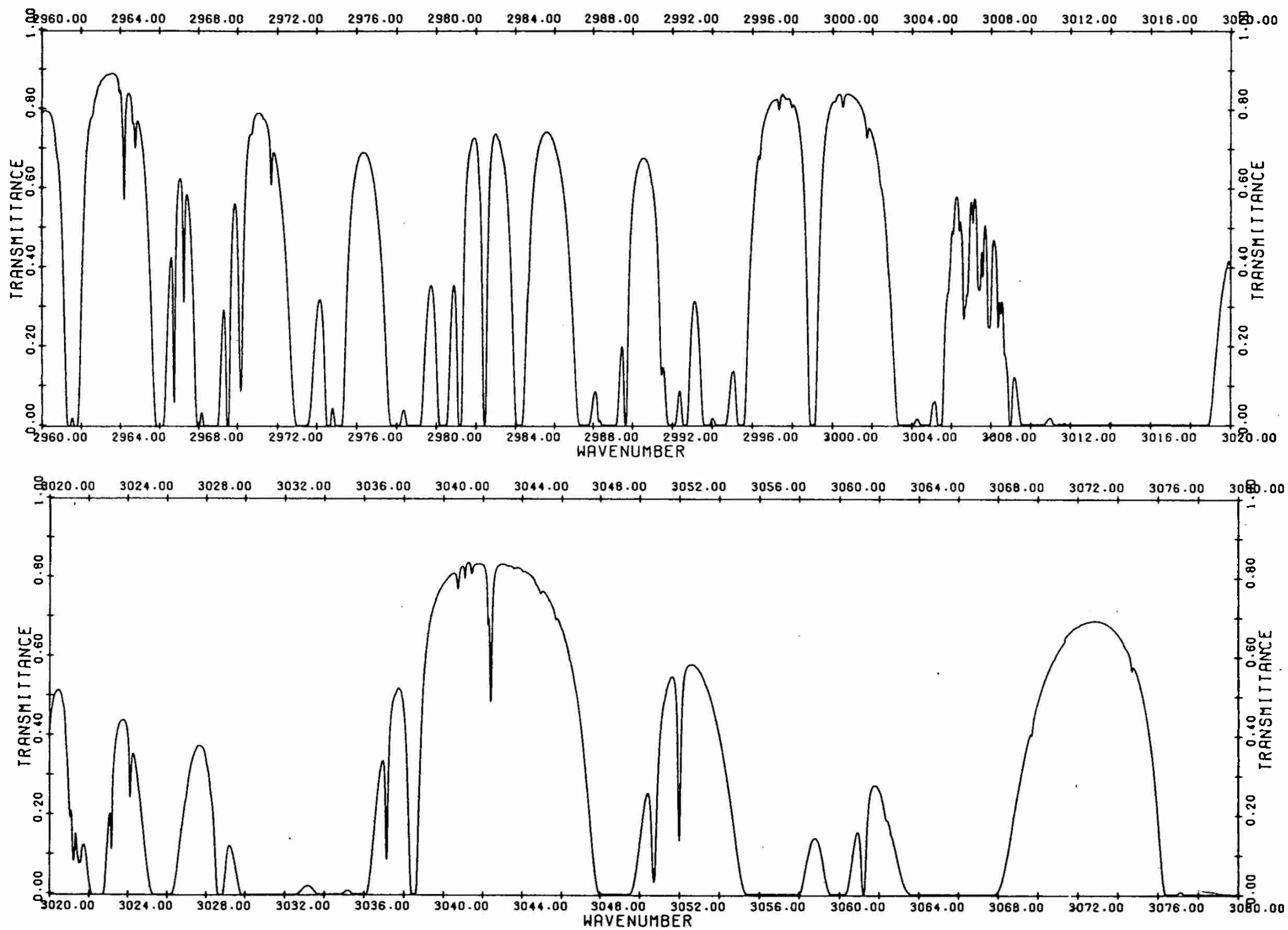


Figure 4w. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

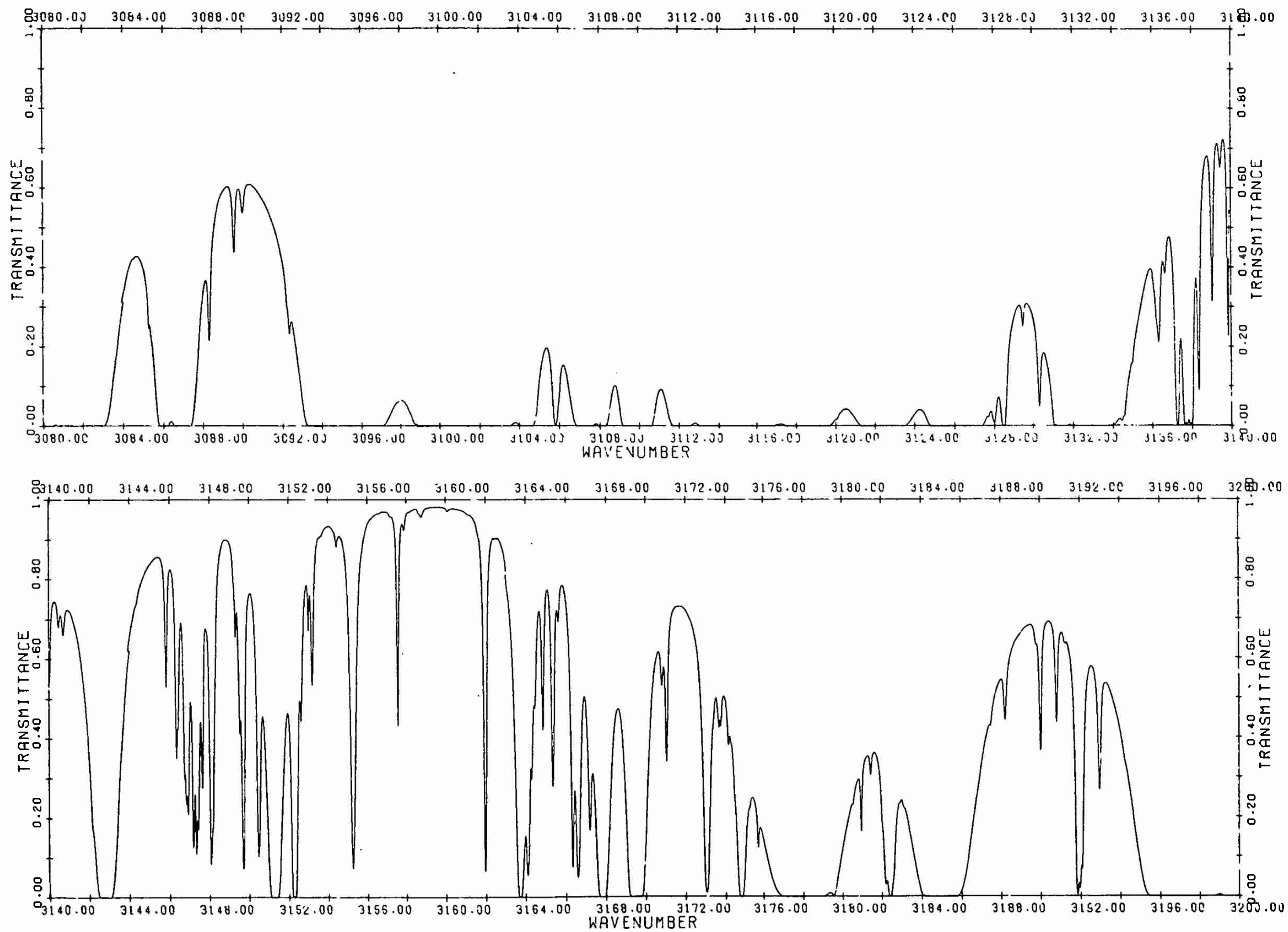


Figure 4x. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal P^th at Sea Level

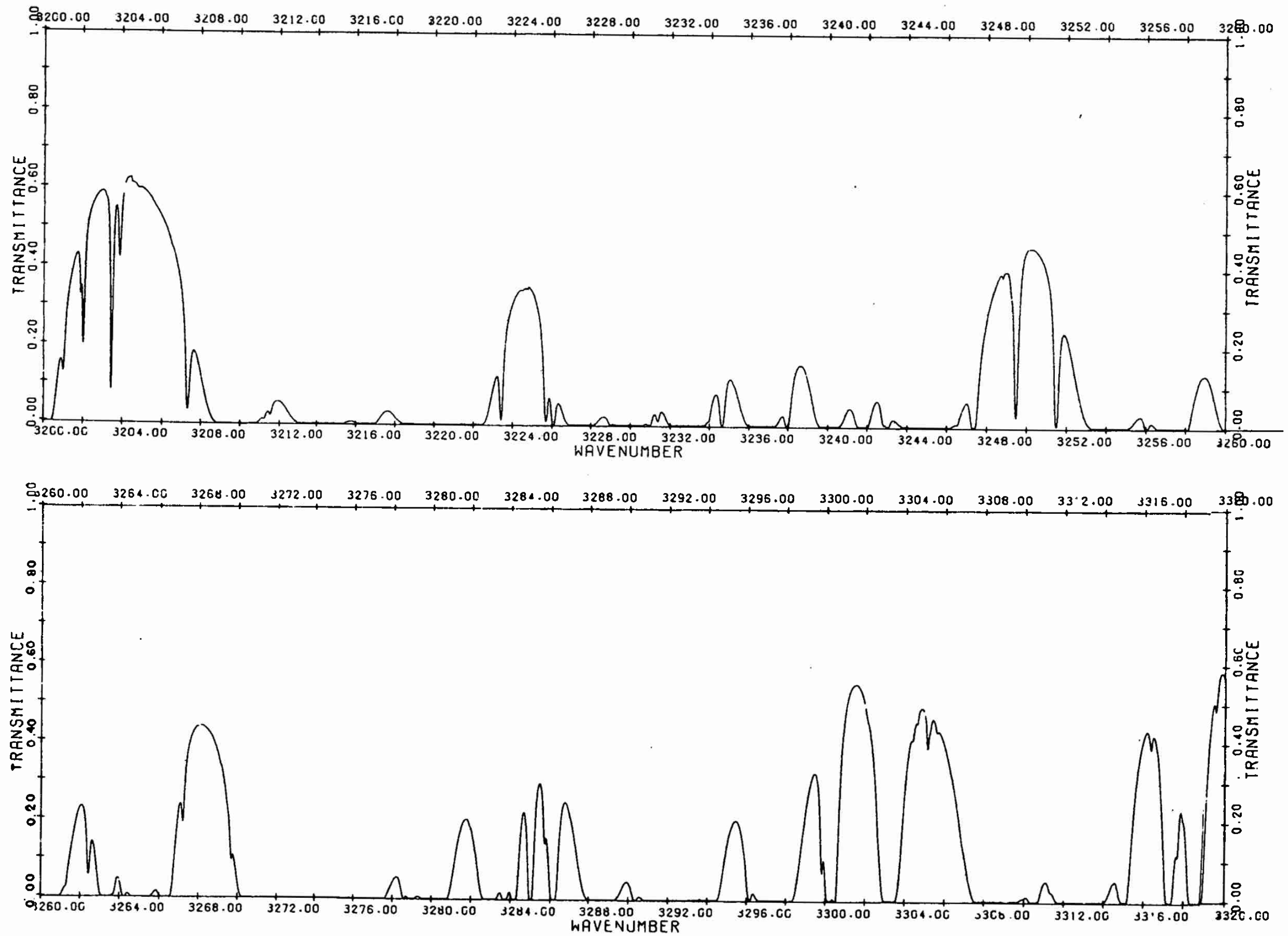


Figure 4y. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

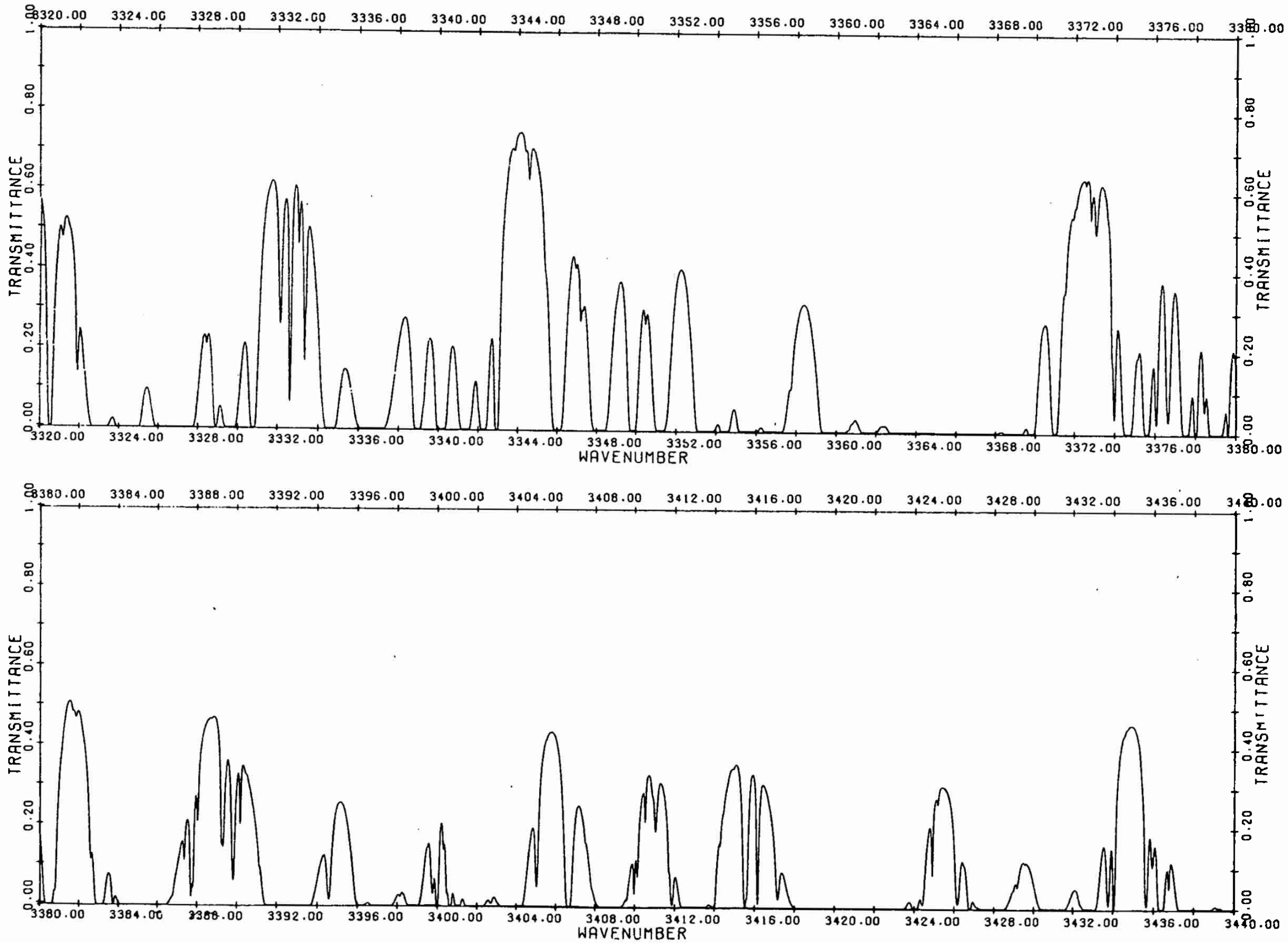


Figure 4z. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

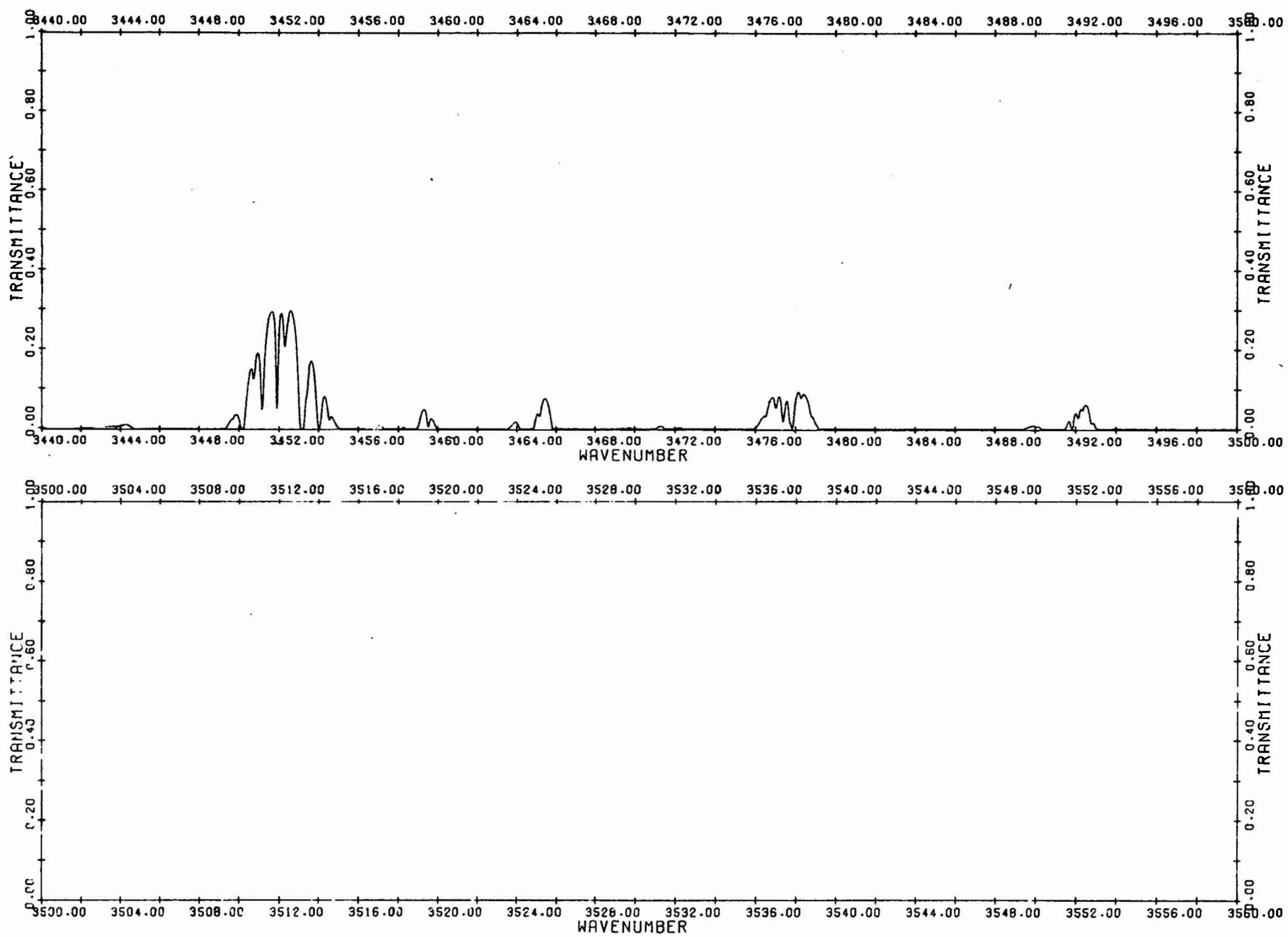


Figure 4aa. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

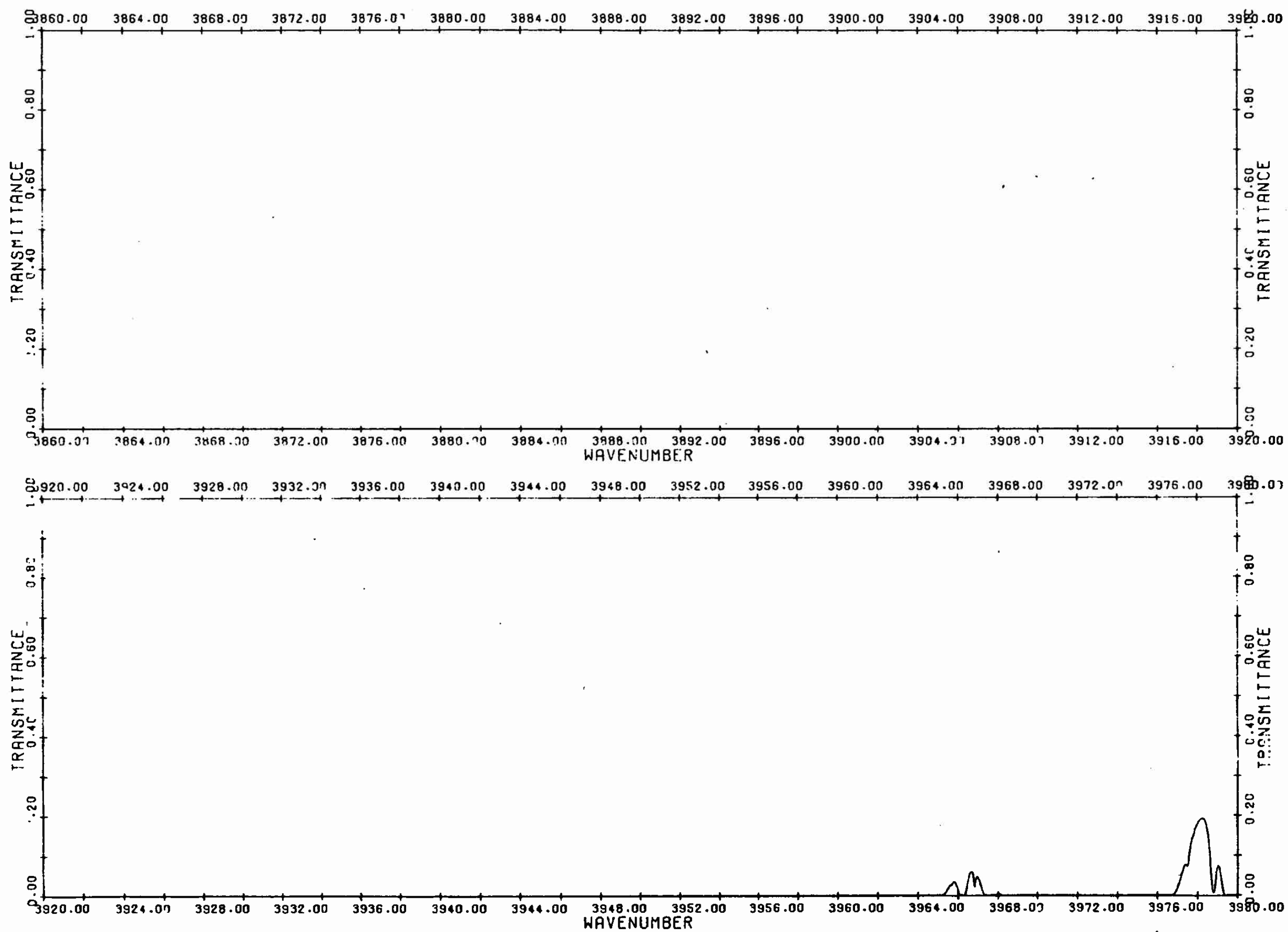


Figure 4ae. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

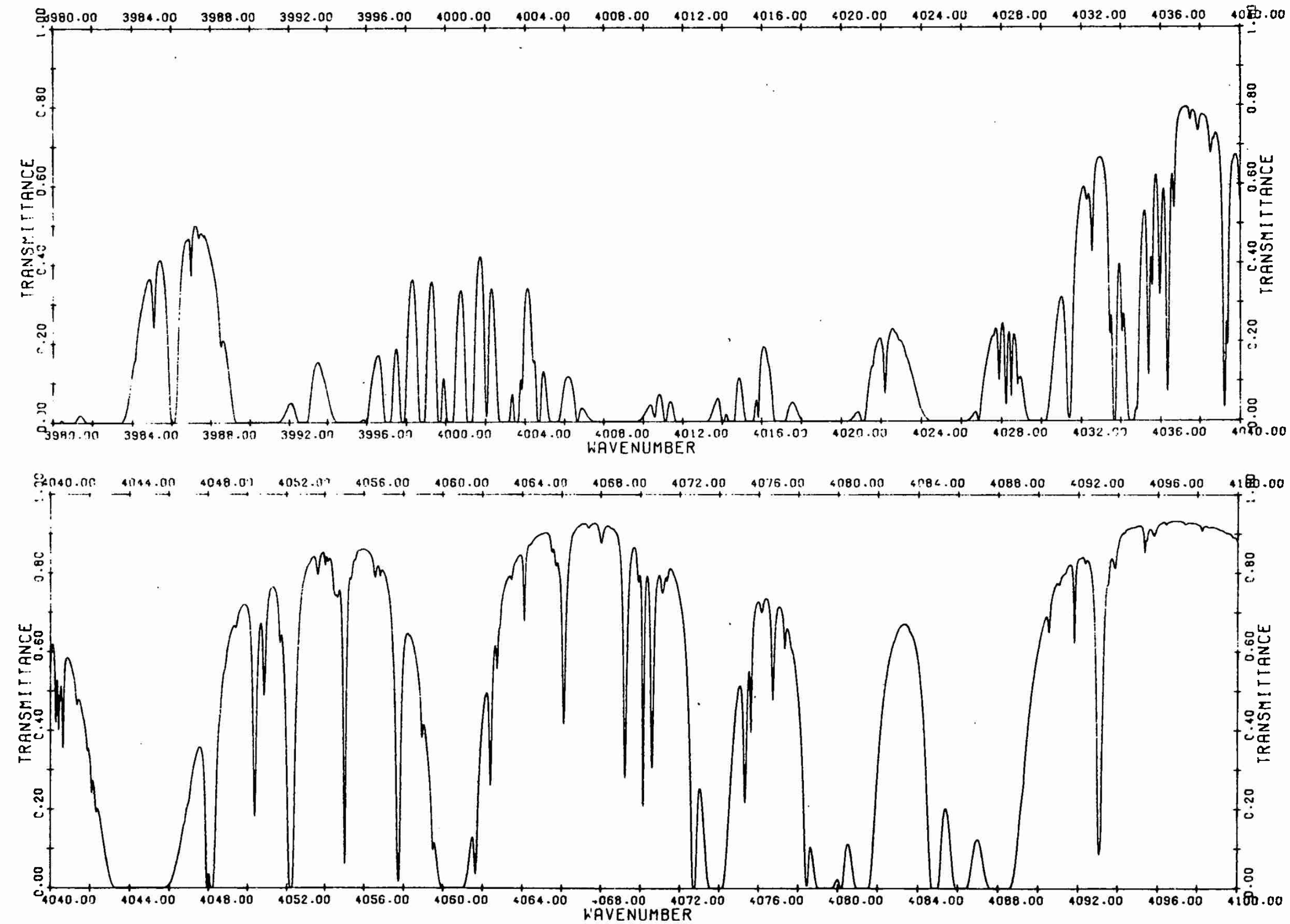


Figure 4af. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

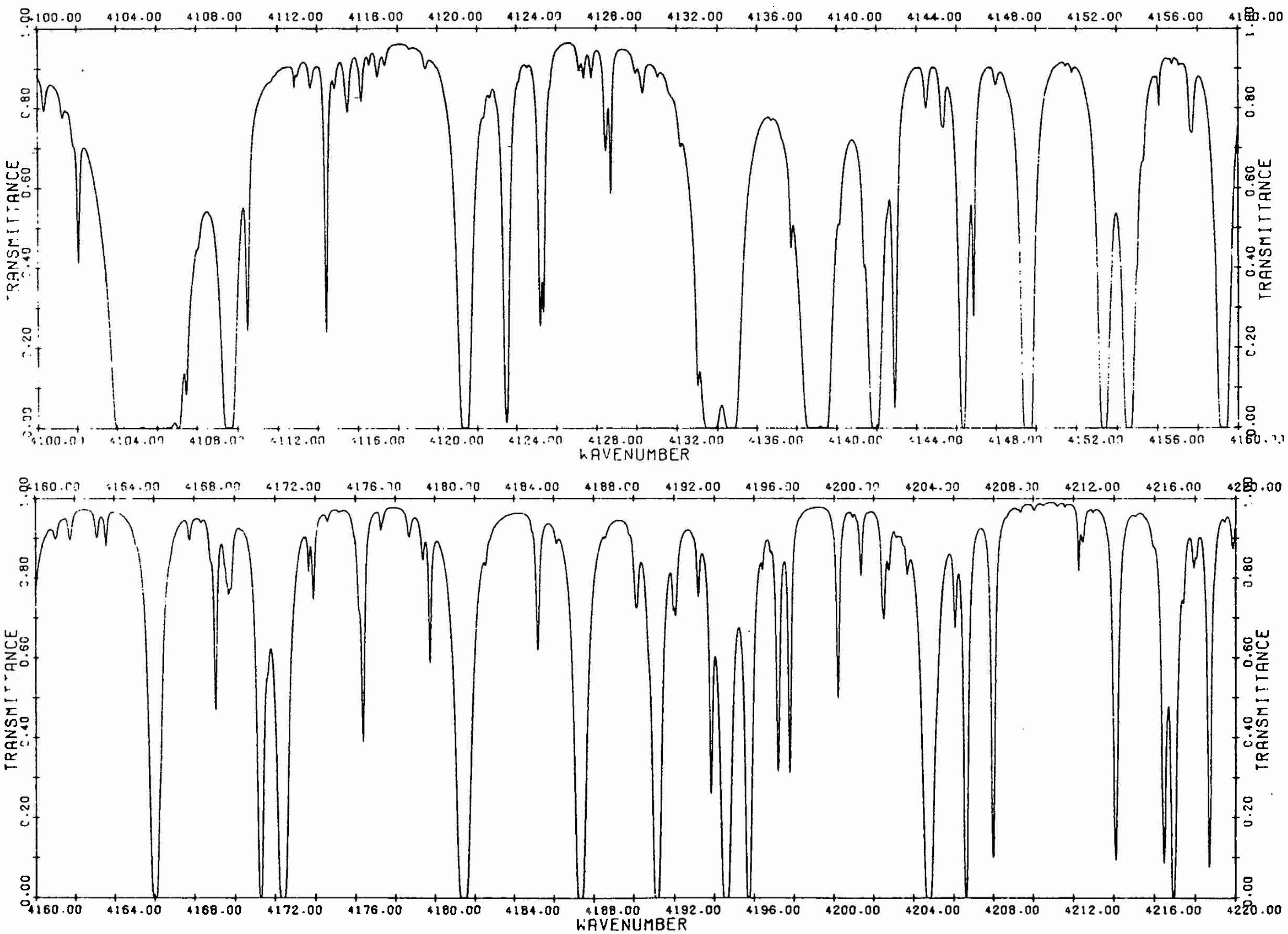


Figure 4ag. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

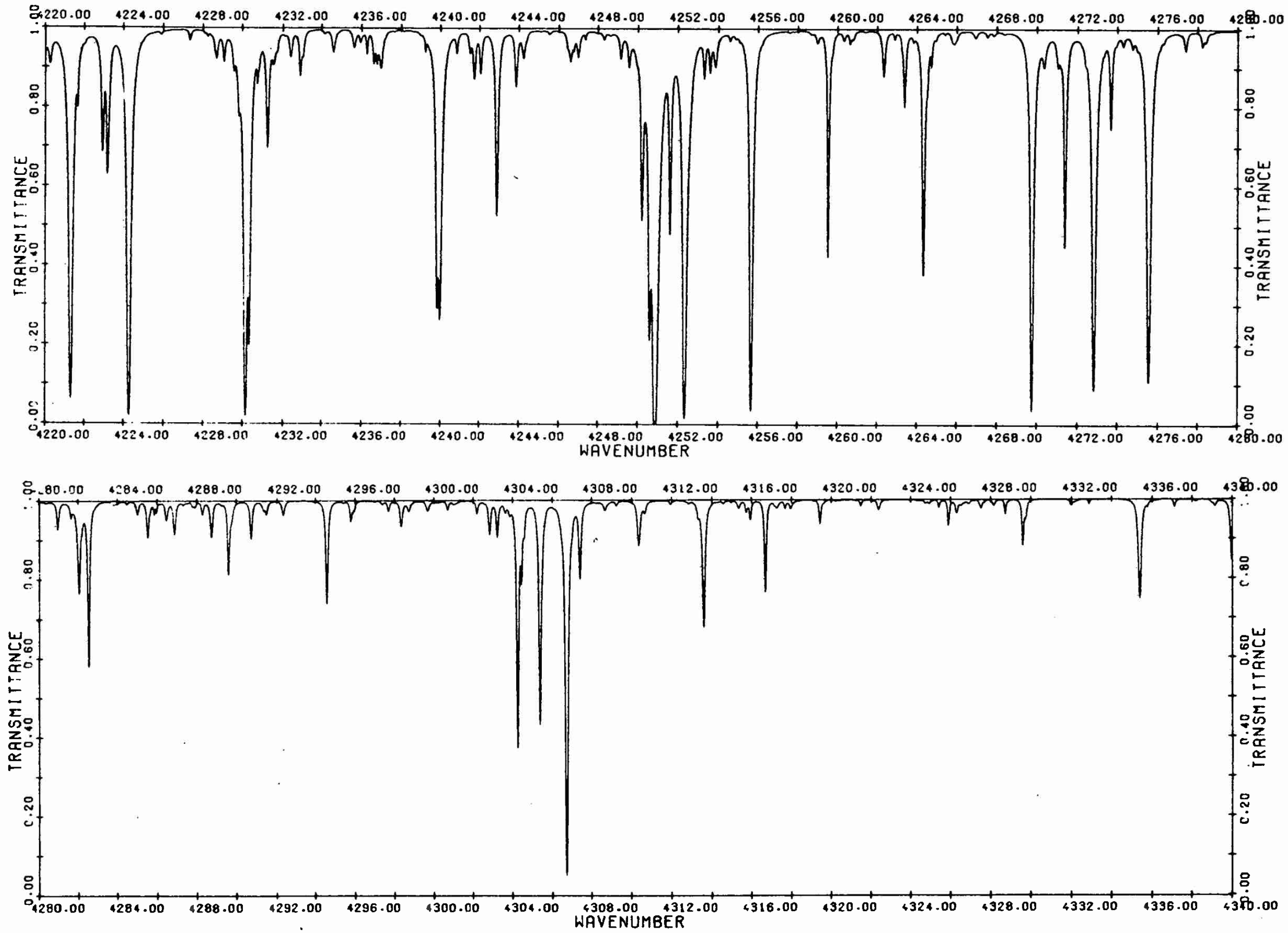


Figure 4ah. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

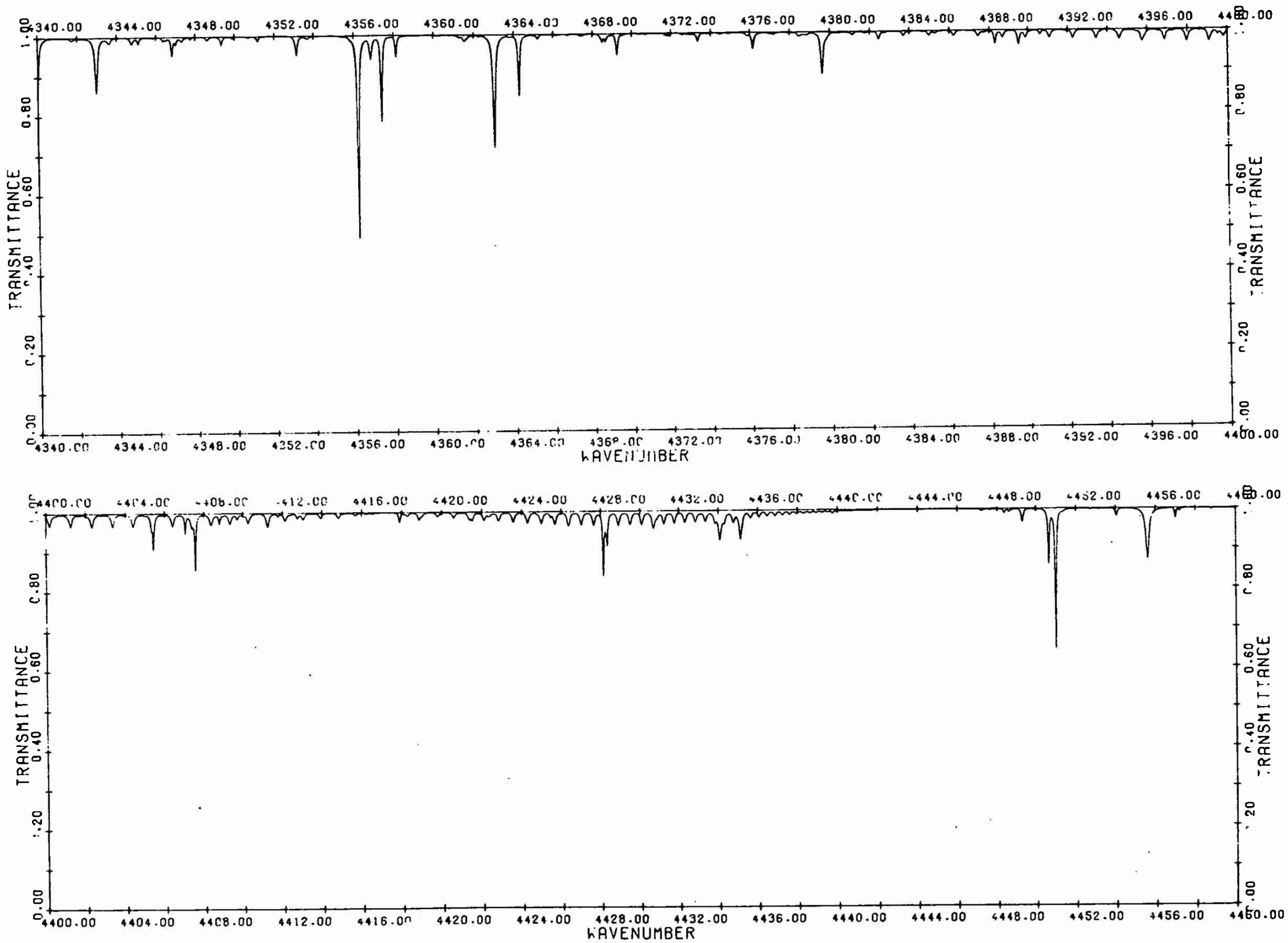


Figure 4ai. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

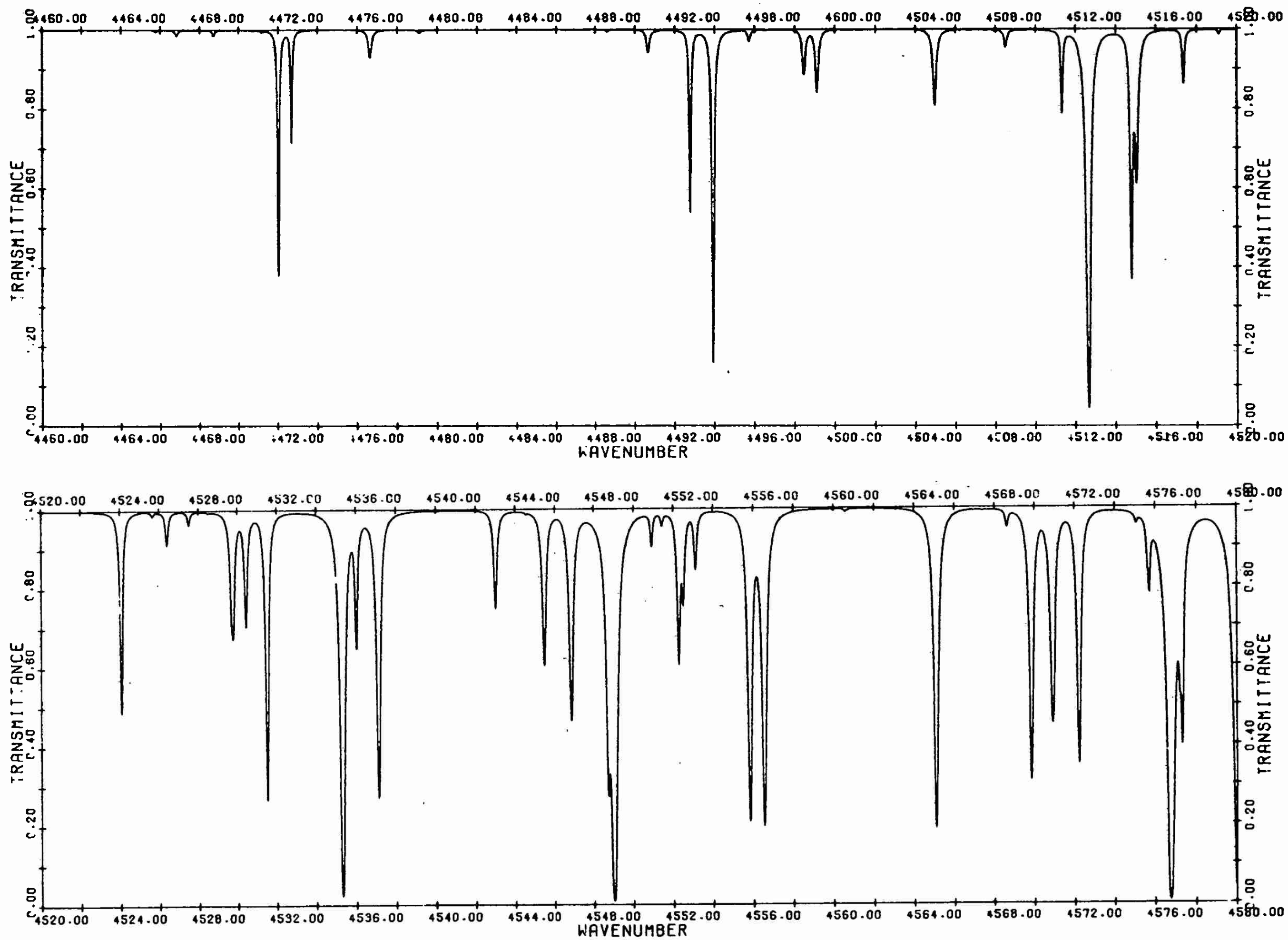


Figure 4aj. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

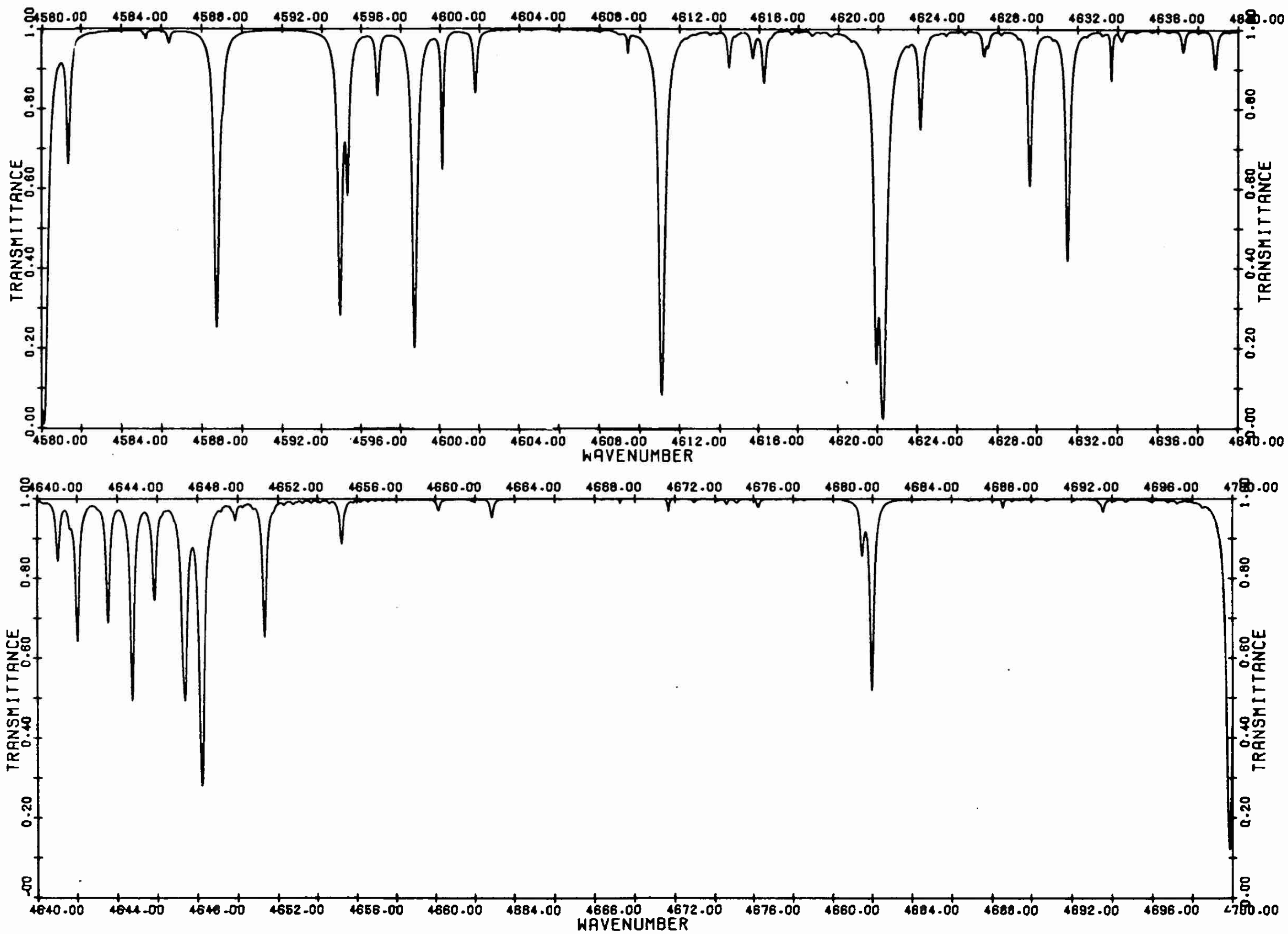
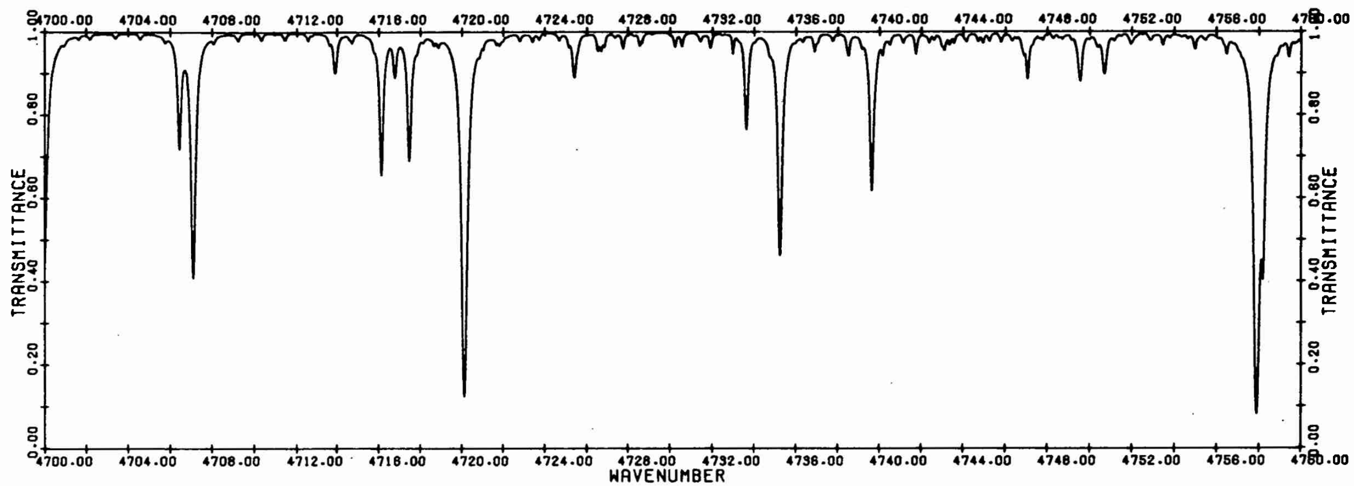


Figure 4ak. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level



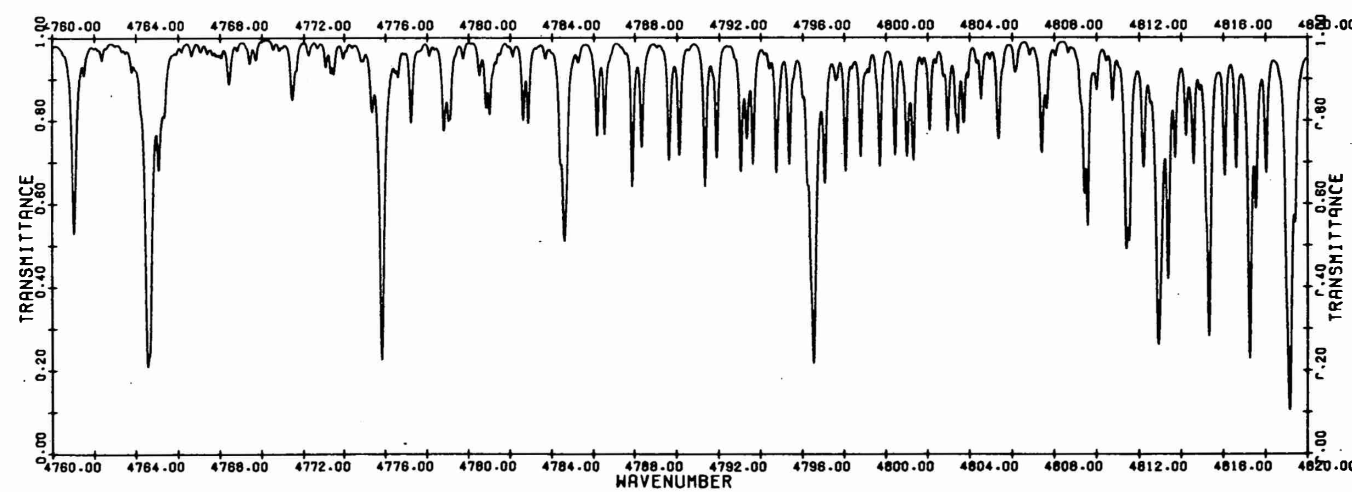


Figure 4al. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

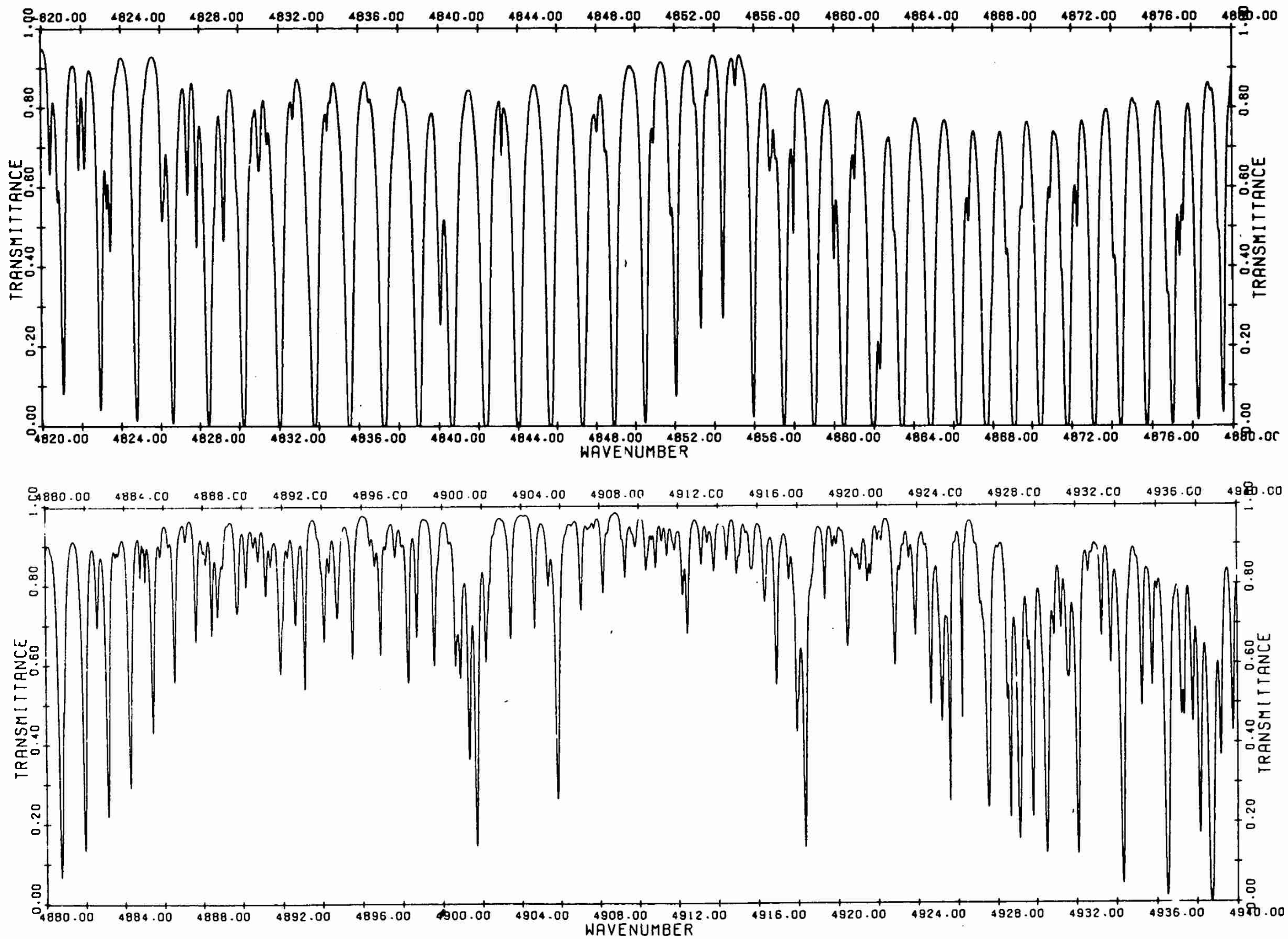


Figure 4am. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

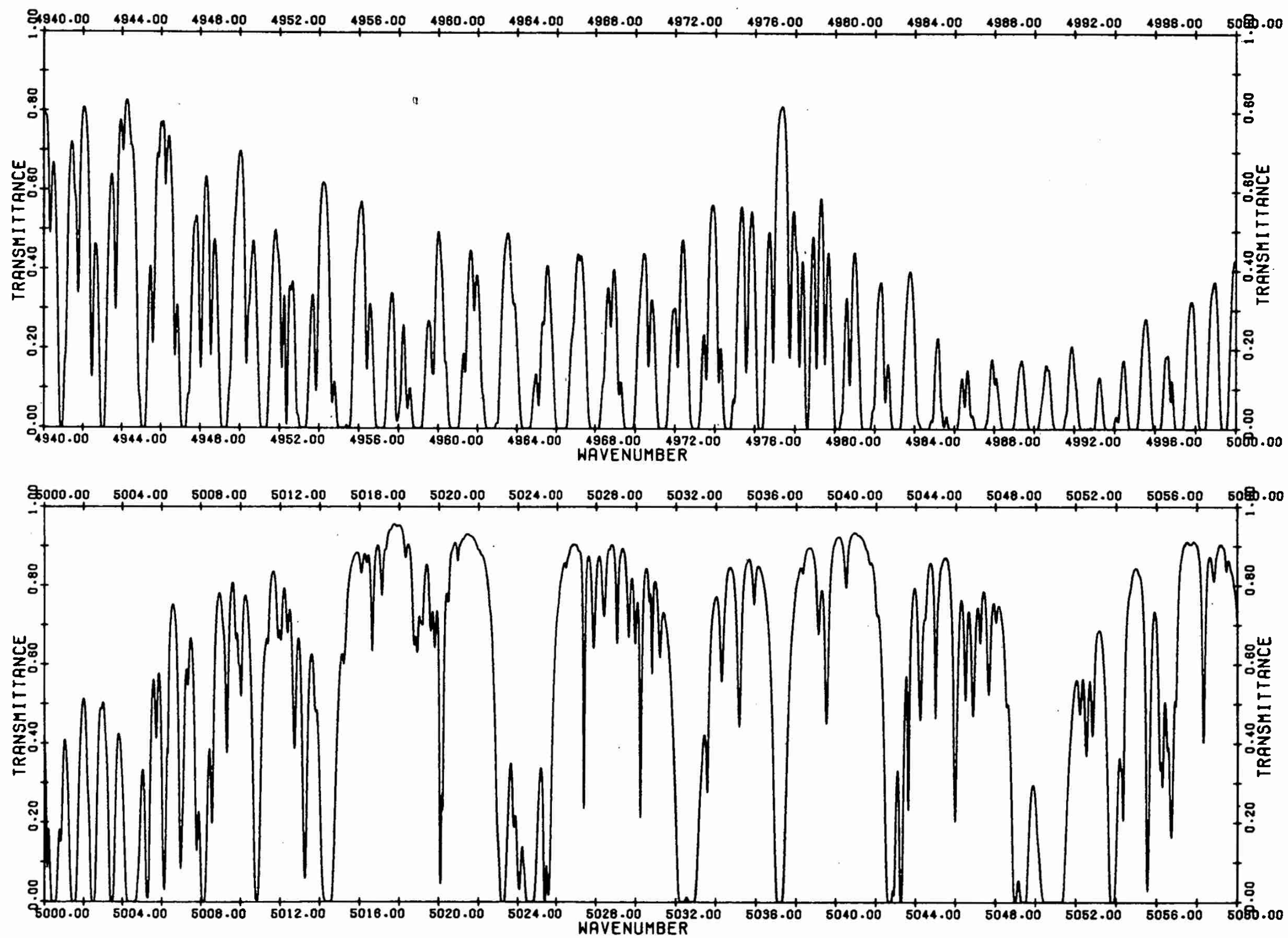


Figure 4an. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

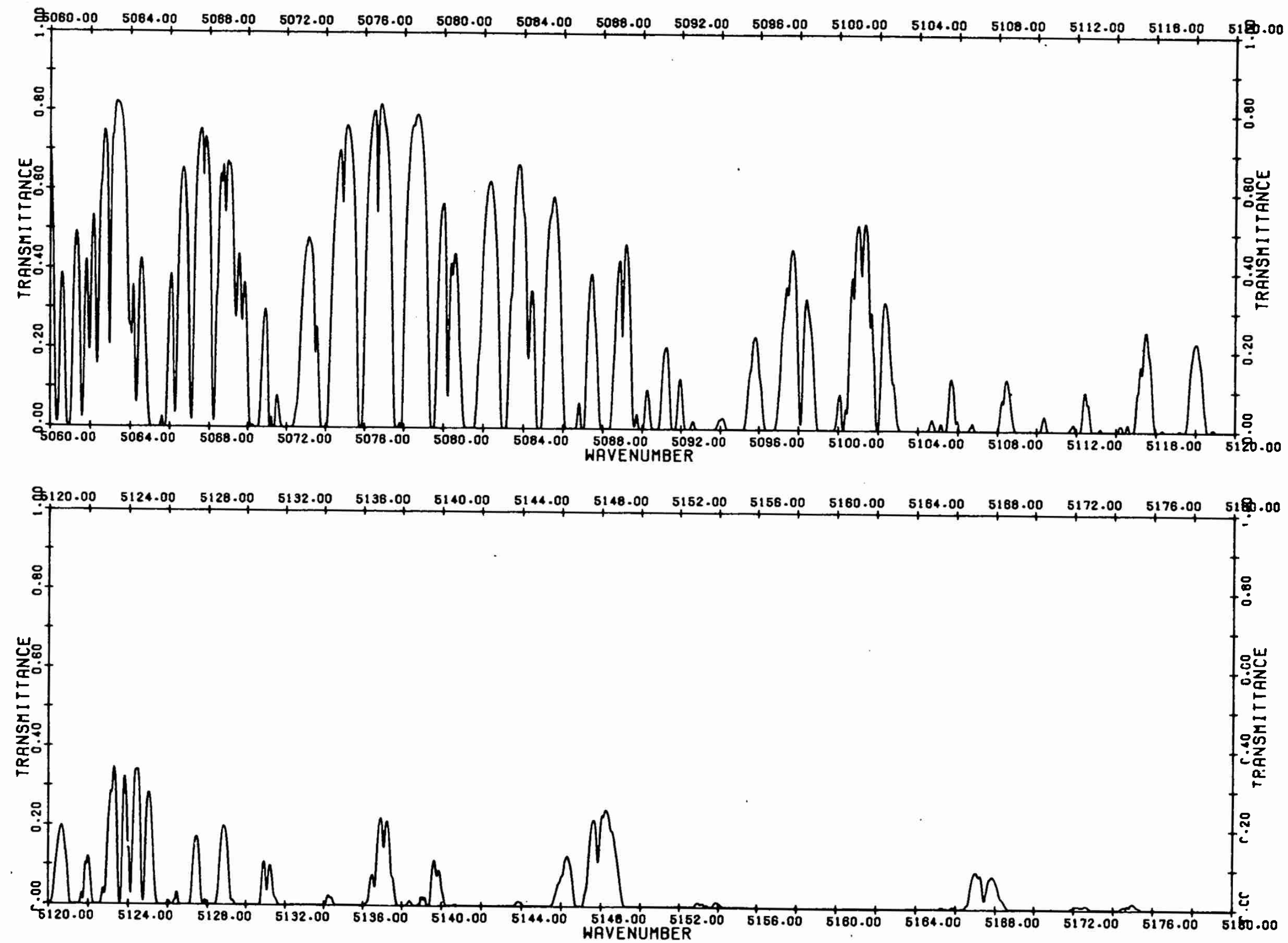


Figure 4ao. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

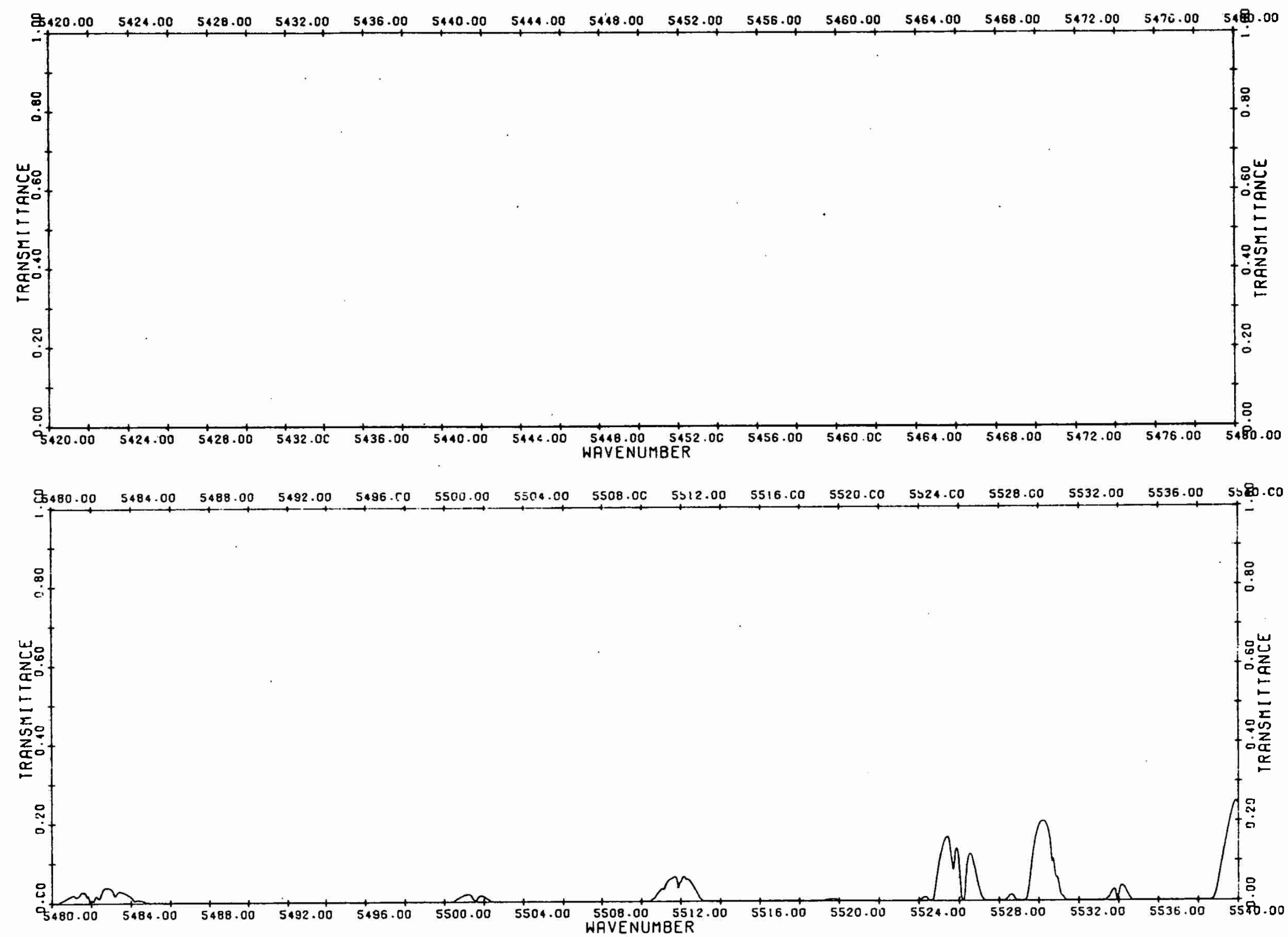


Figure 4ar. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

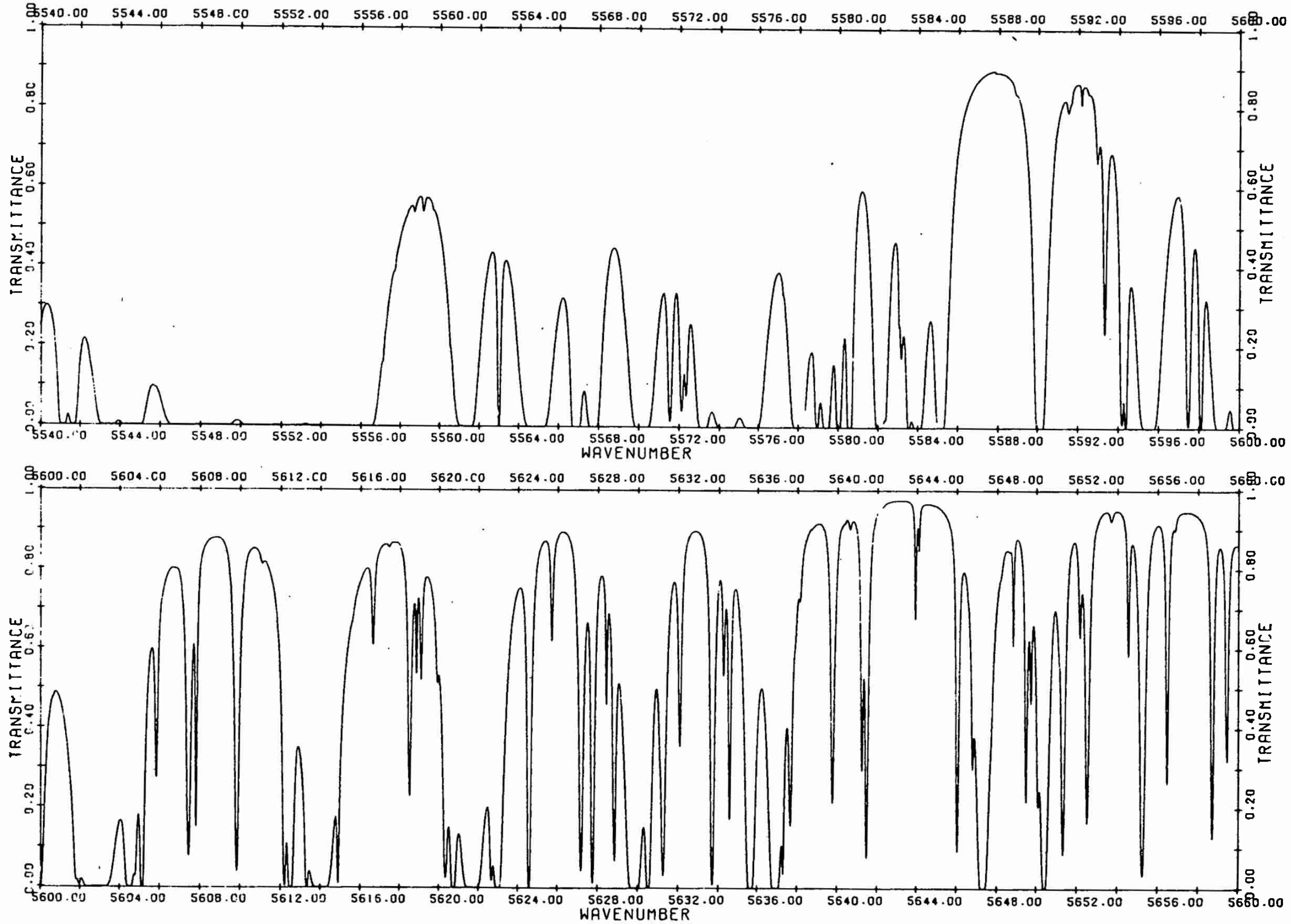


Figure 4as. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

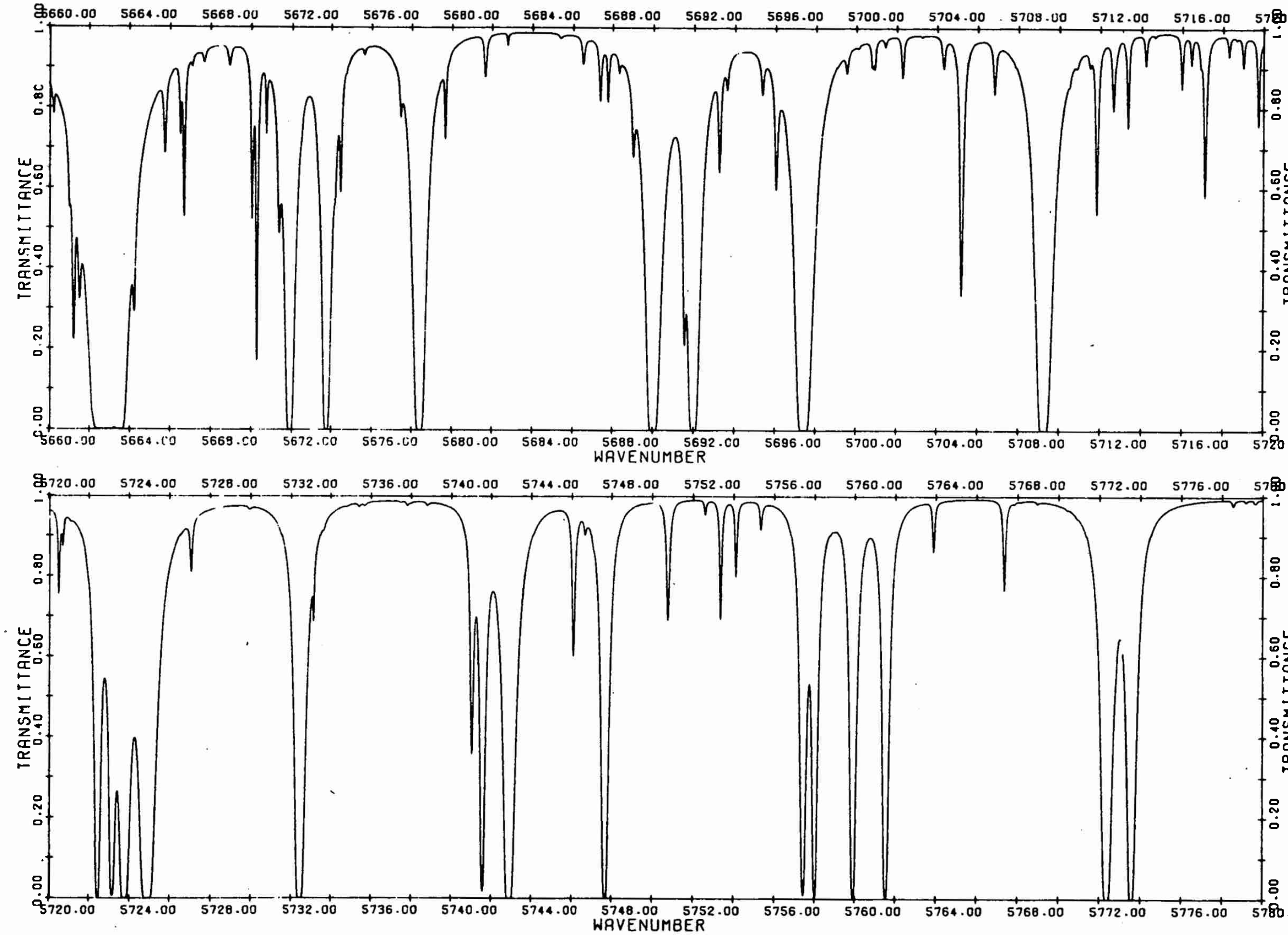


Figure 4at. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

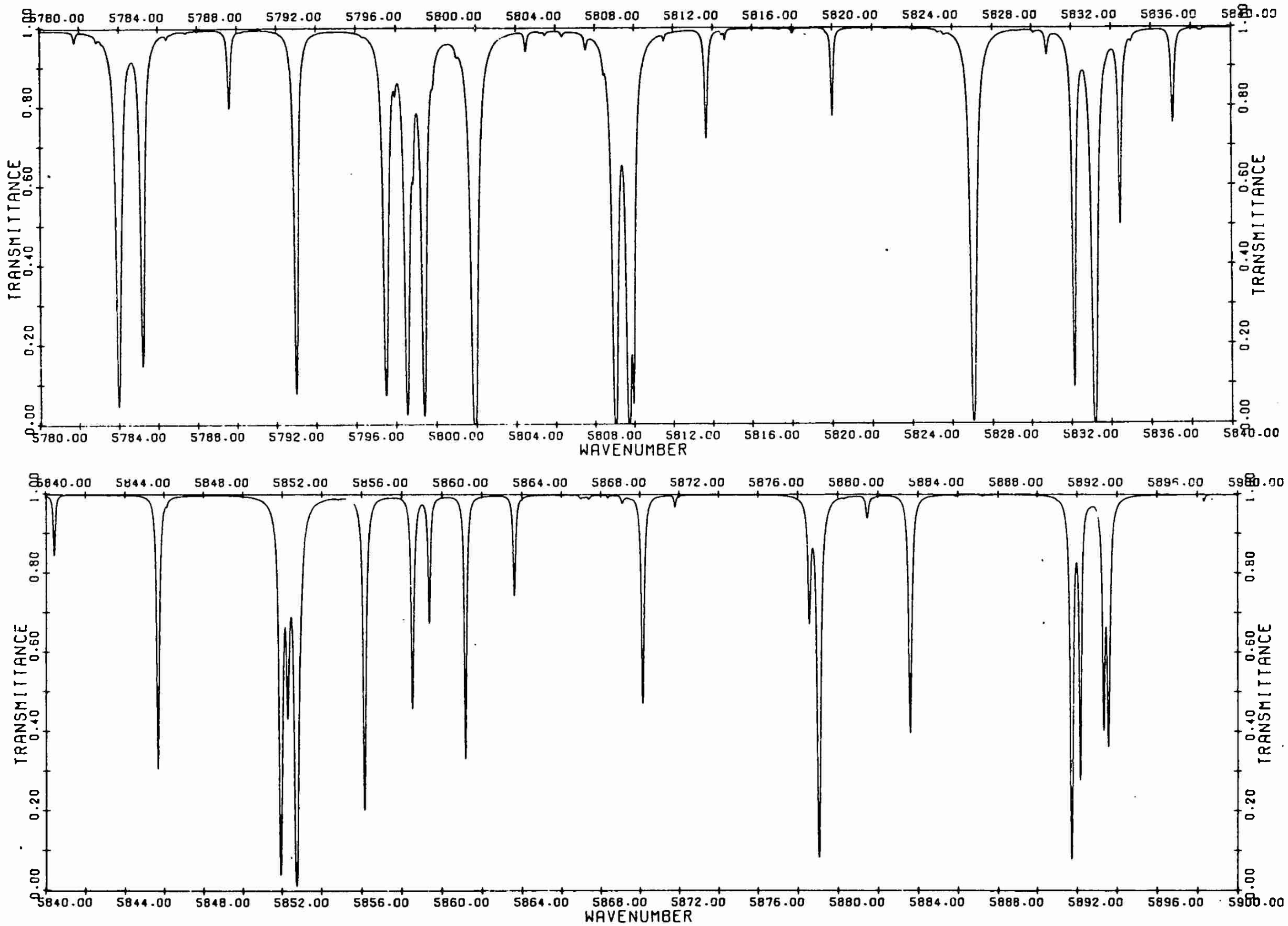


Figure 4au. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

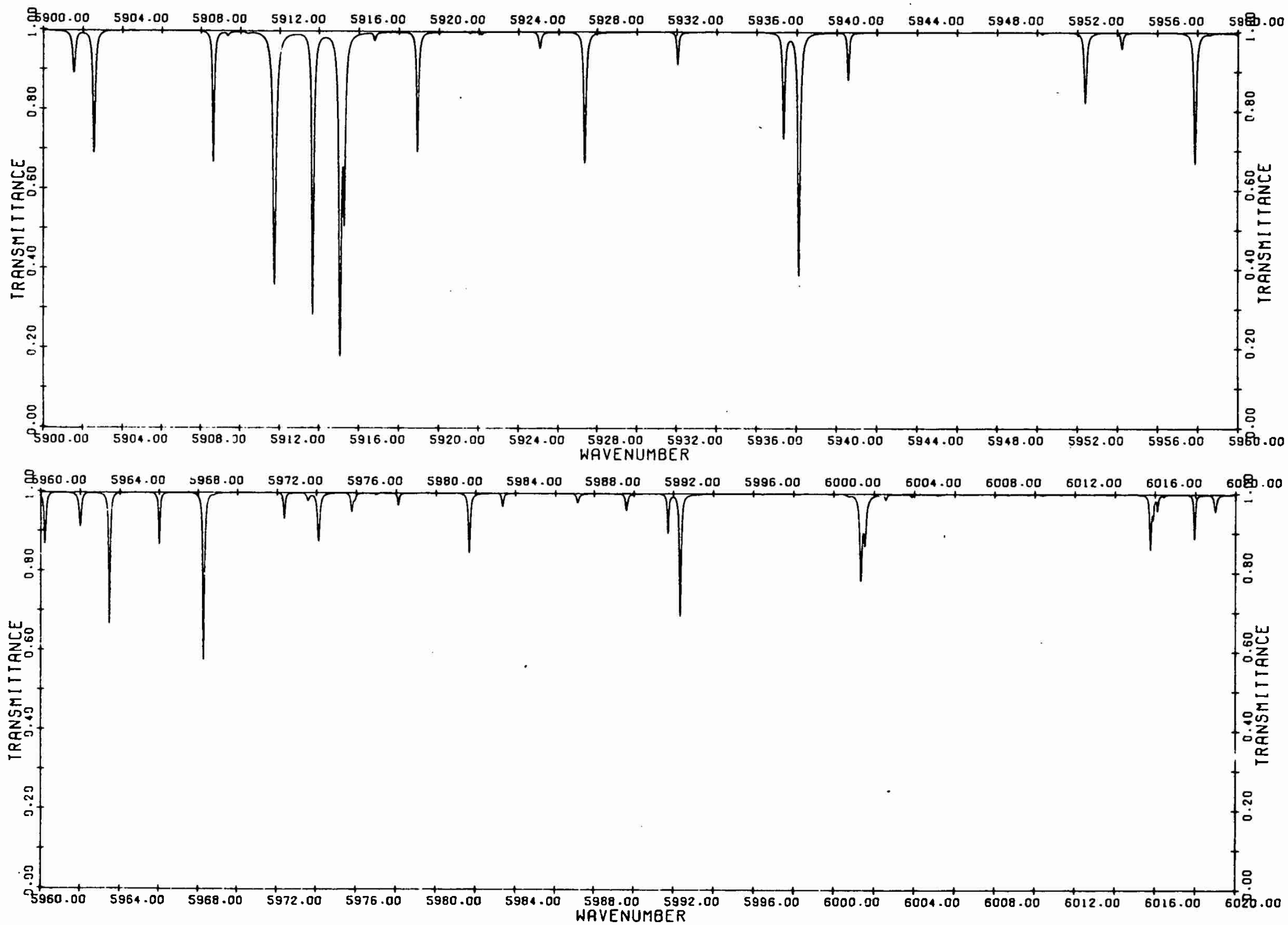


Figure 4av. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

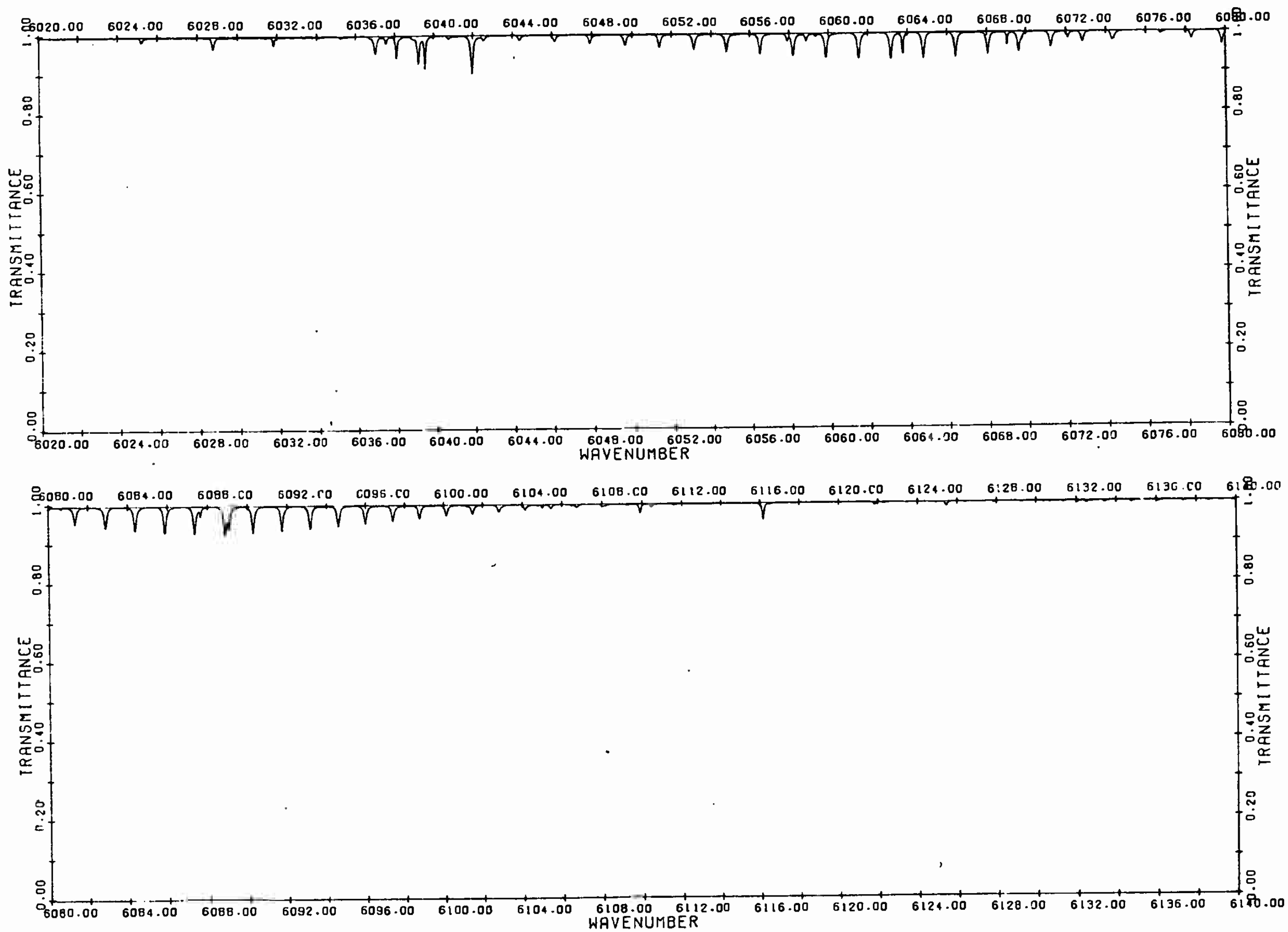


Figure 4aw. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

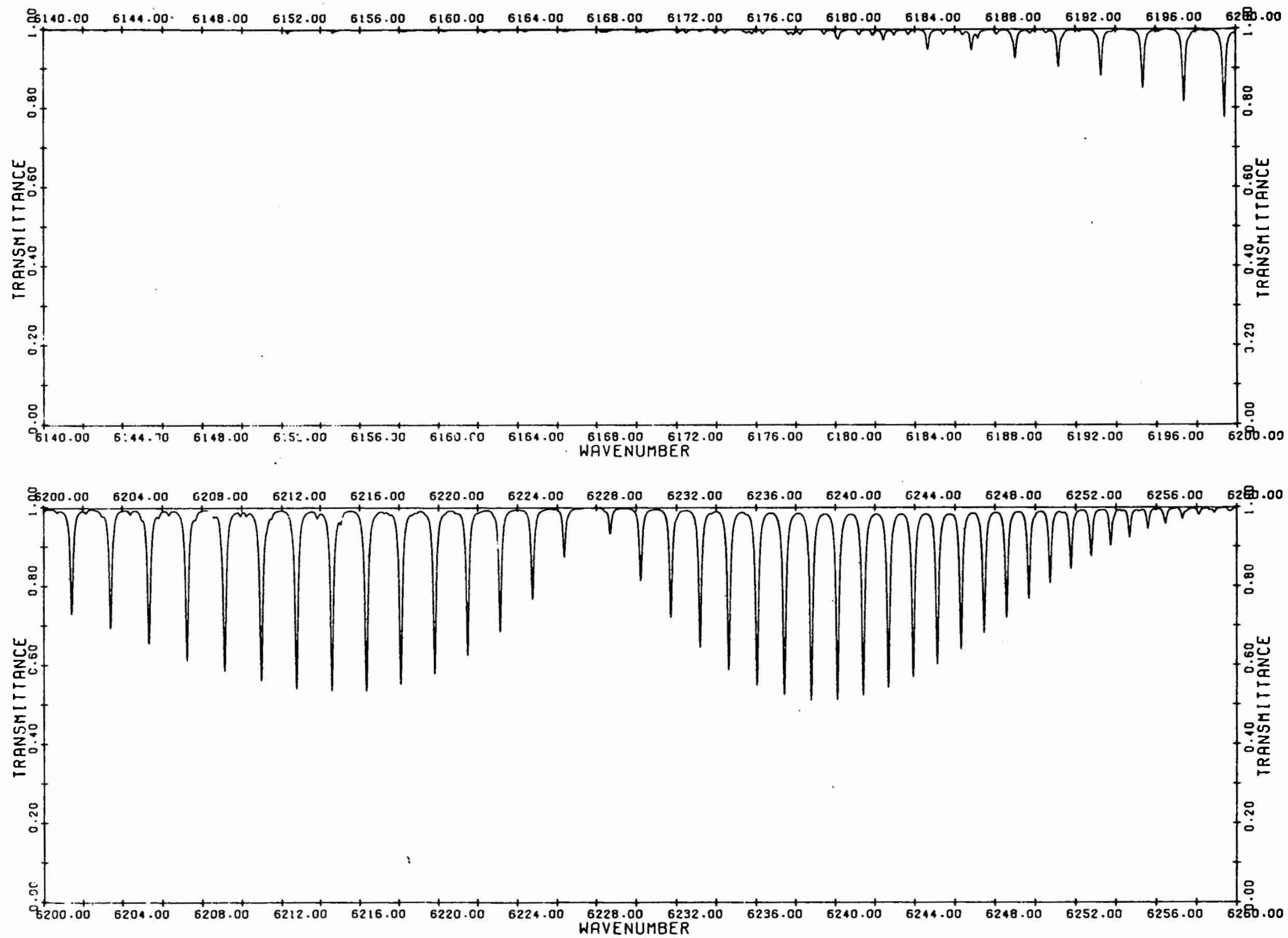


Figure 4ax. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

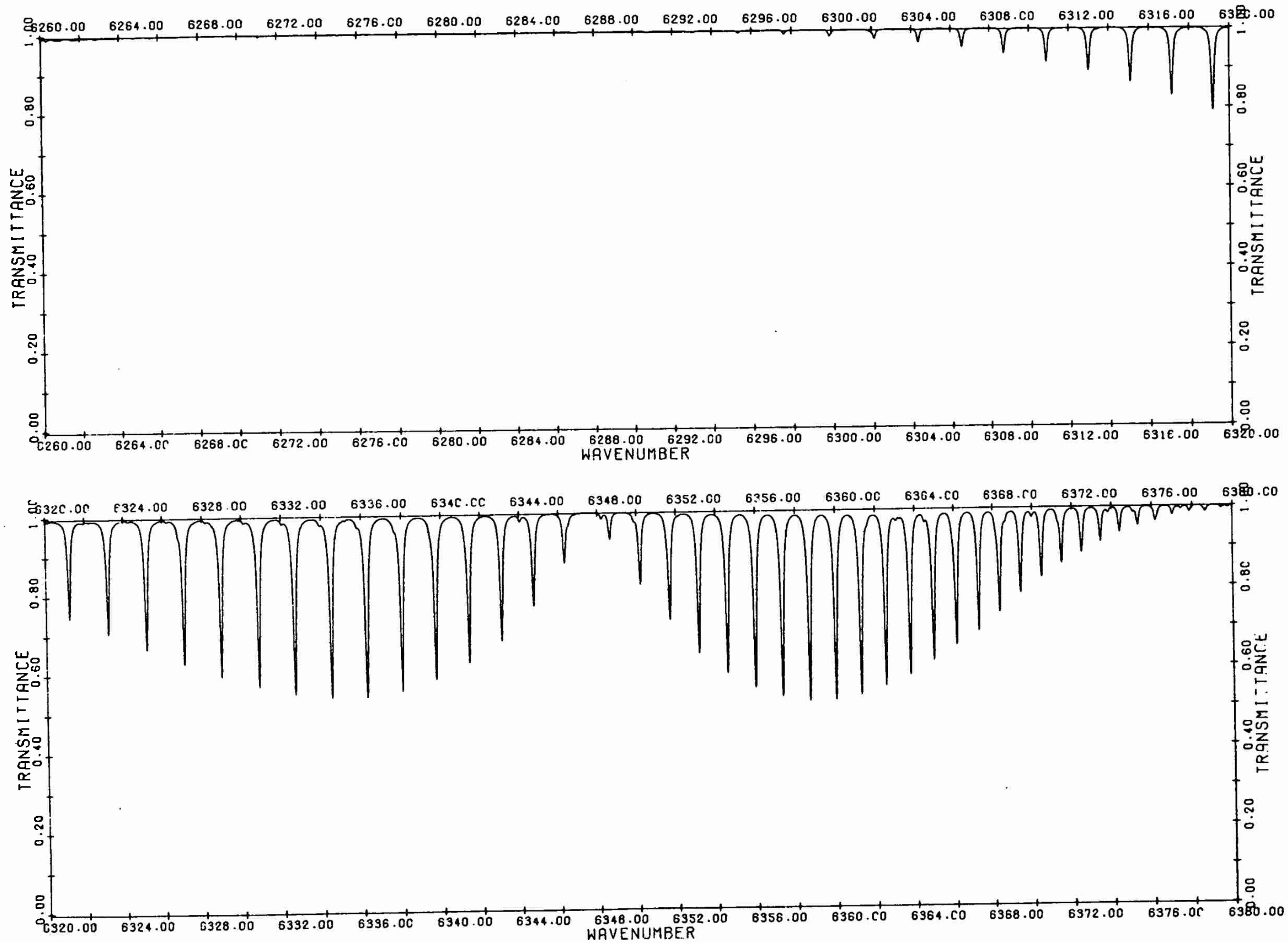


Figure 4ay. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

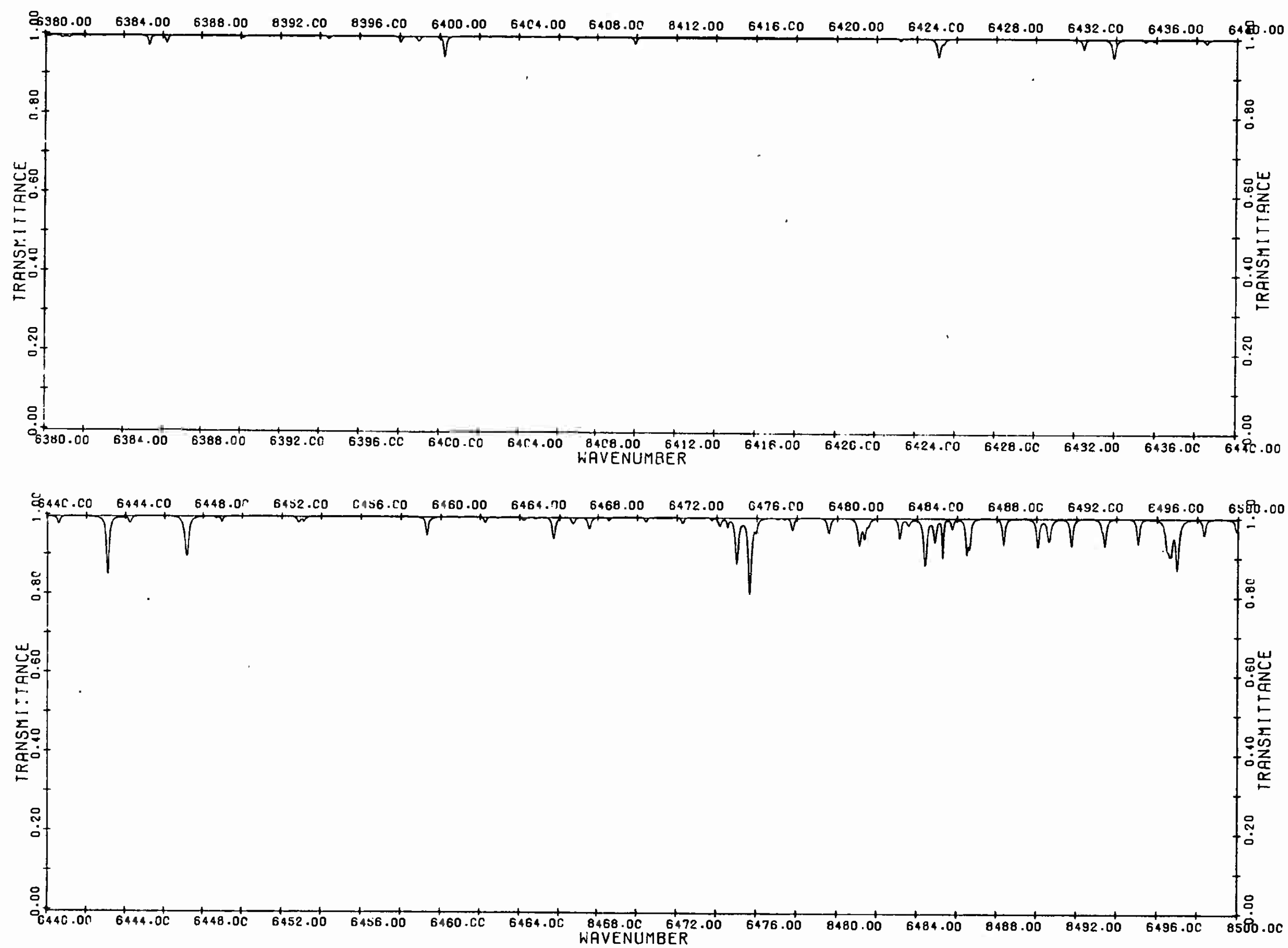


Figure 4az. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level .

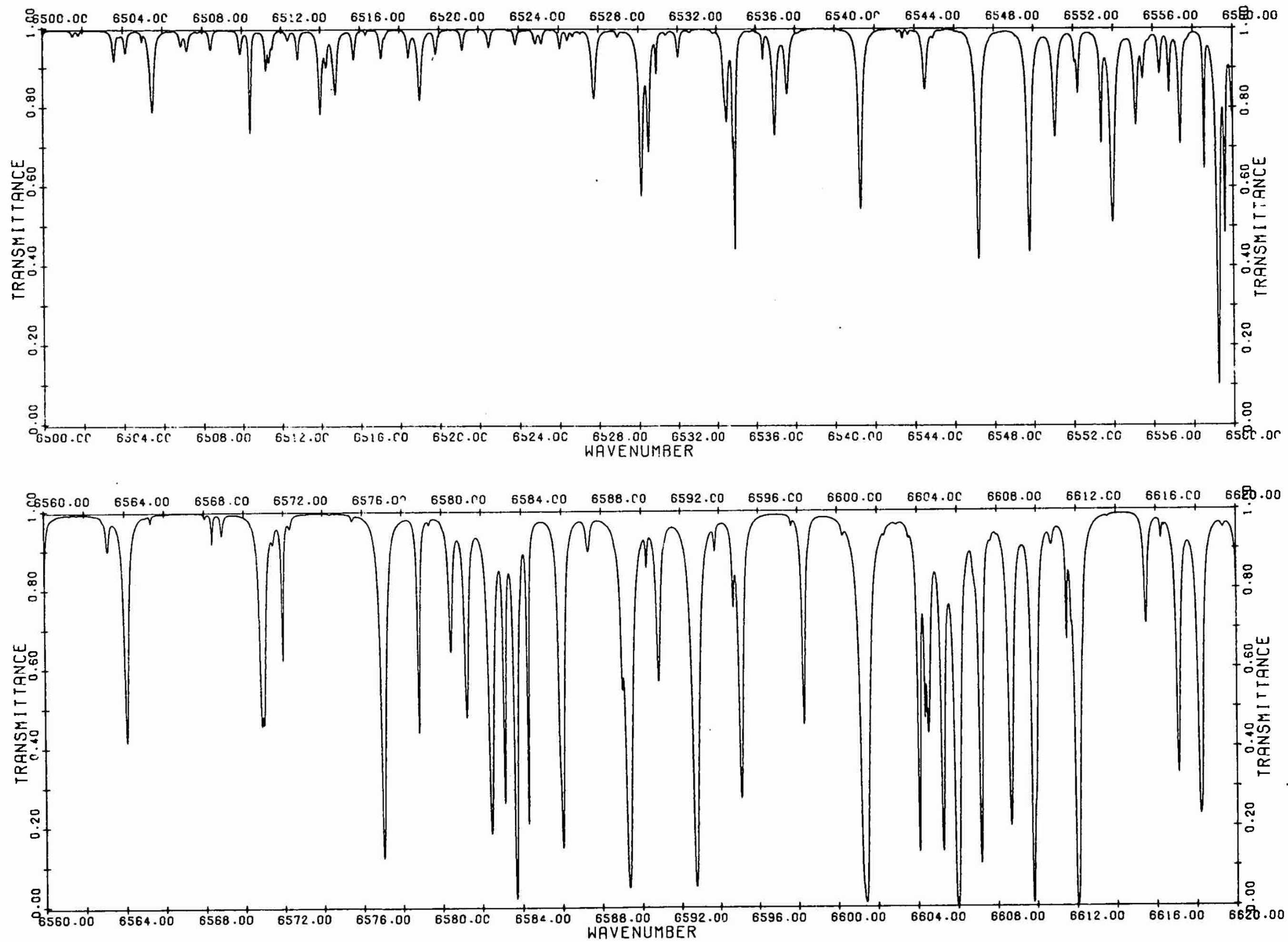


Figure 4ba. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

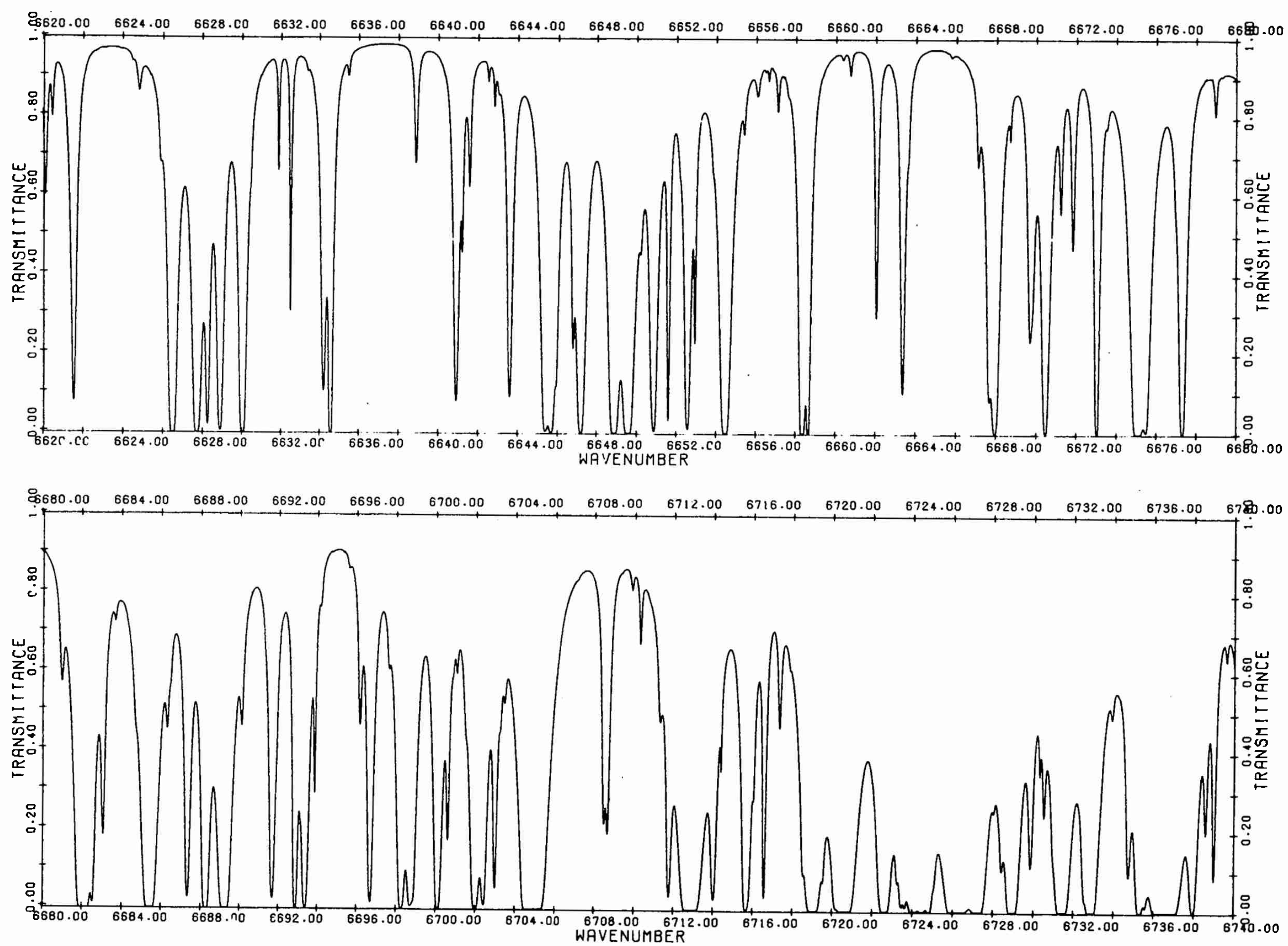


Figure 4bb. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

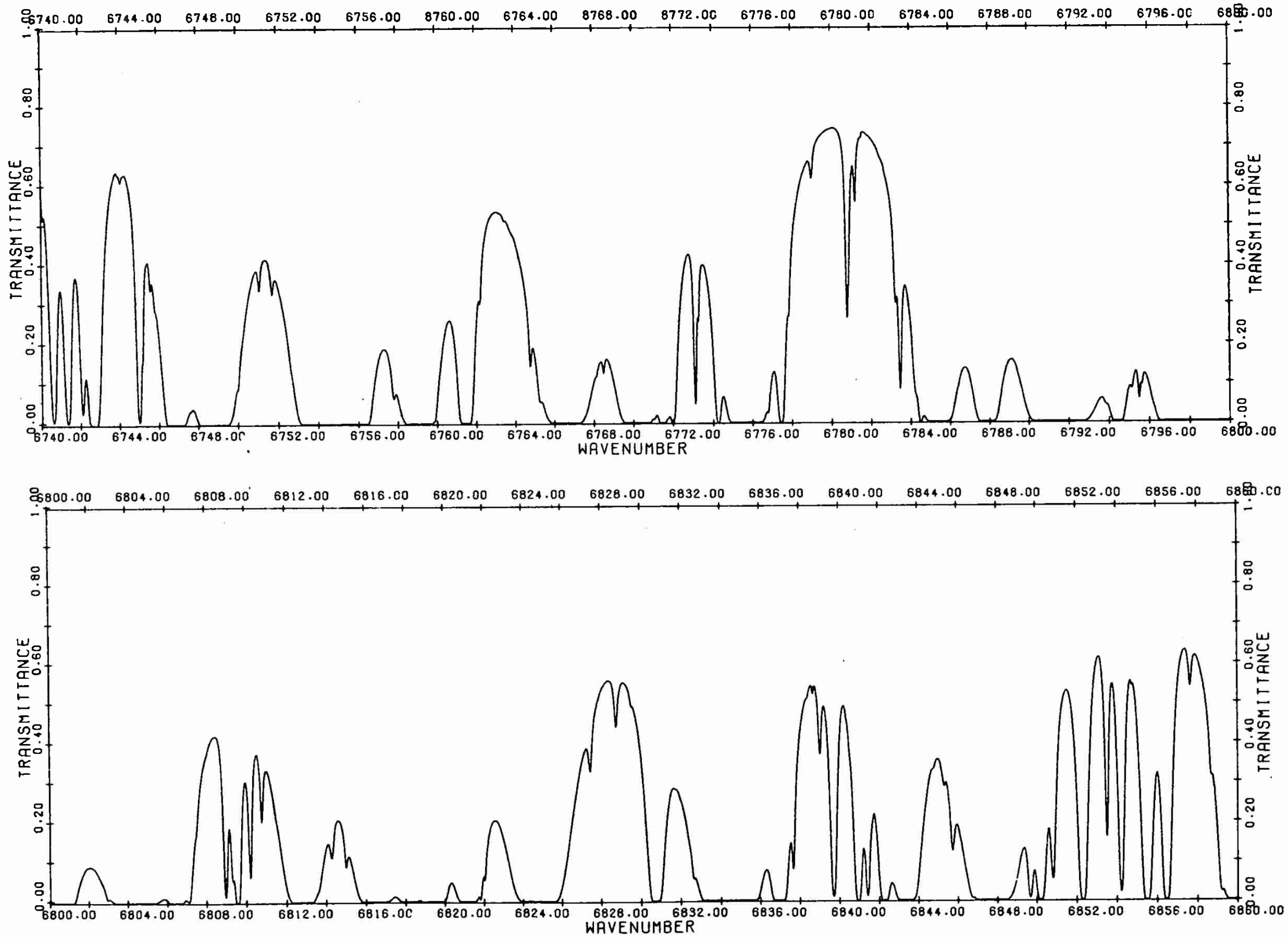


Figure 4bc. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

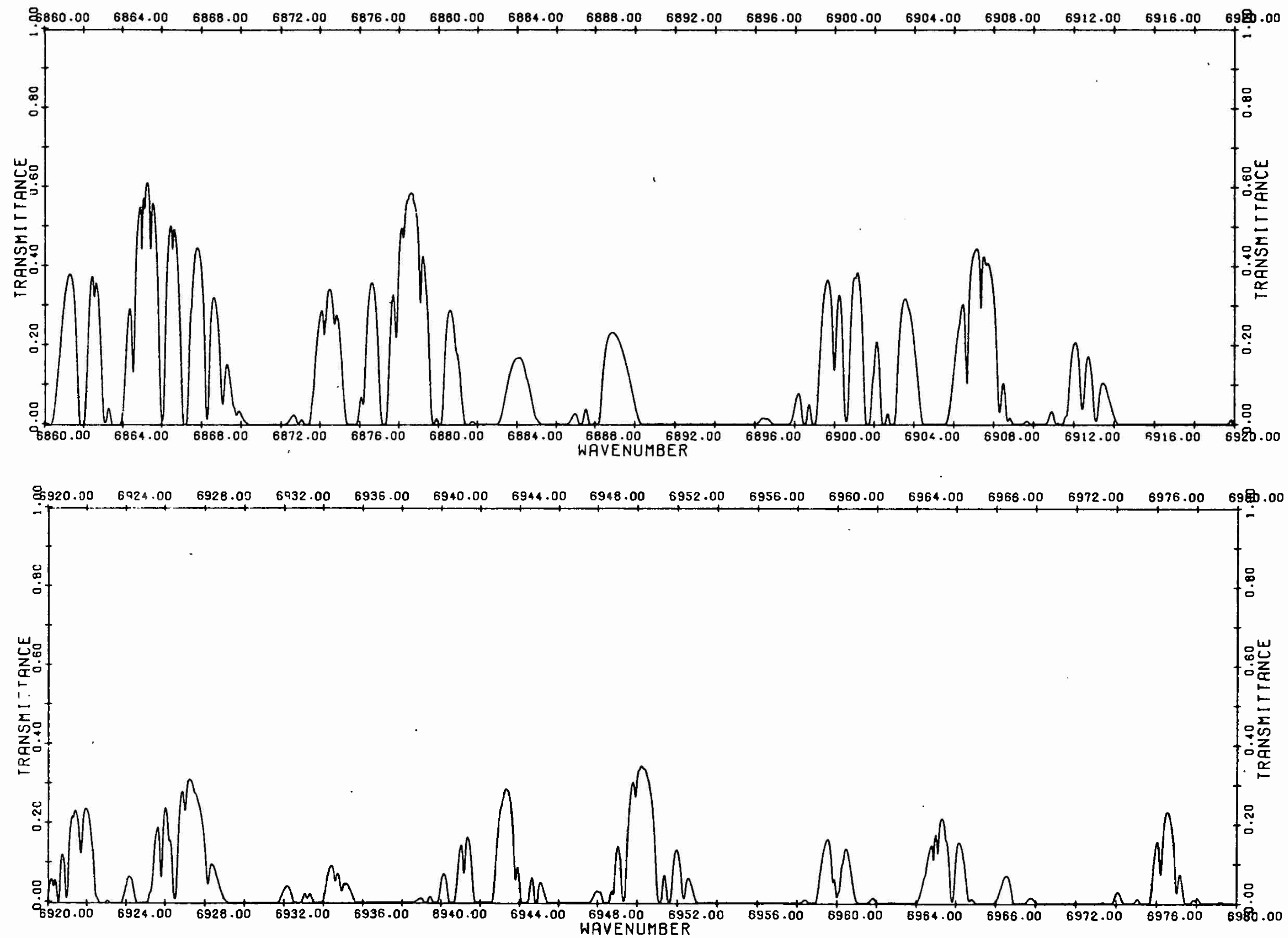


Figure 4bd. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

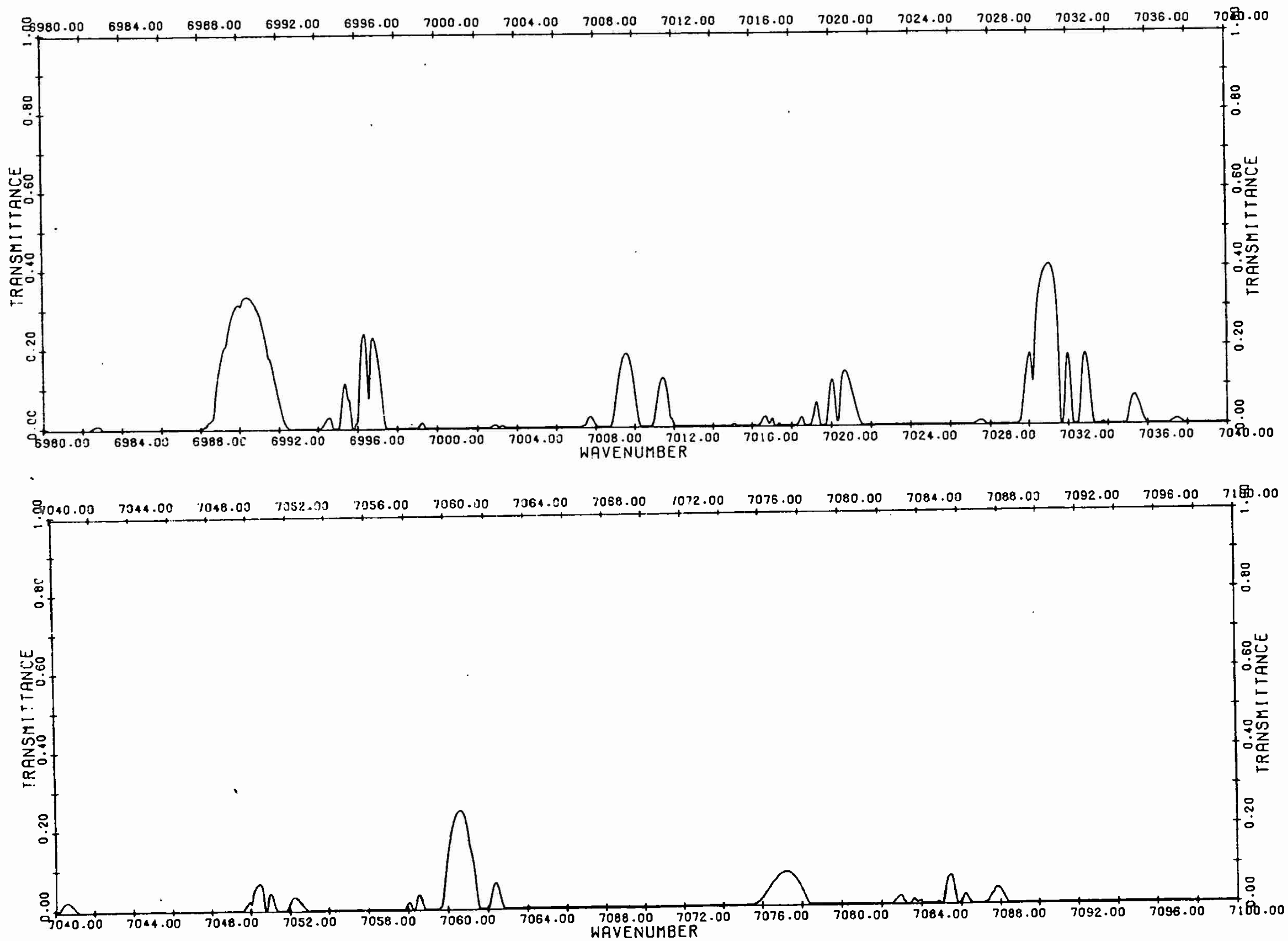


Figure 4be. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

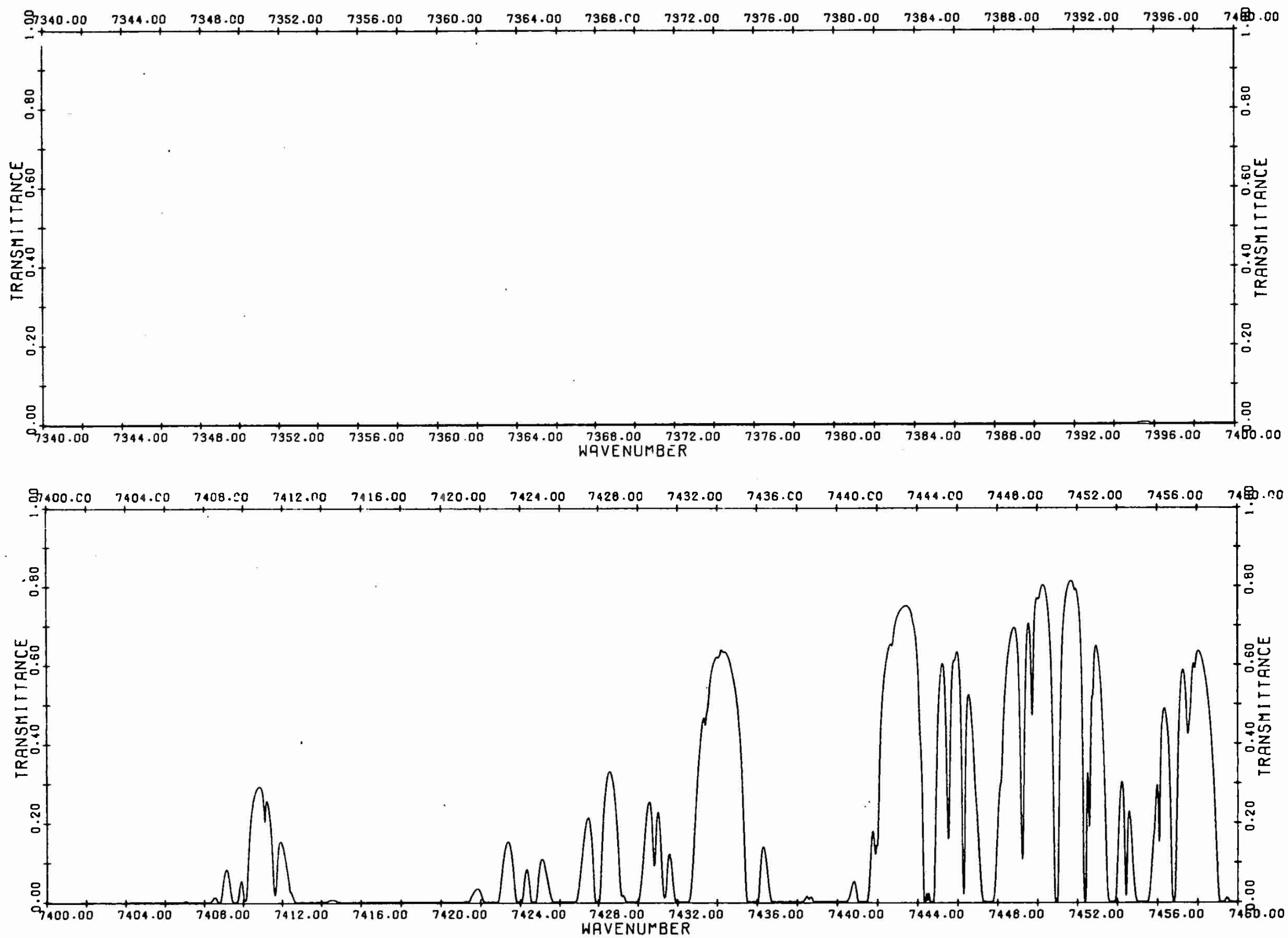


Figure 4bh. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

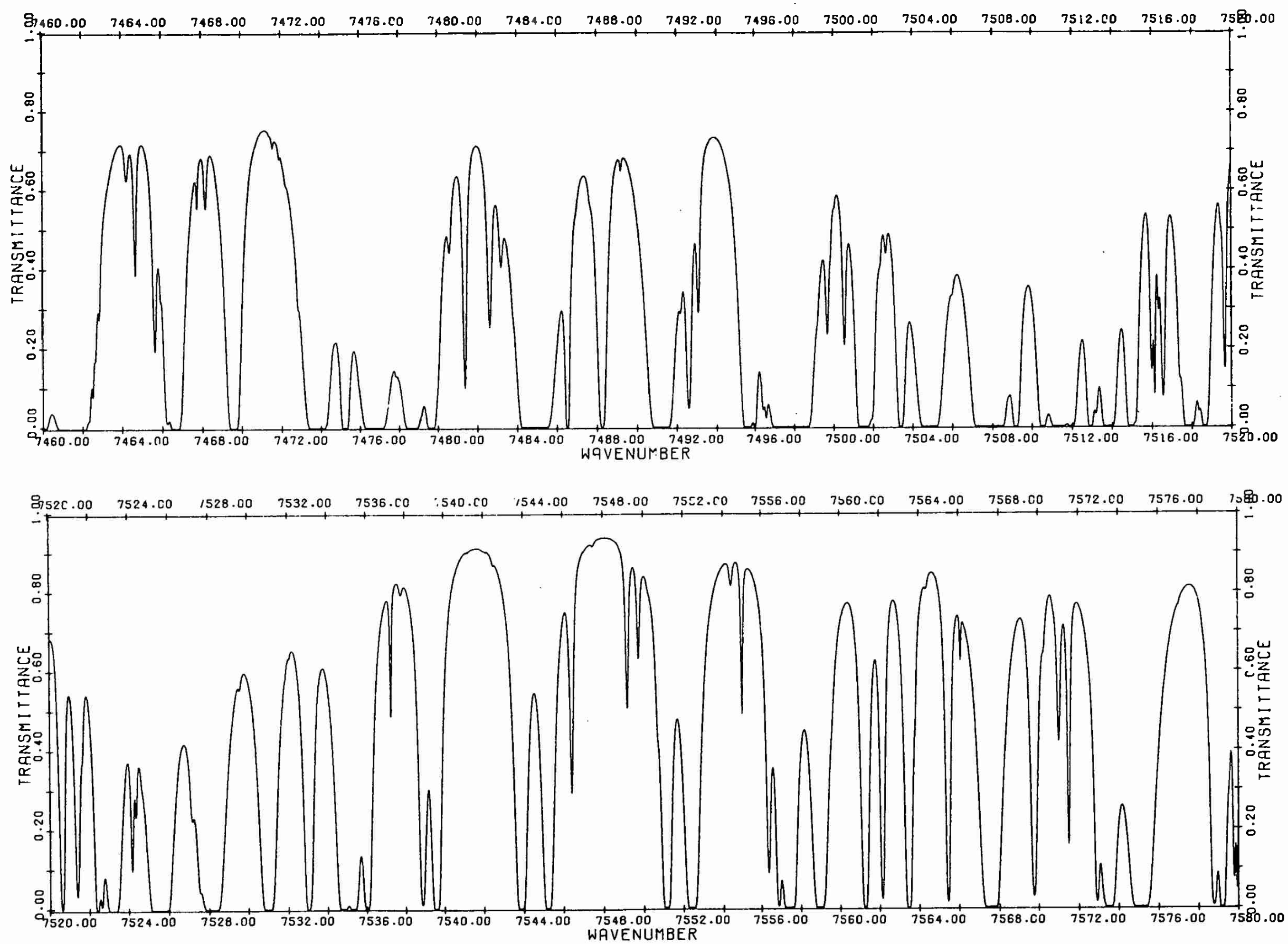


Figure 4bi. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

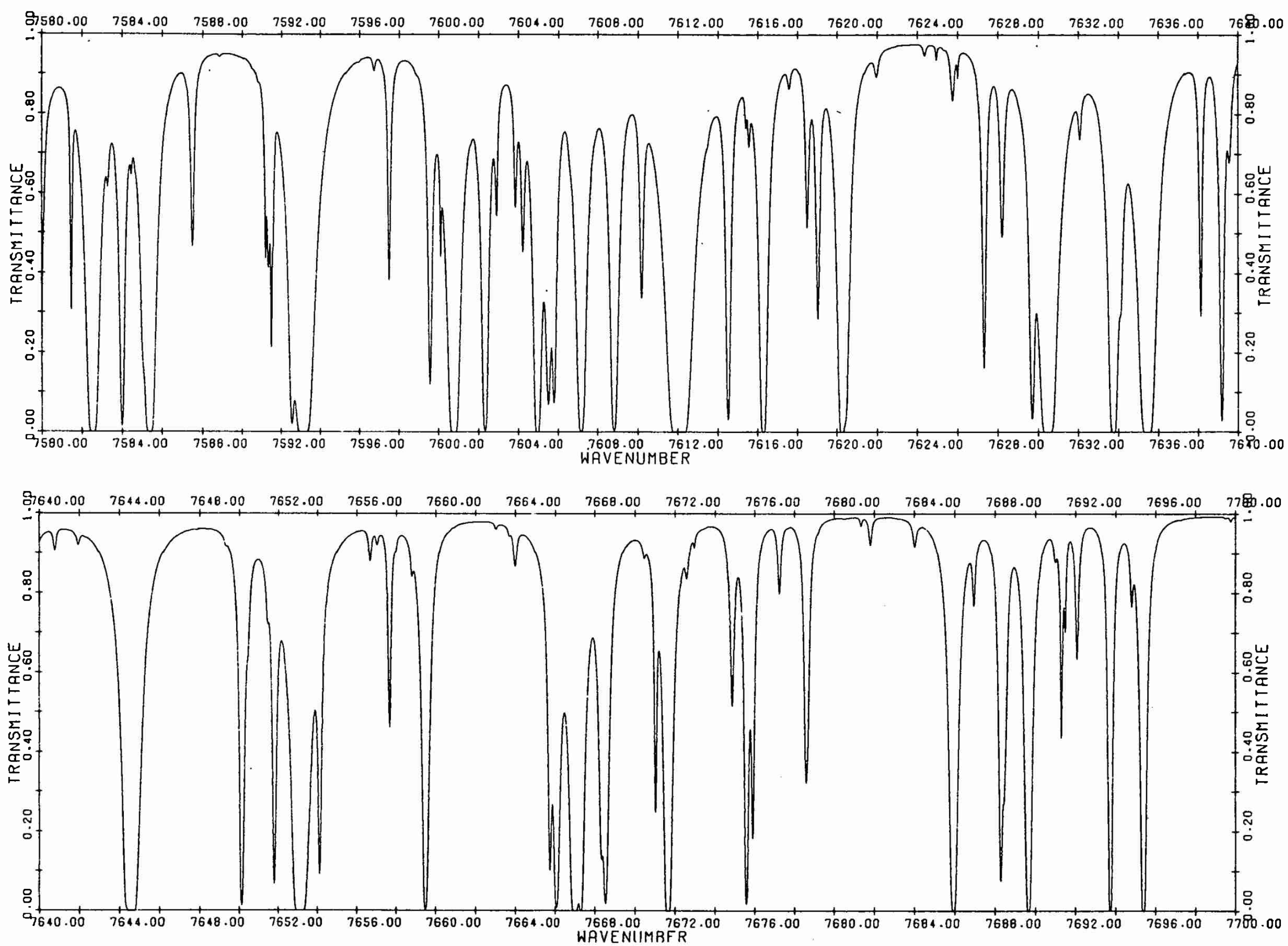


Figure 4bj. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

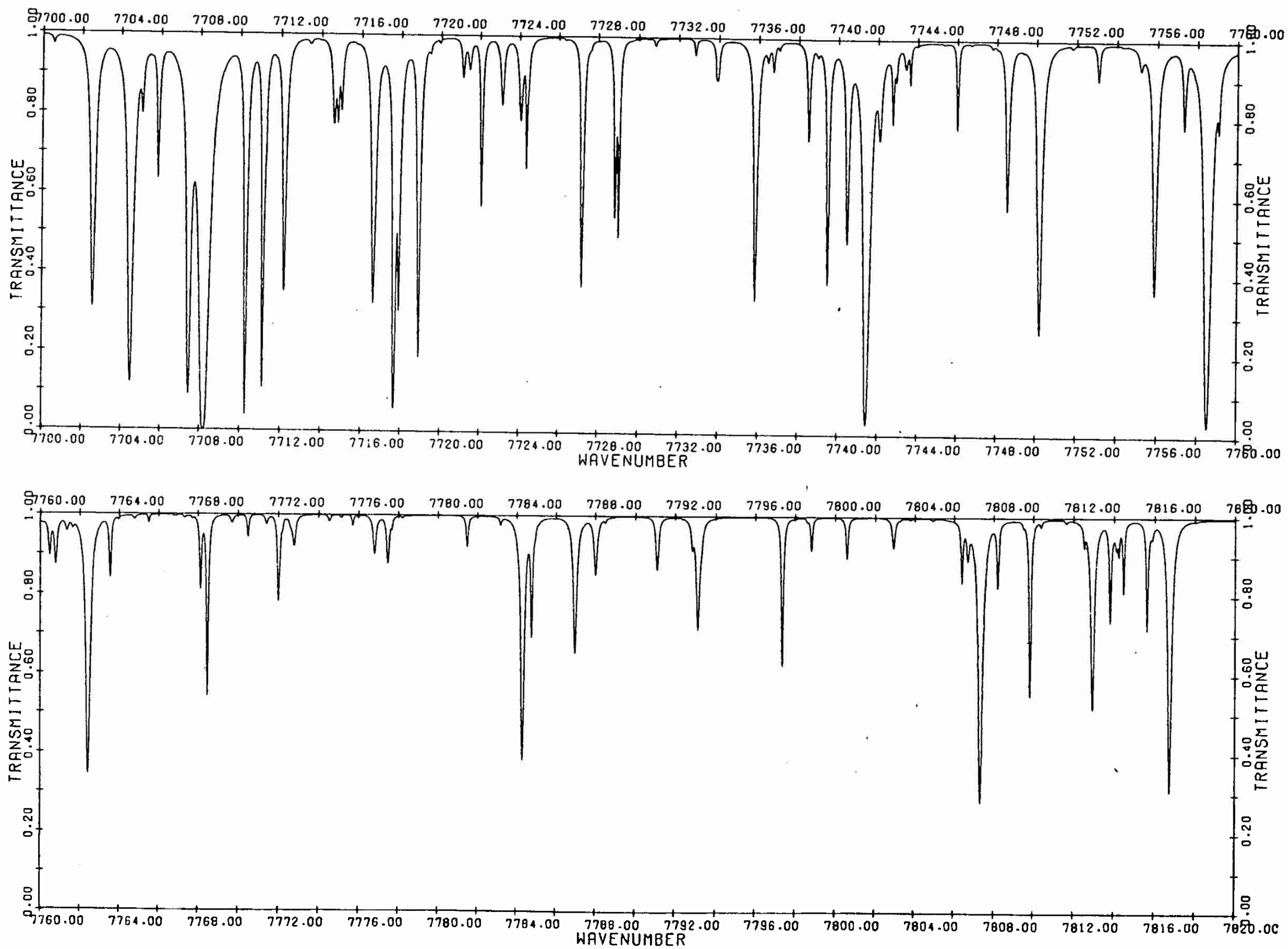


Figure 4bk. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

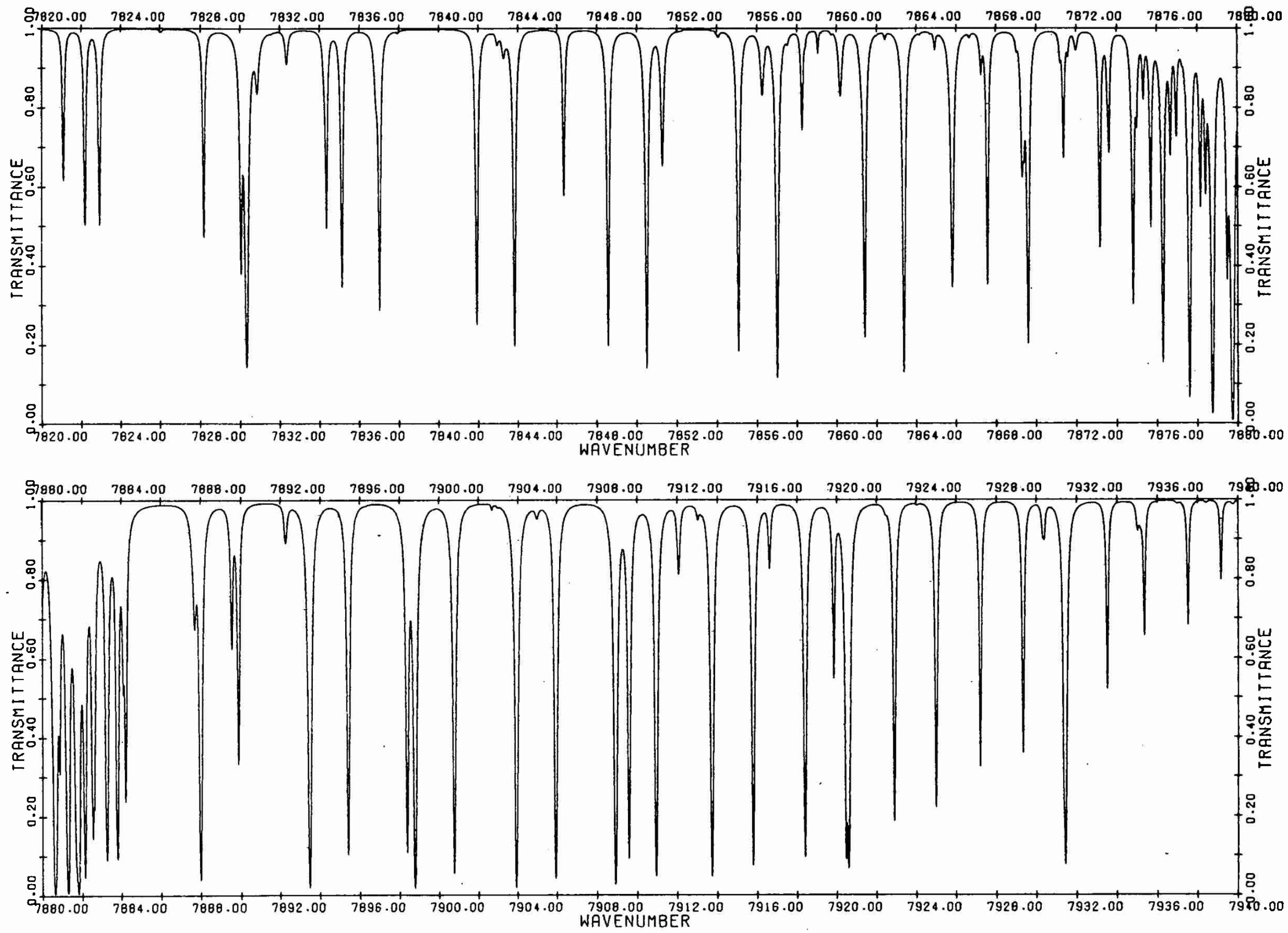


Figure 4bl. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

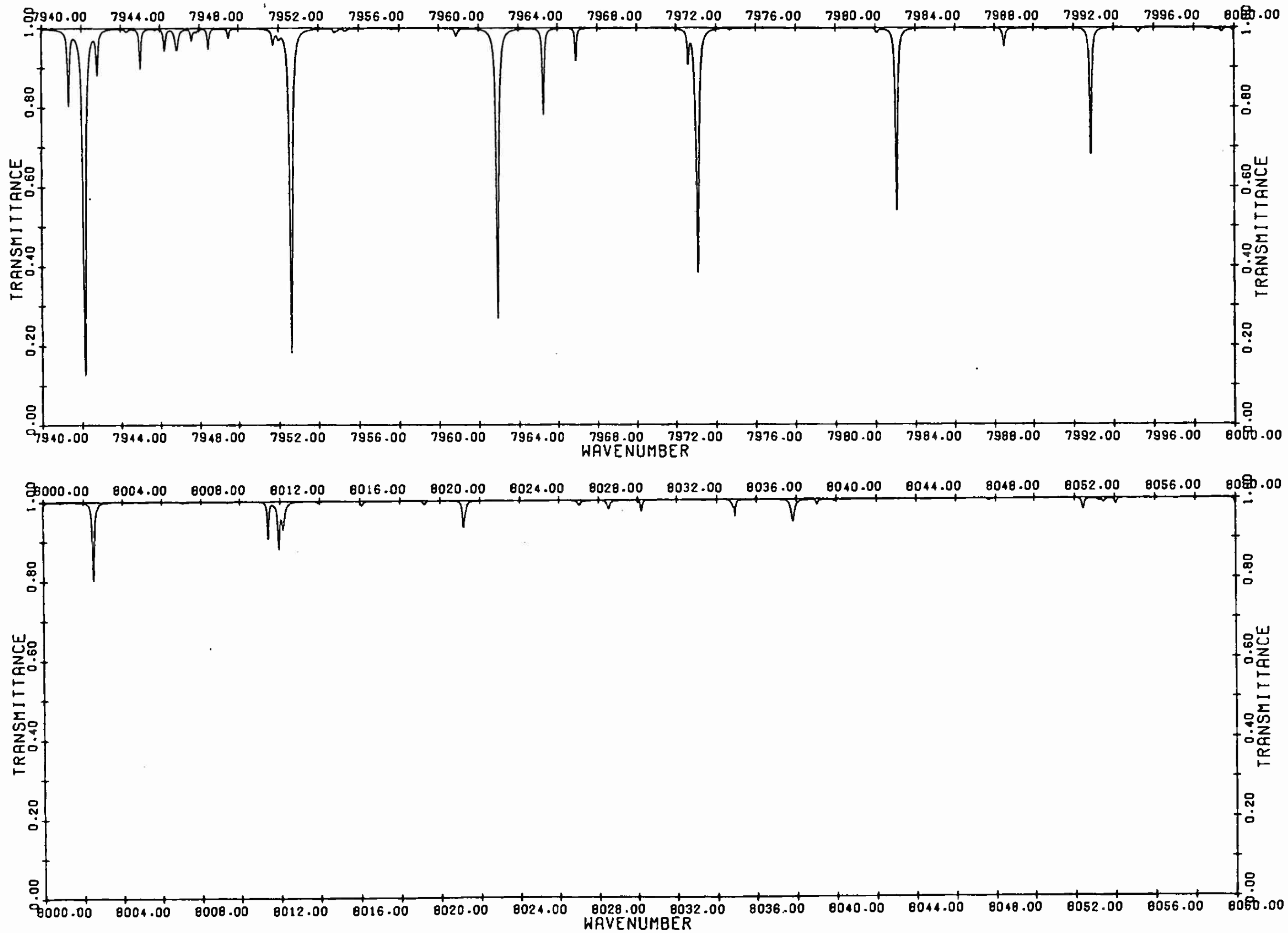


Figure 4bm. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

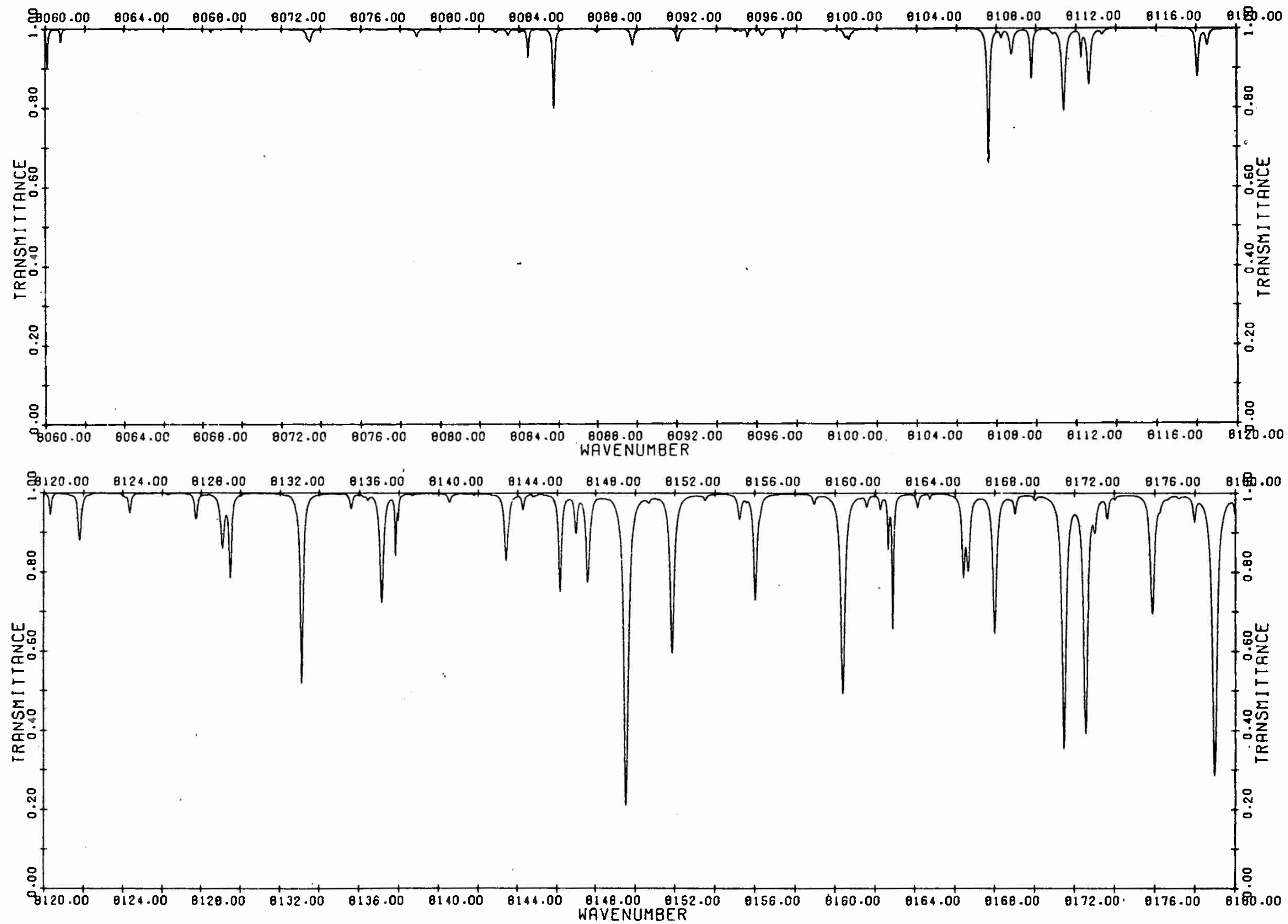


Figure 4bn. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

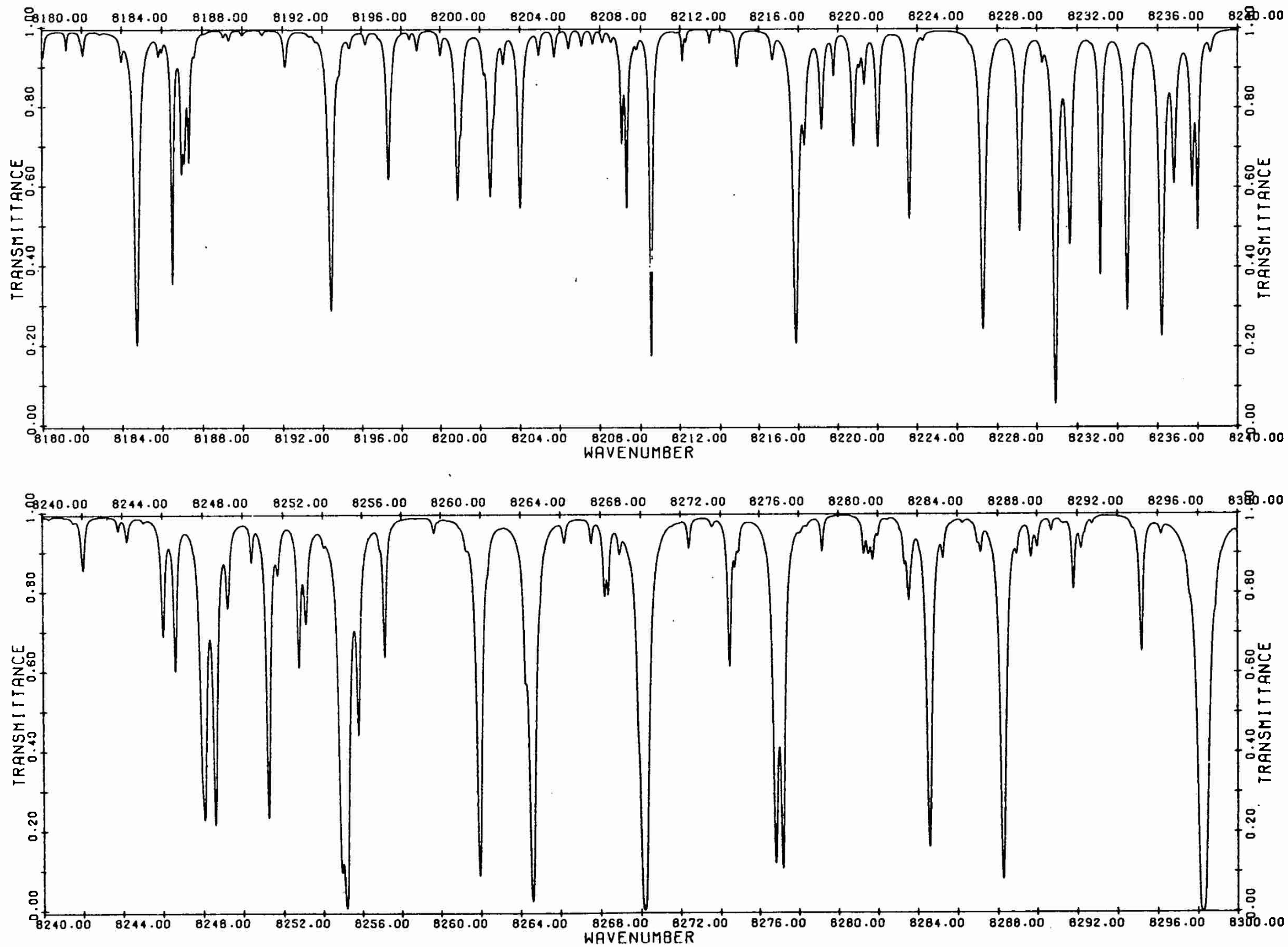


Figure 4bo. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

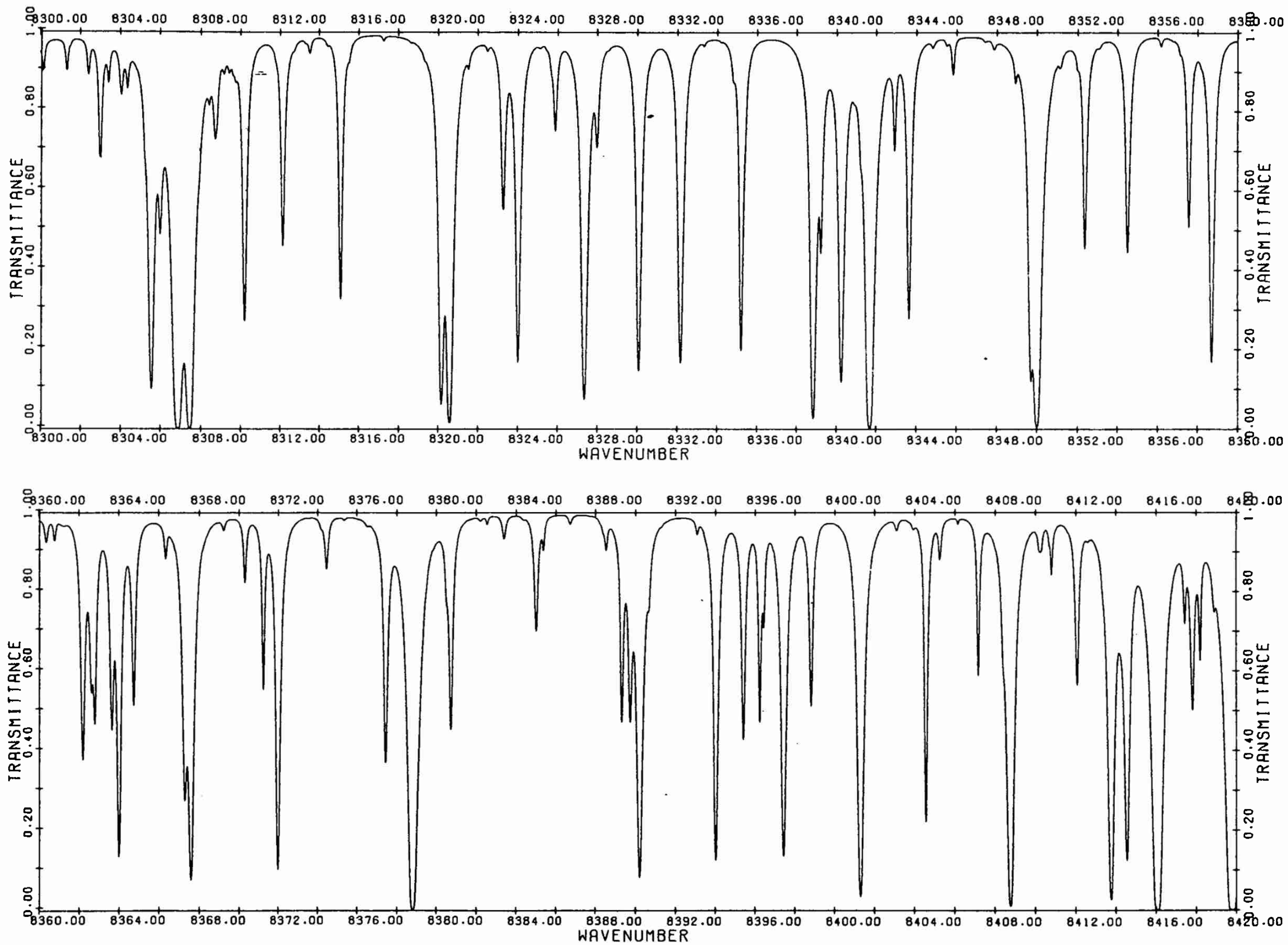


Figure 4bp. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

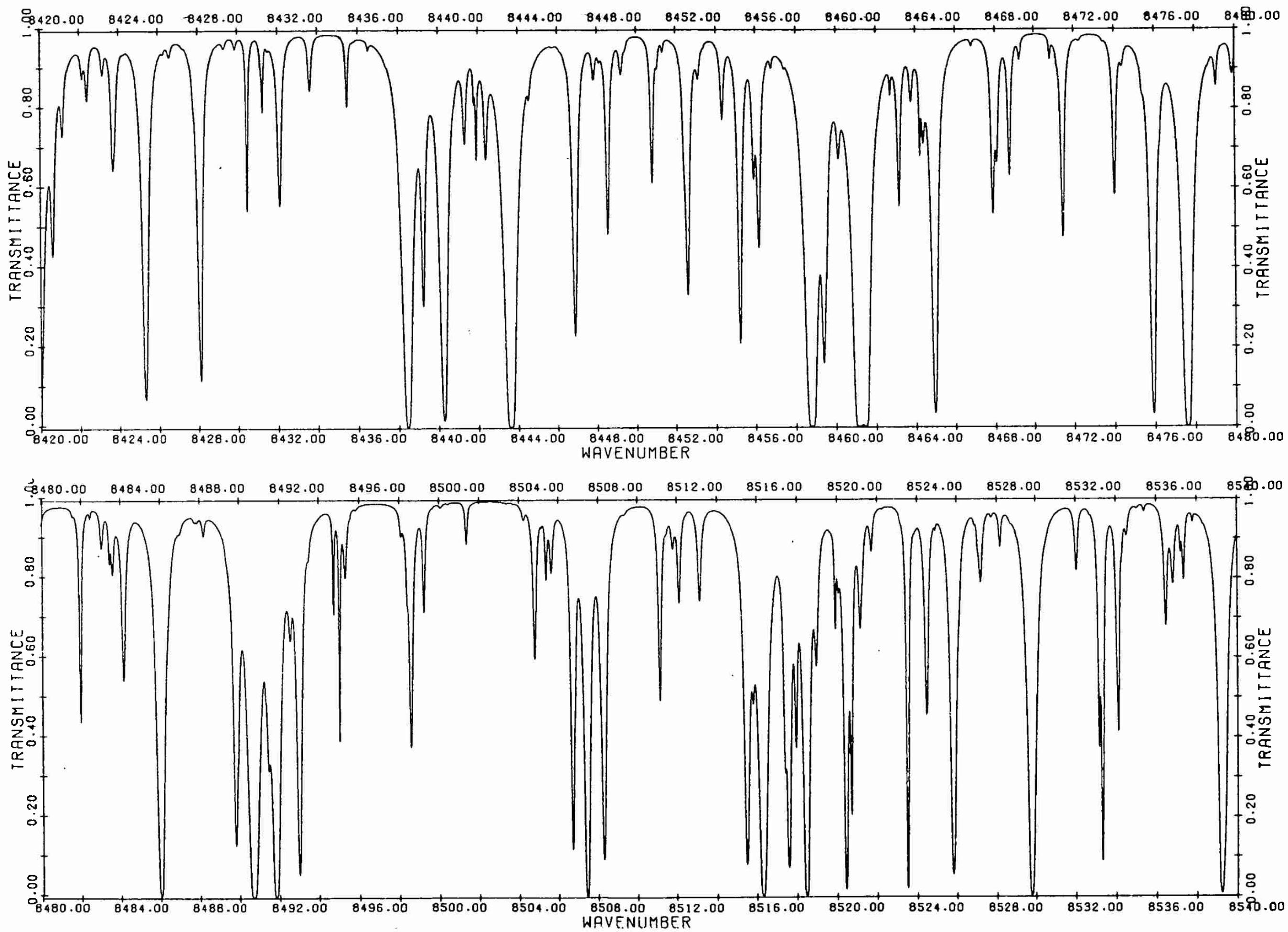


Figure 4bq. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

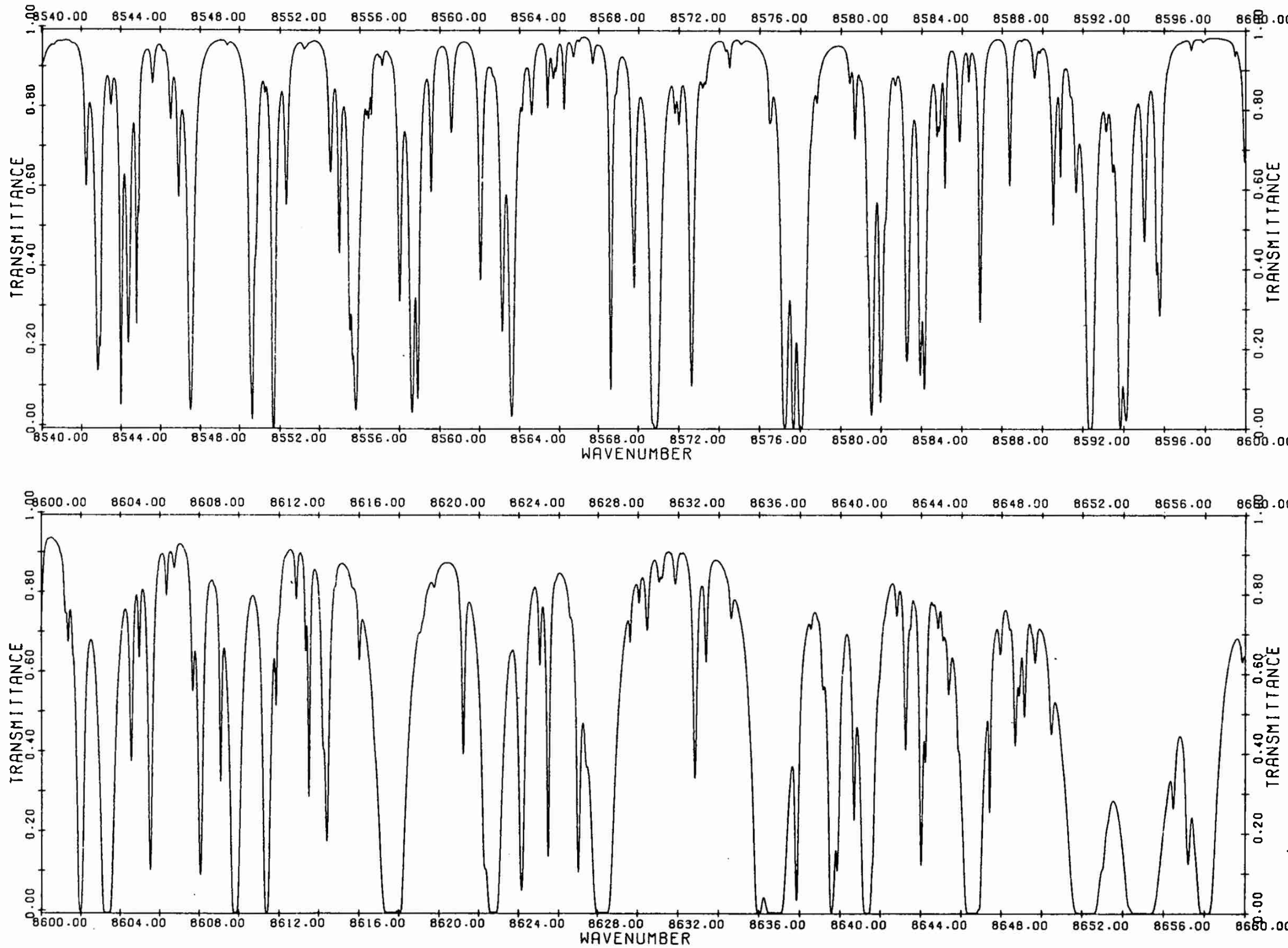


Figure 4br. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

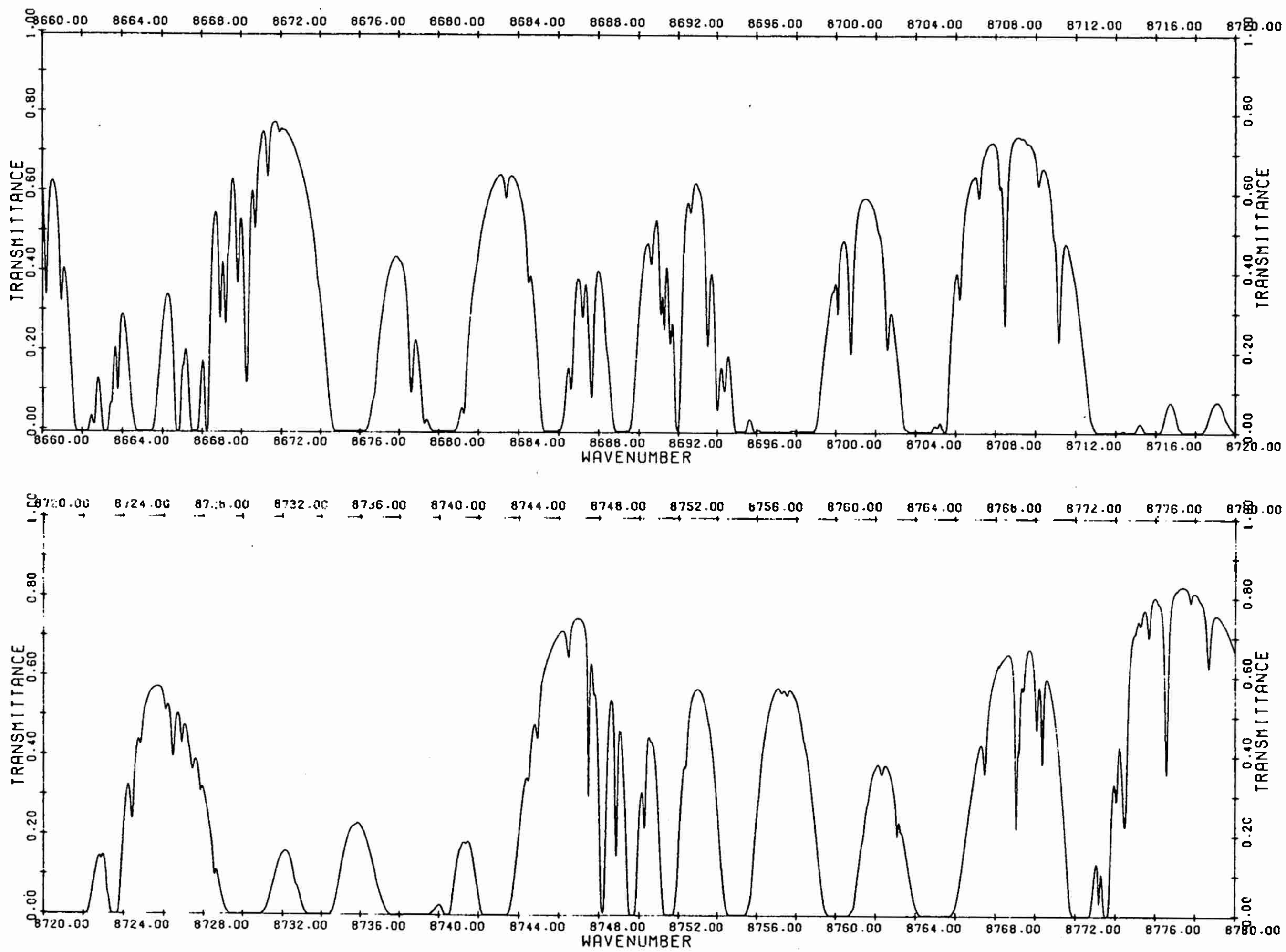


Figure 4bs. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

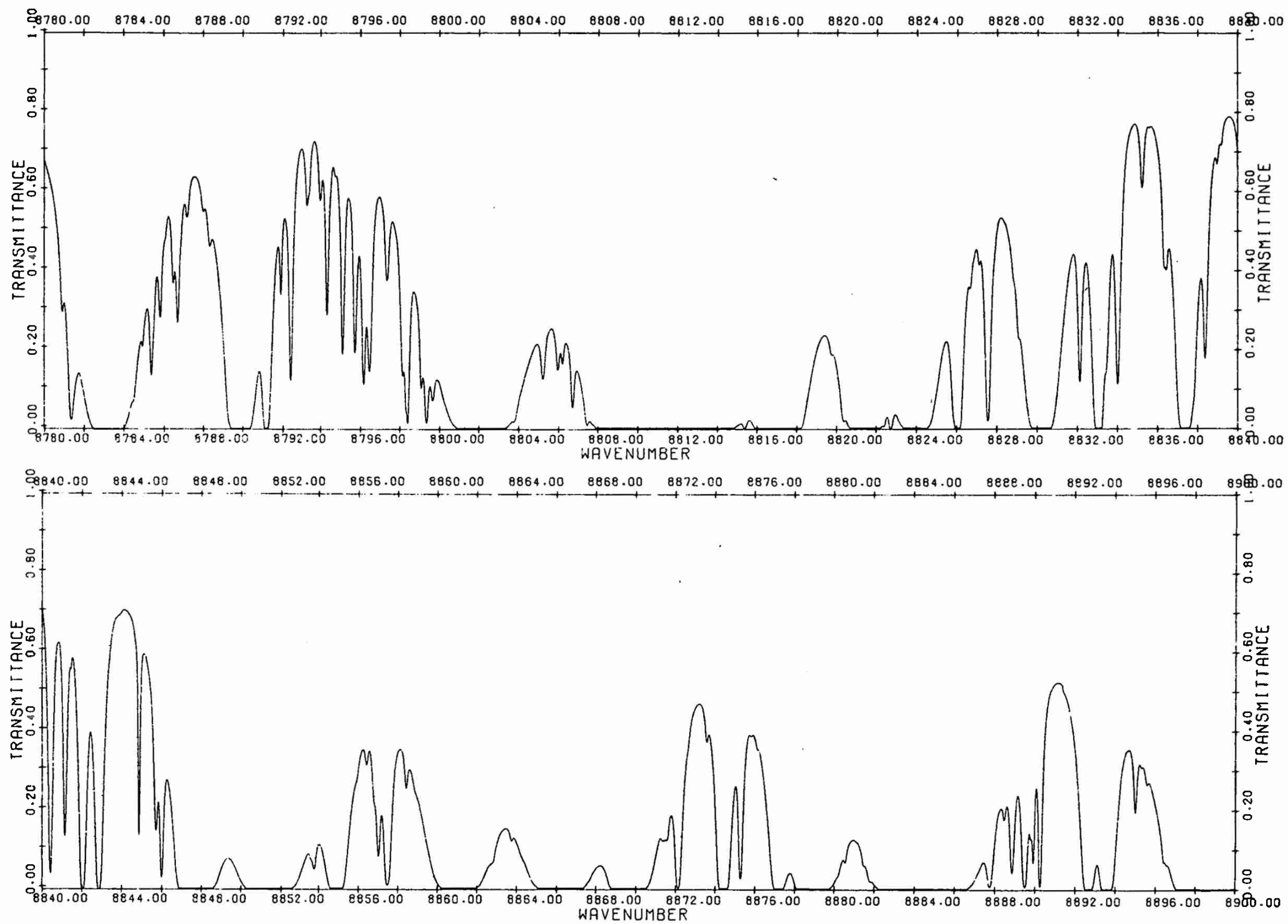


Figure 4bt. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

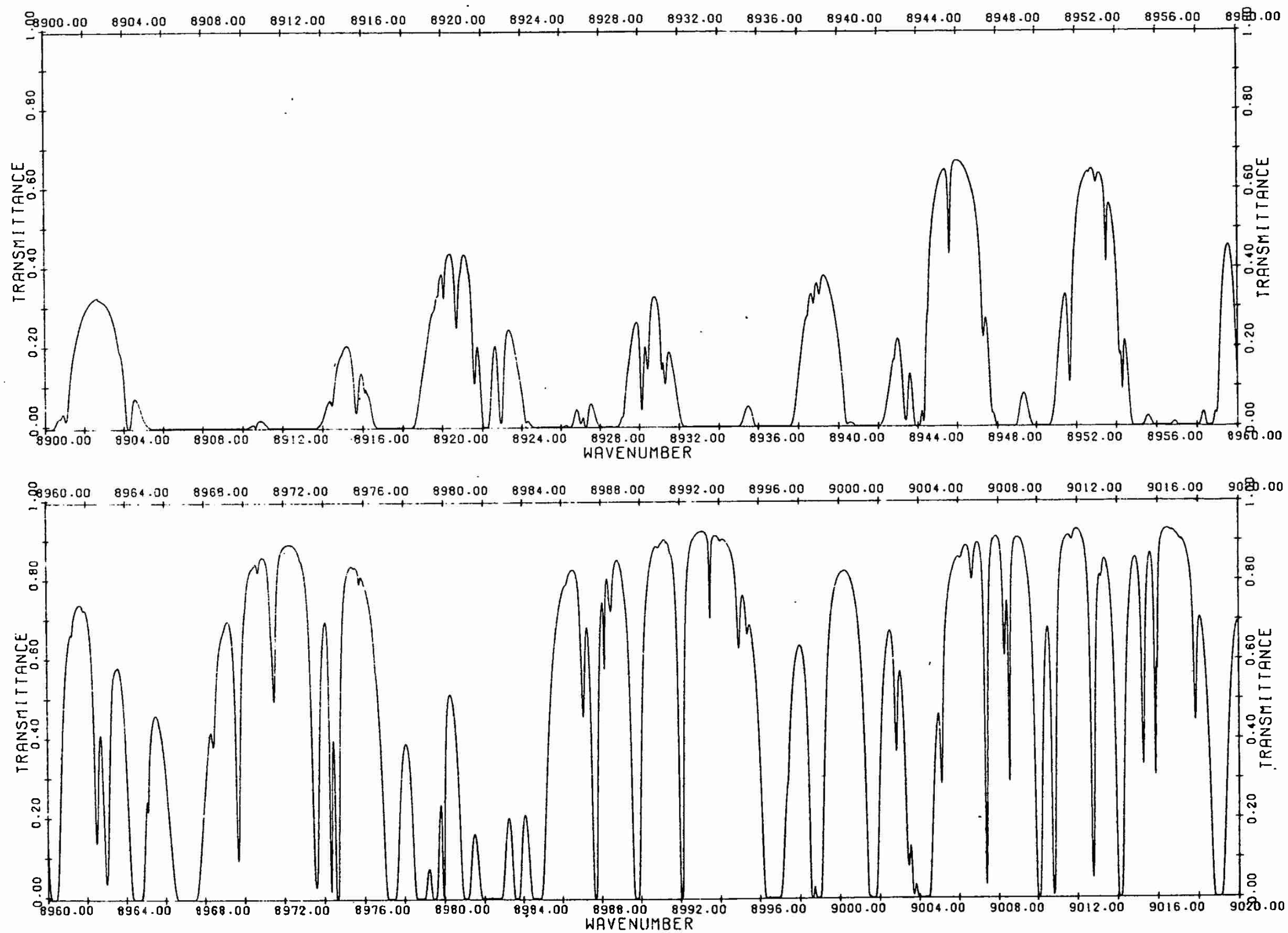


Figure 4bu. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

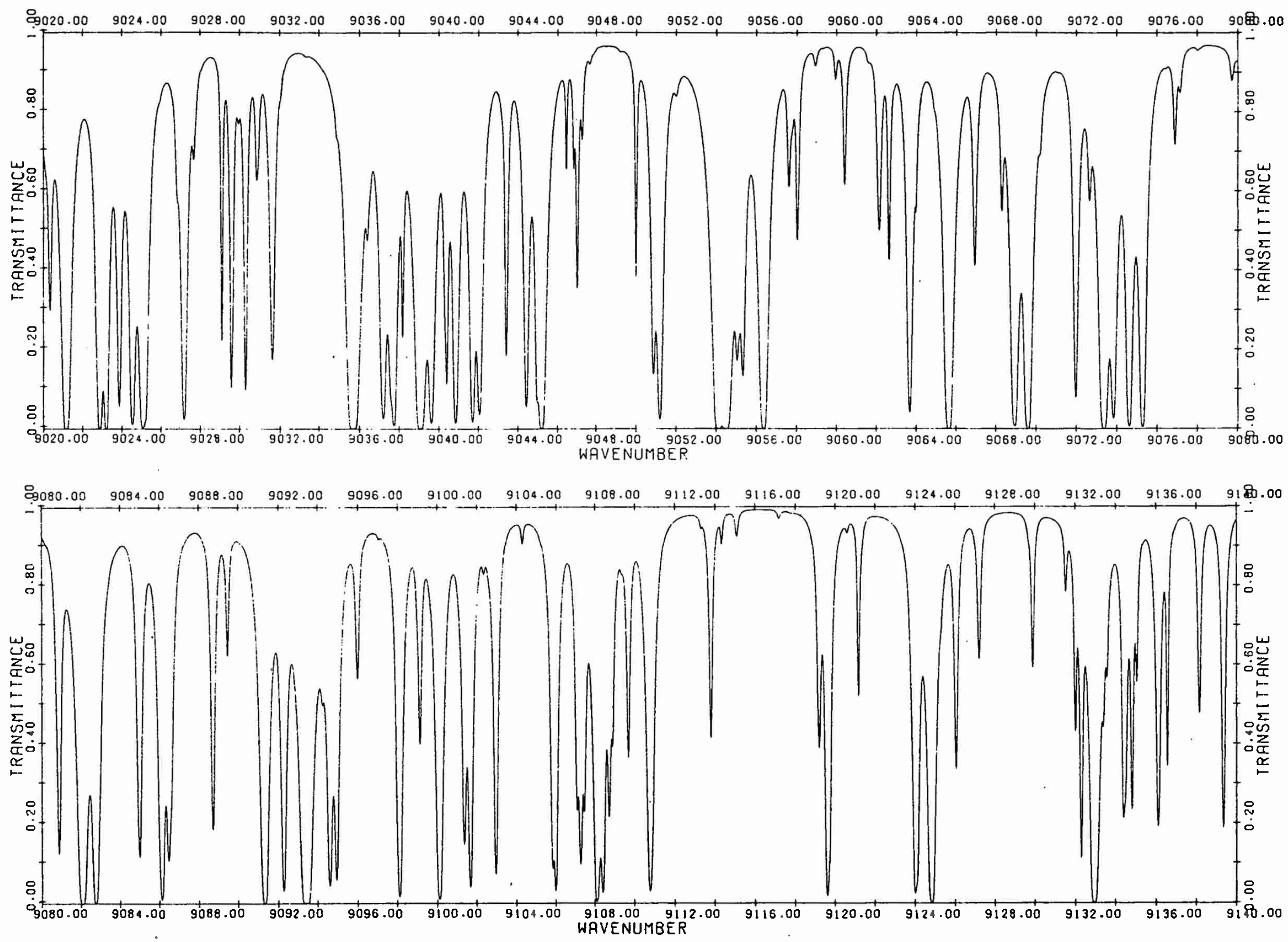


Figure 4bv. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

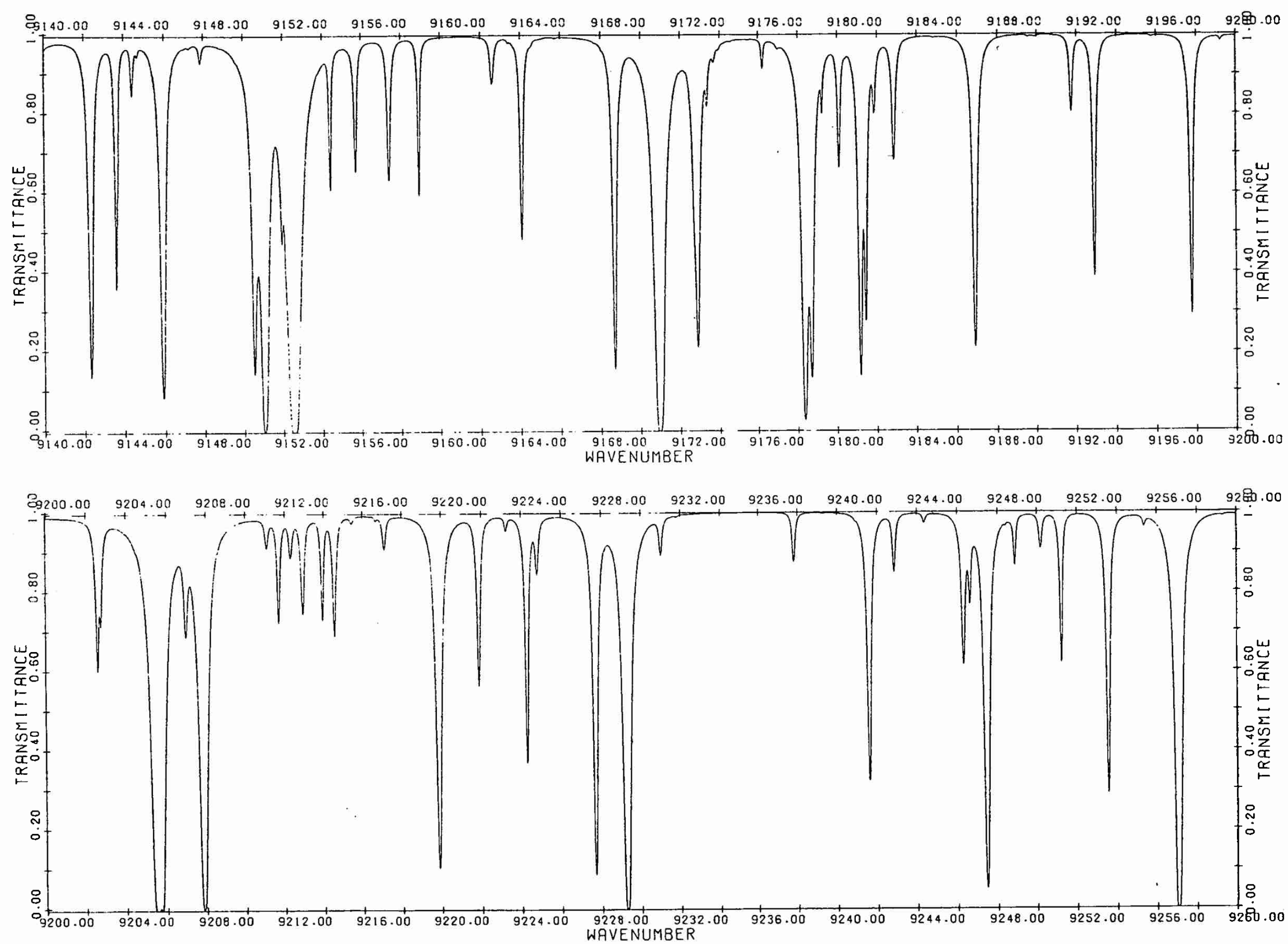


Figure 4bw. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

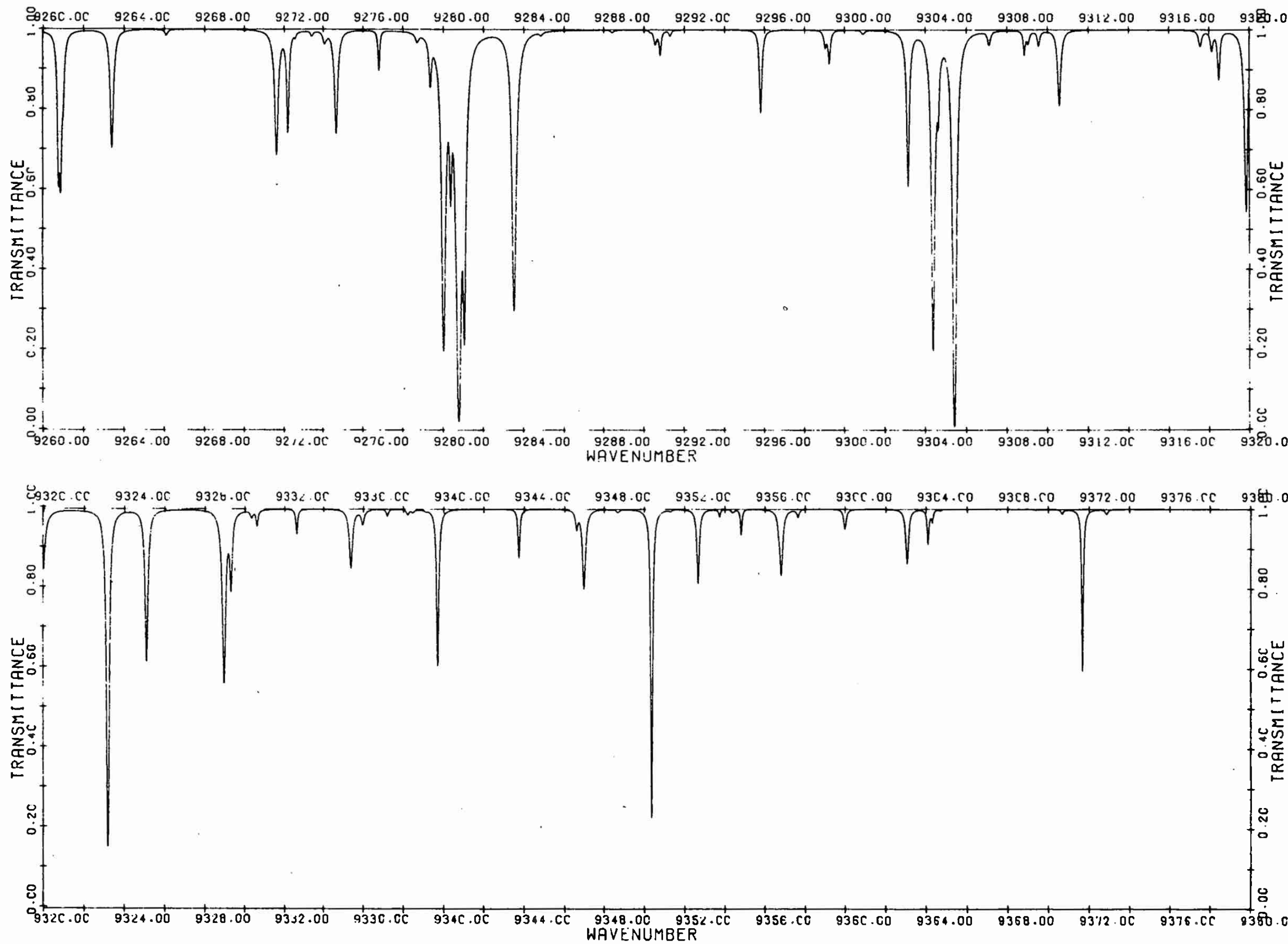


Figure 4bx. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

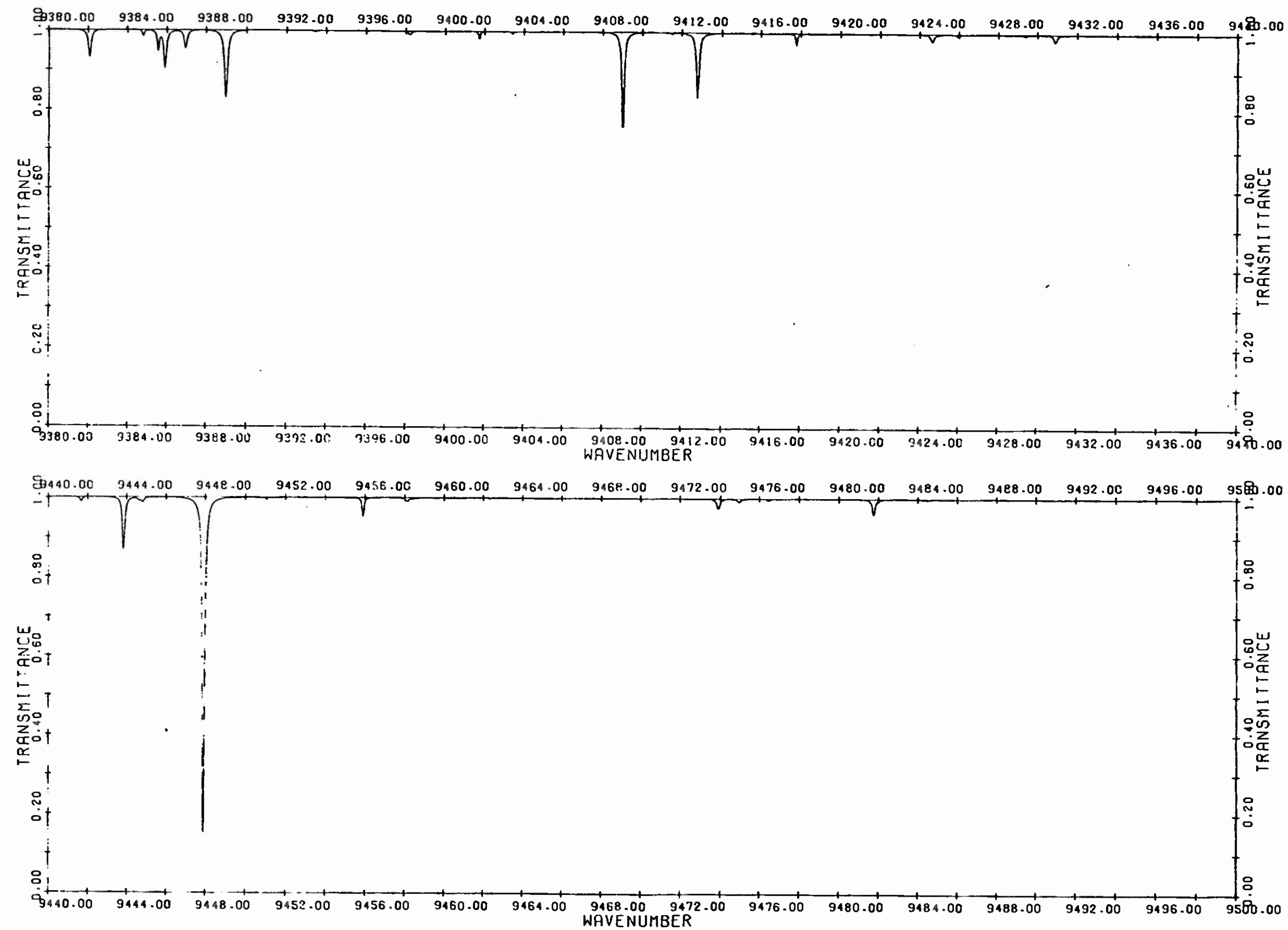


Figure 4by. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

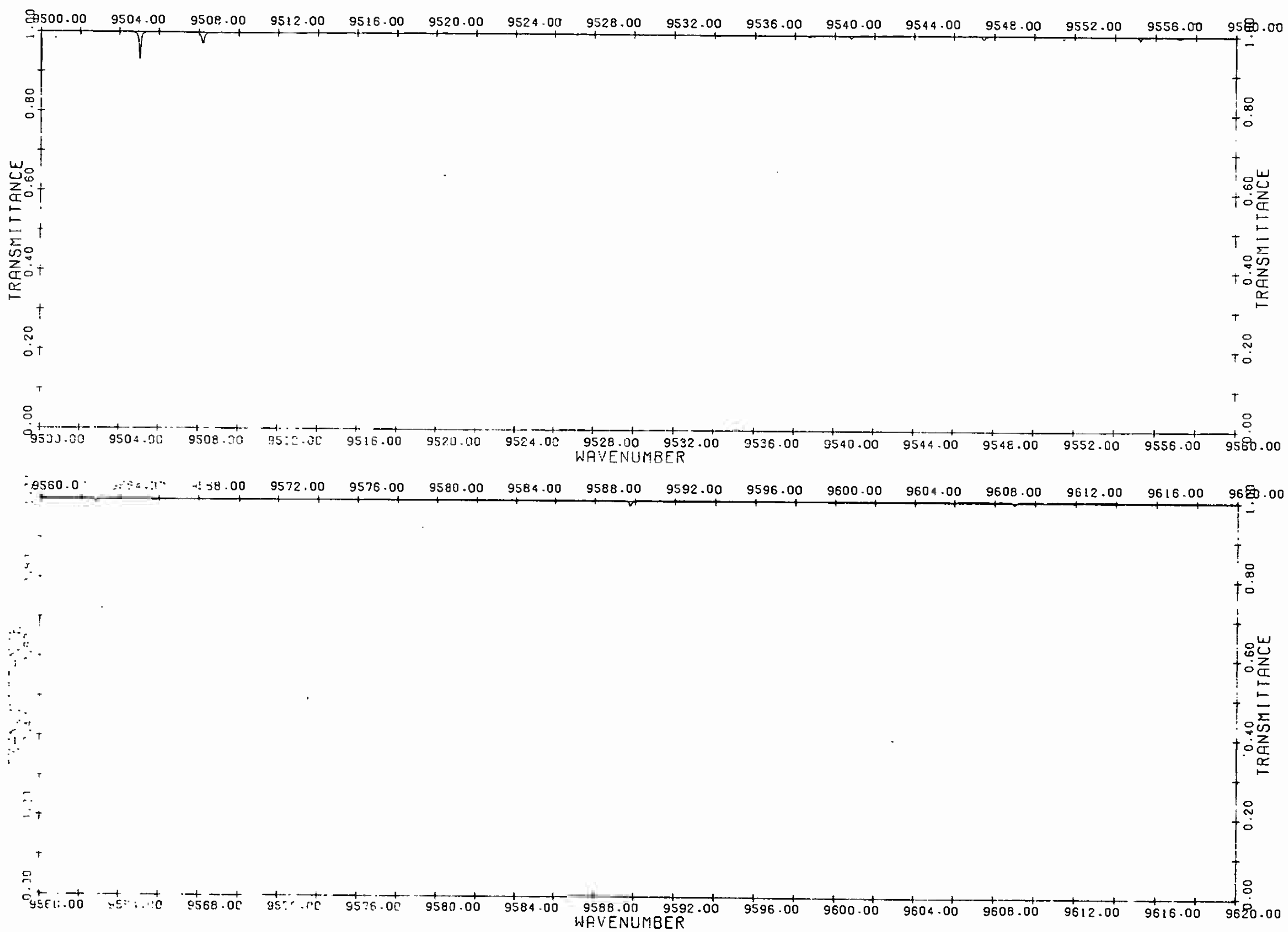


Figure 4bz. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

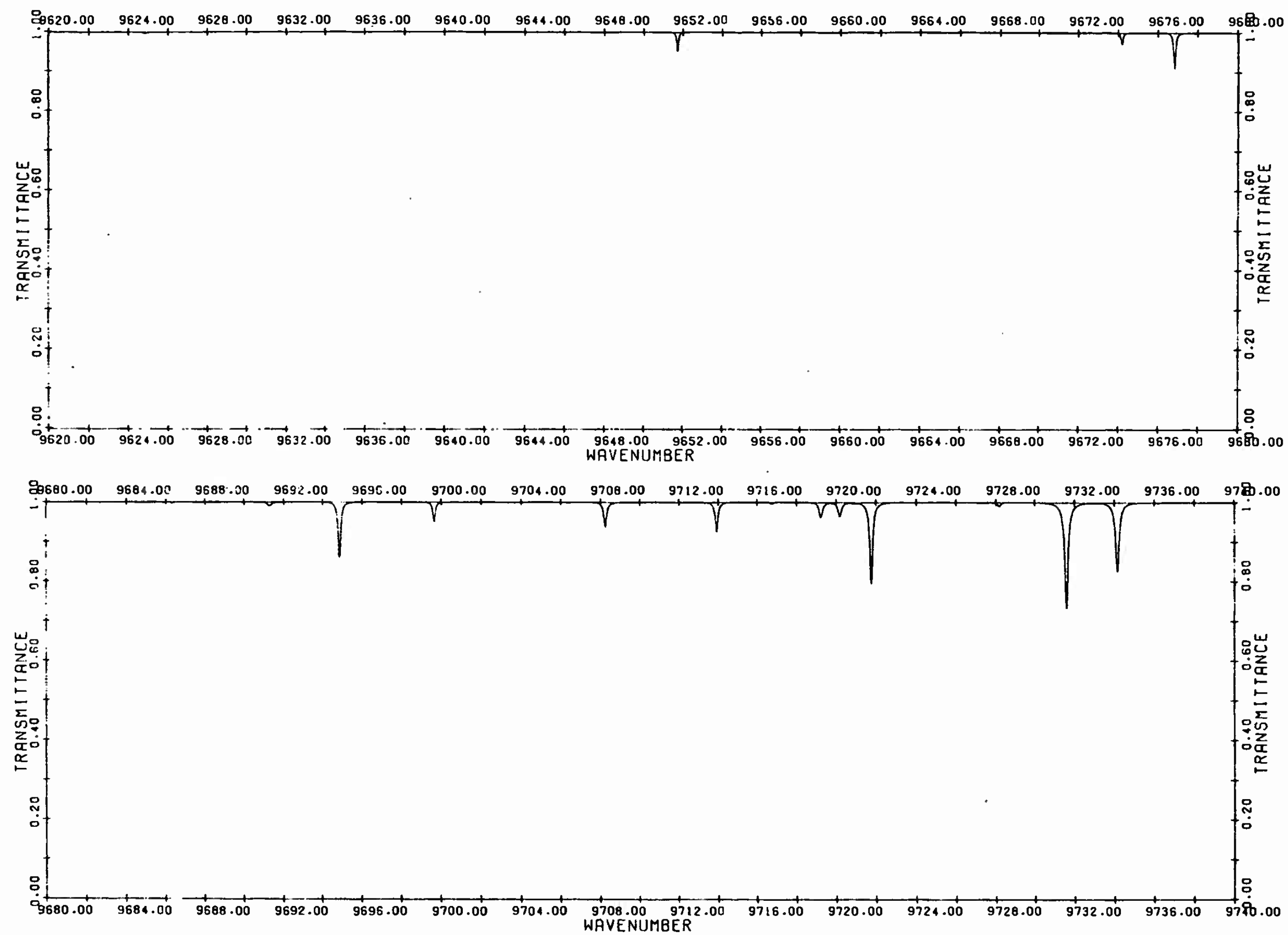


Figure 4ca. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

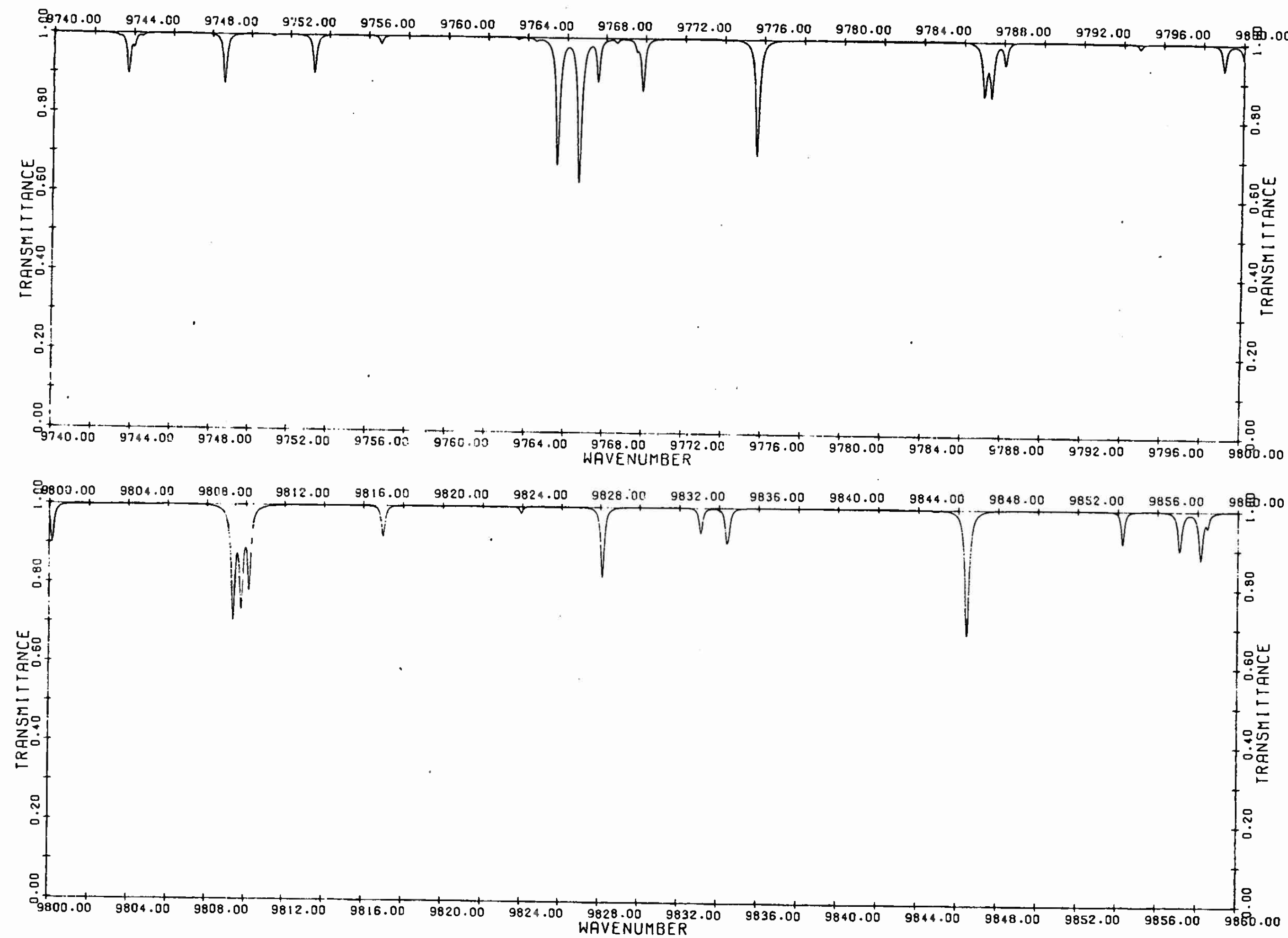


Figure 4cb. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

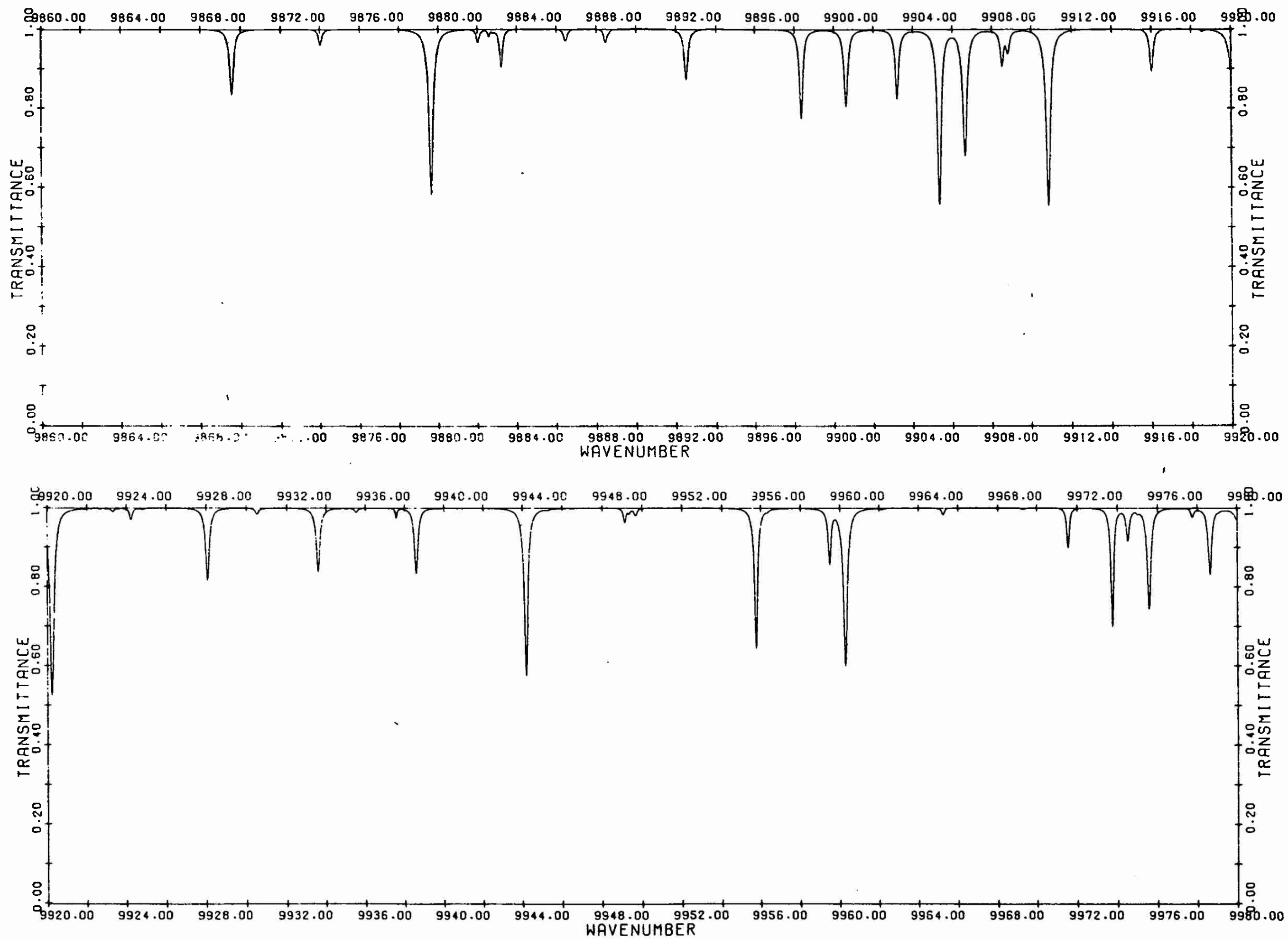


Figure 4cc. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

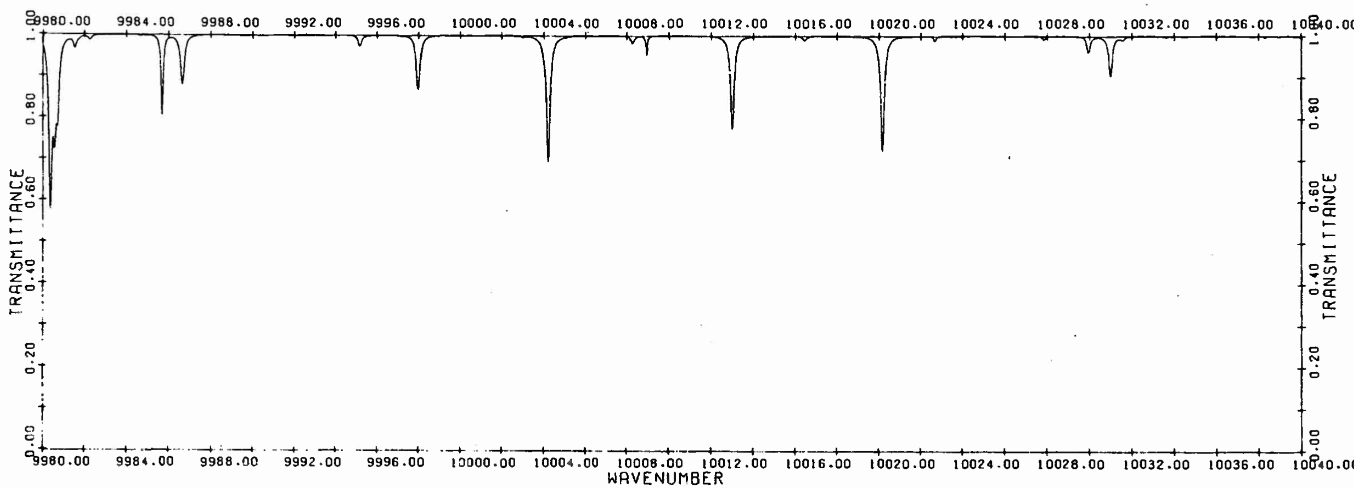


Figure 4cd. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

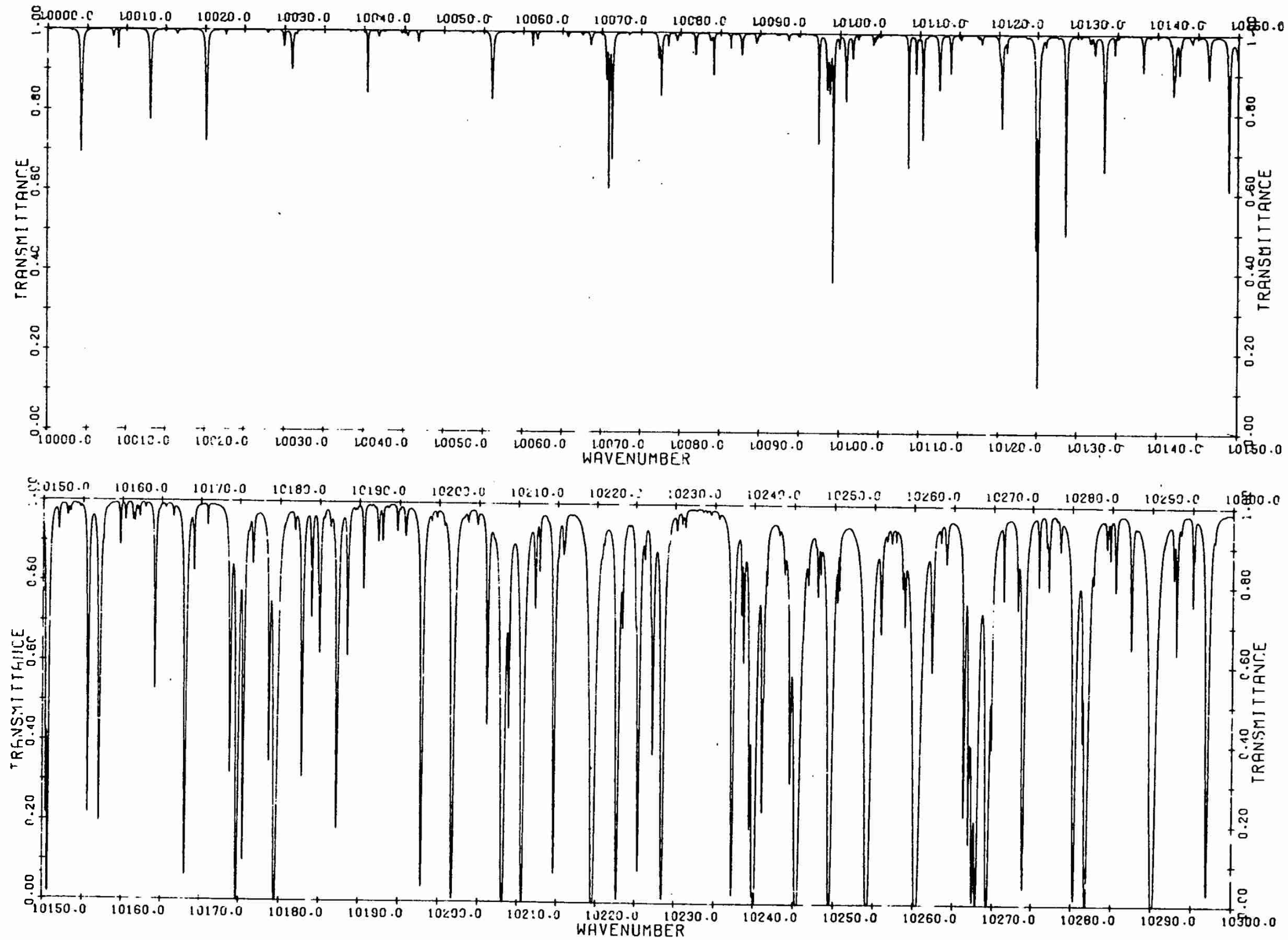


Figure 4ce. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

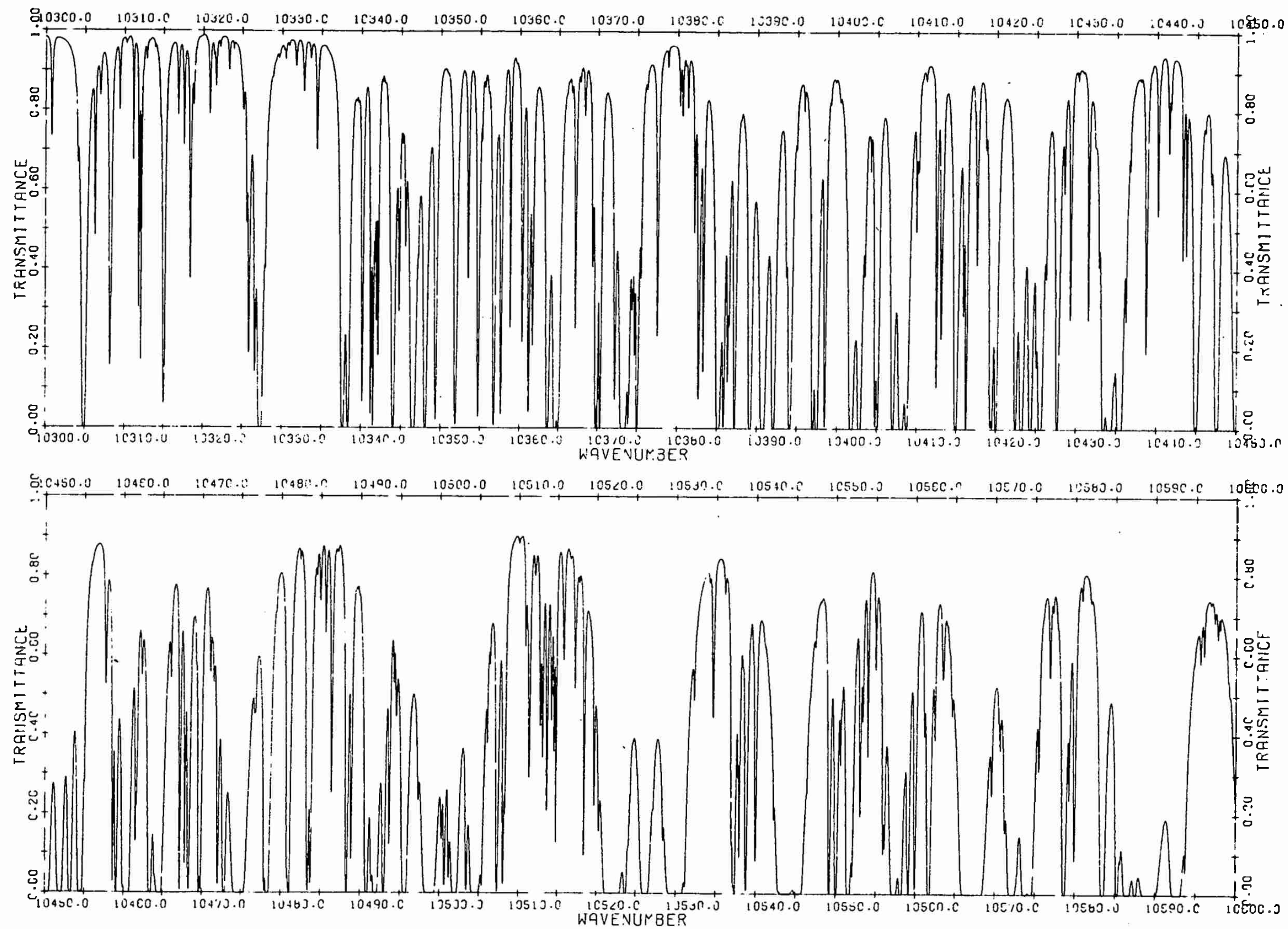


Figure 4cf. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

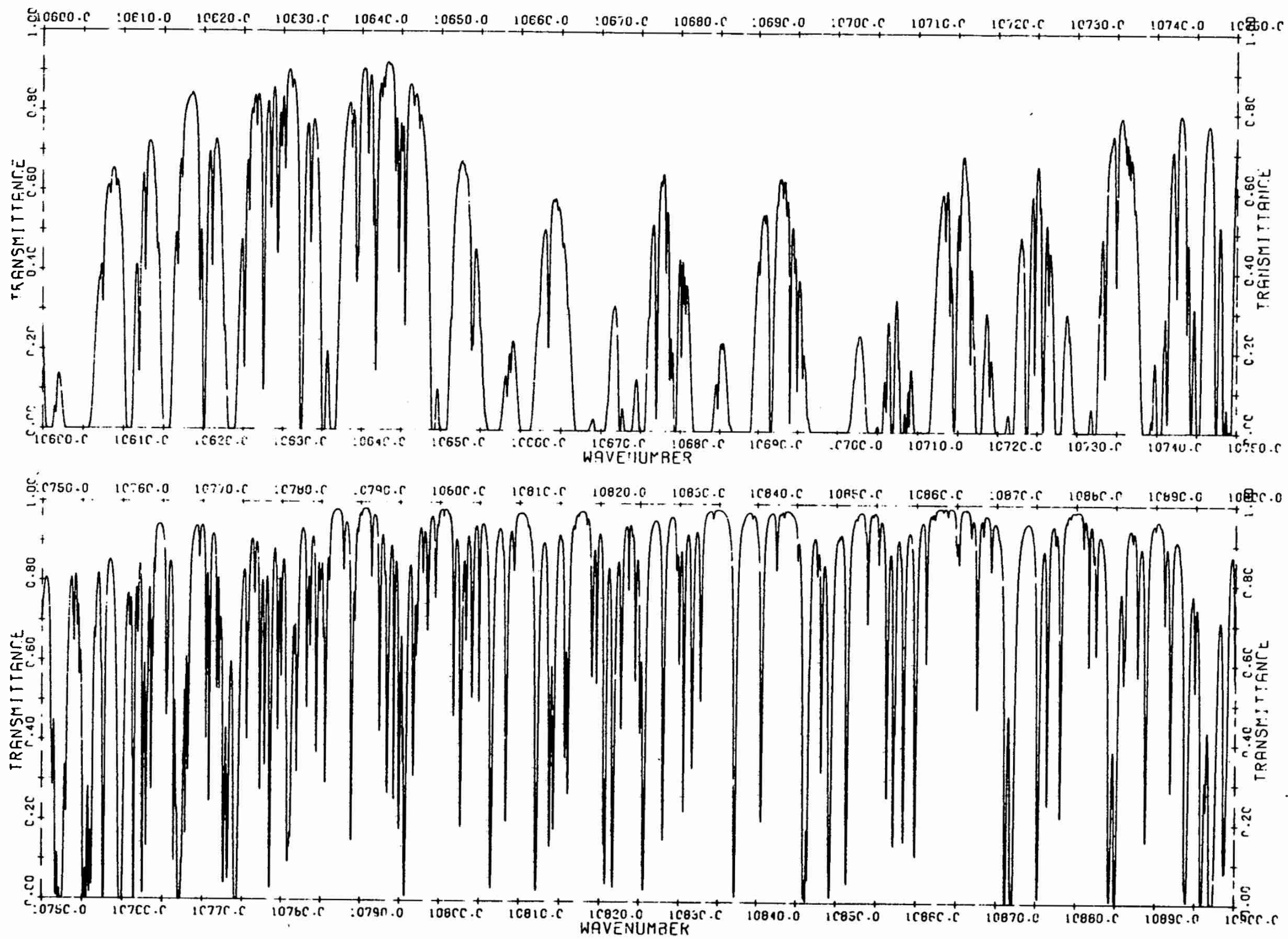


Figure 4cg. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

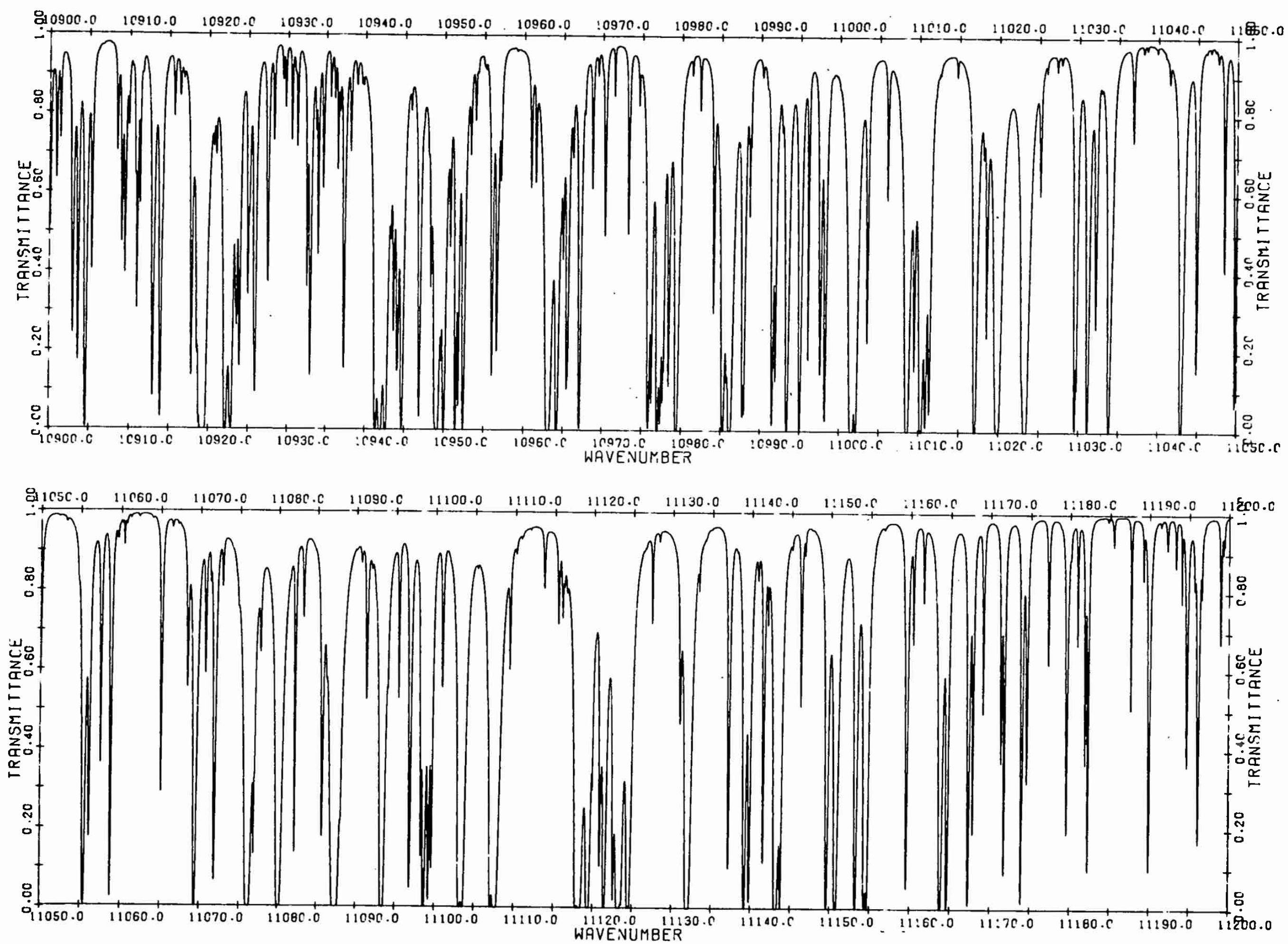


Figure 4ch. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

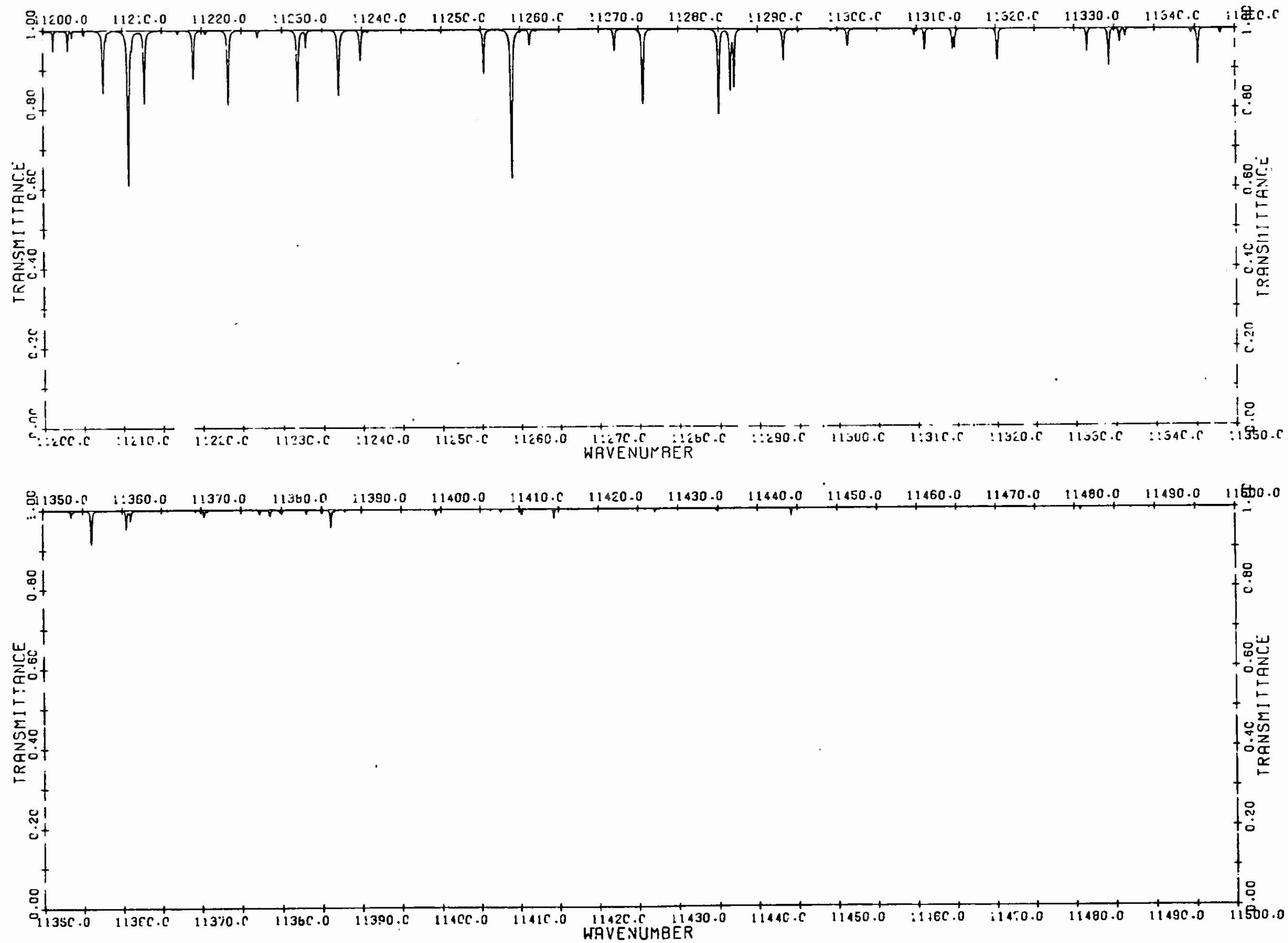


Figure 4ci. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

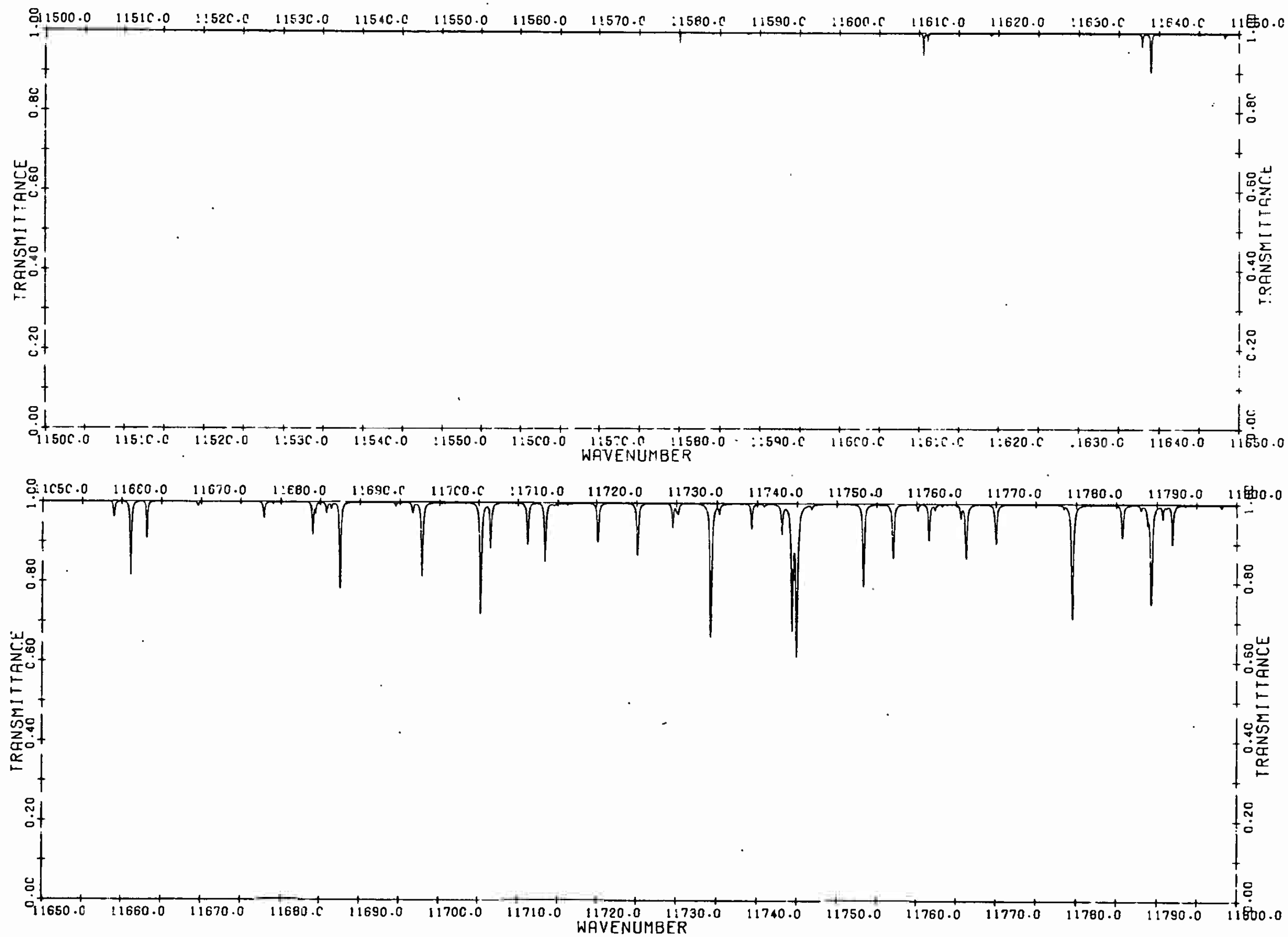


Figure 4cj. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

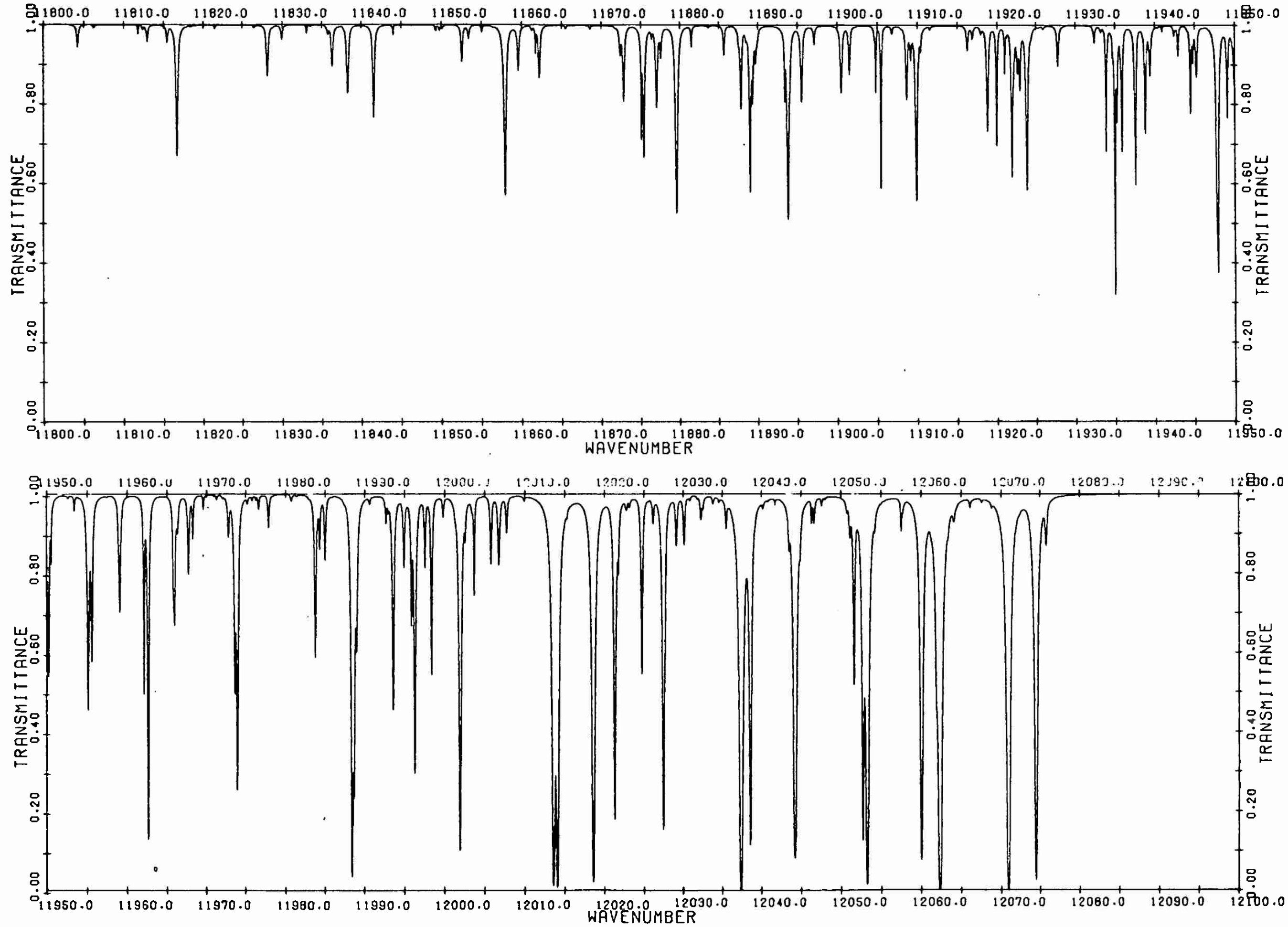


Figure 4ck. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

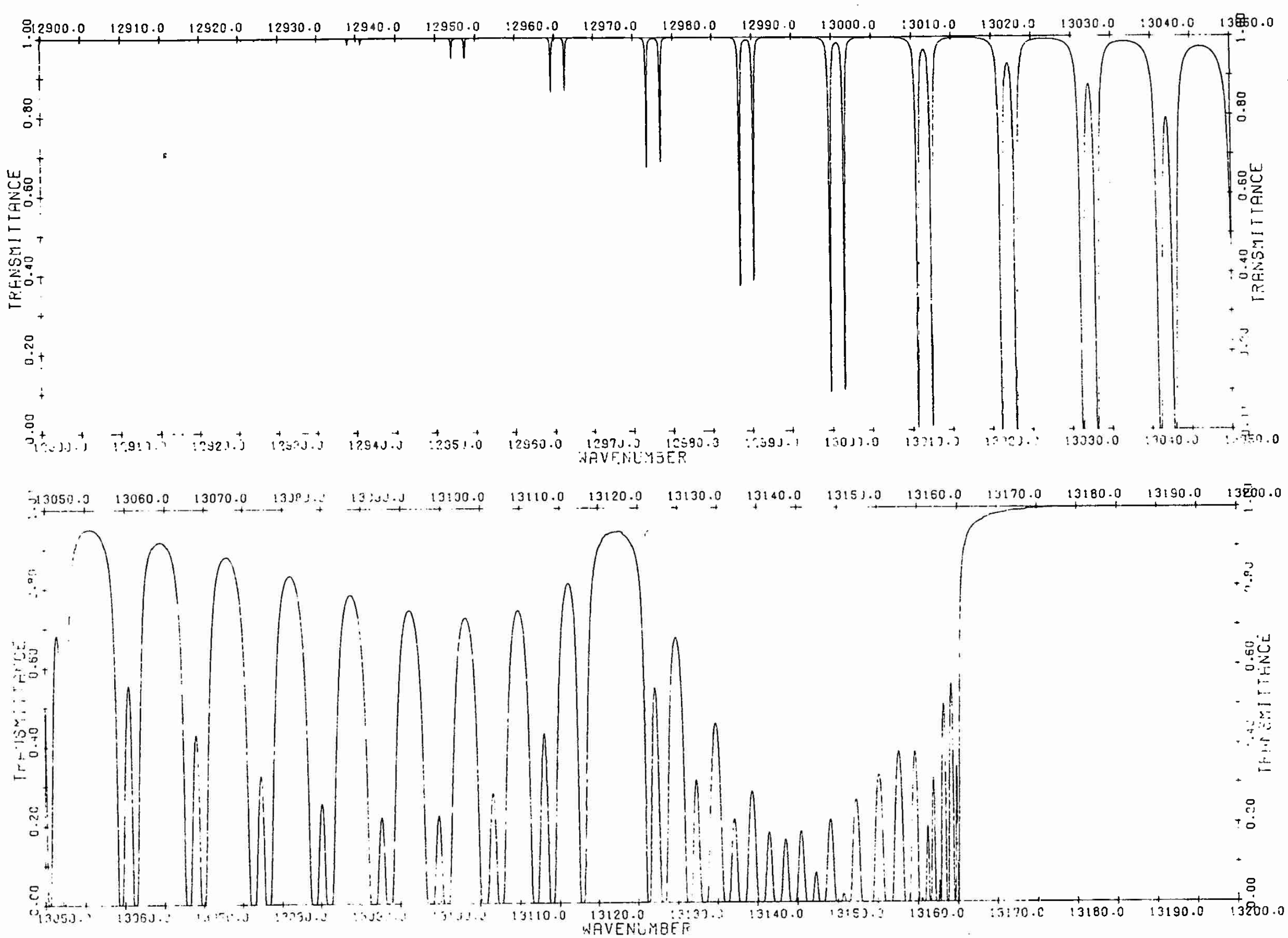


Figure 4cl. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at Sea Level

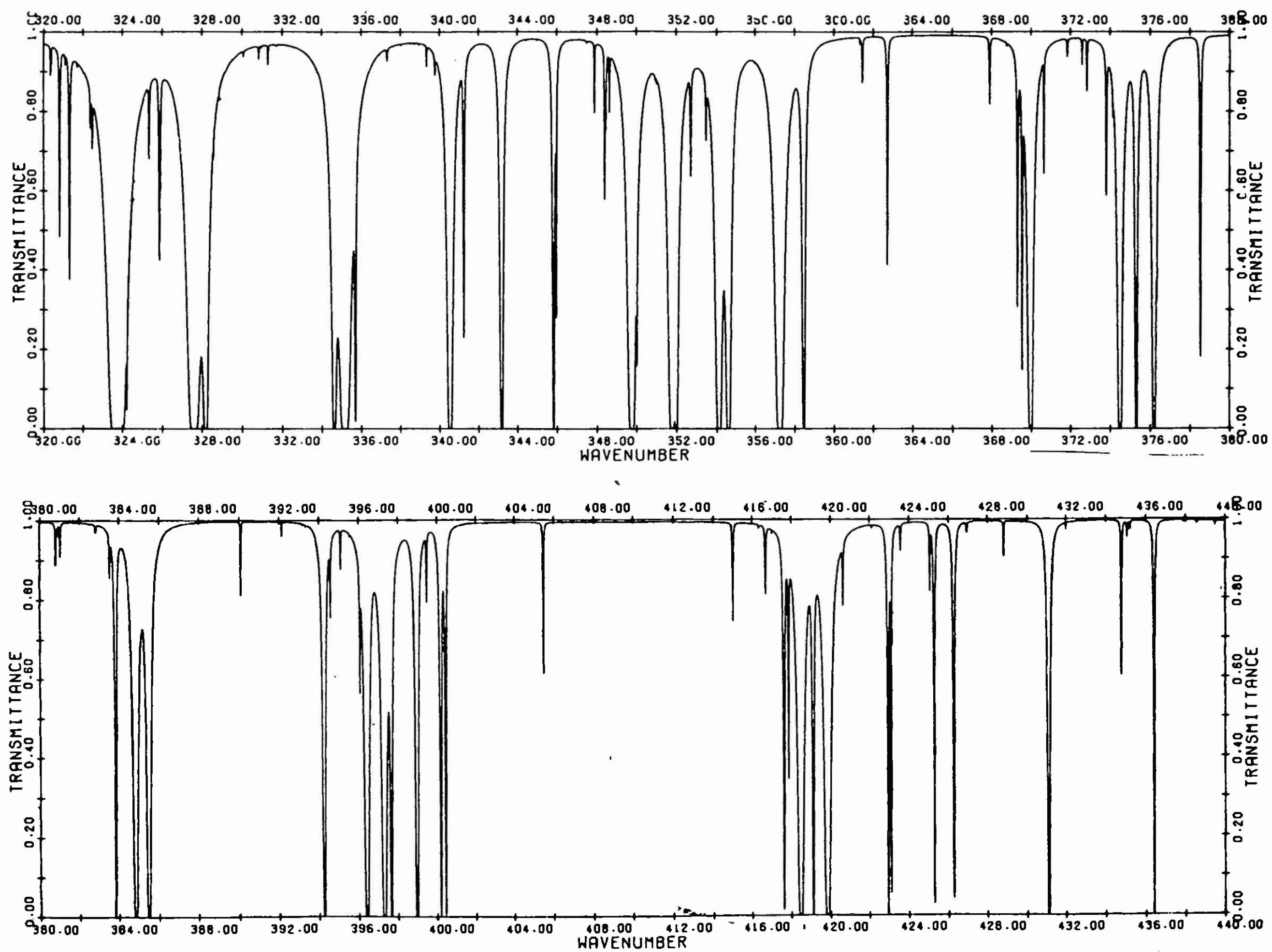


Figure 5a. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

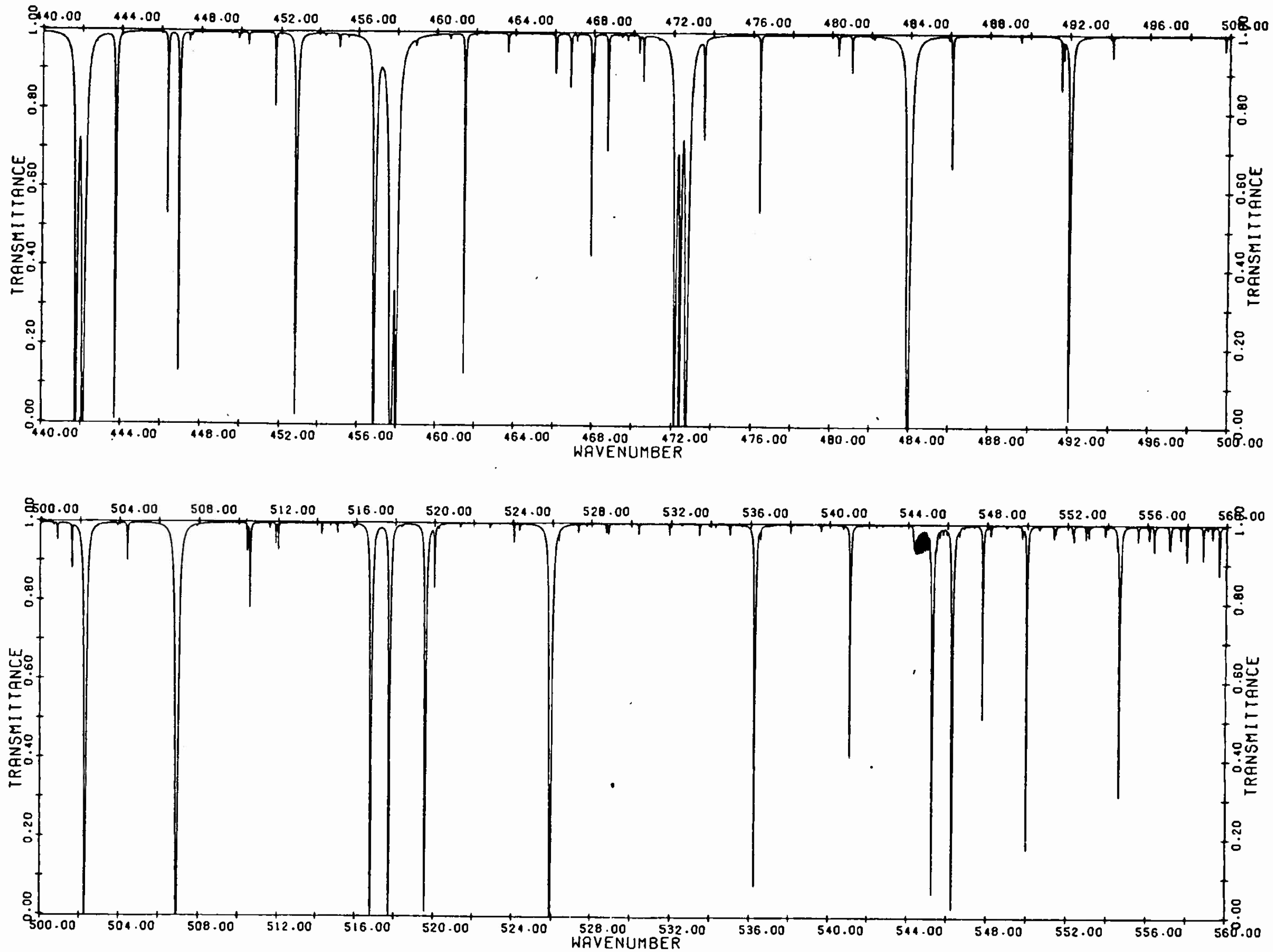


Figure 5b. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

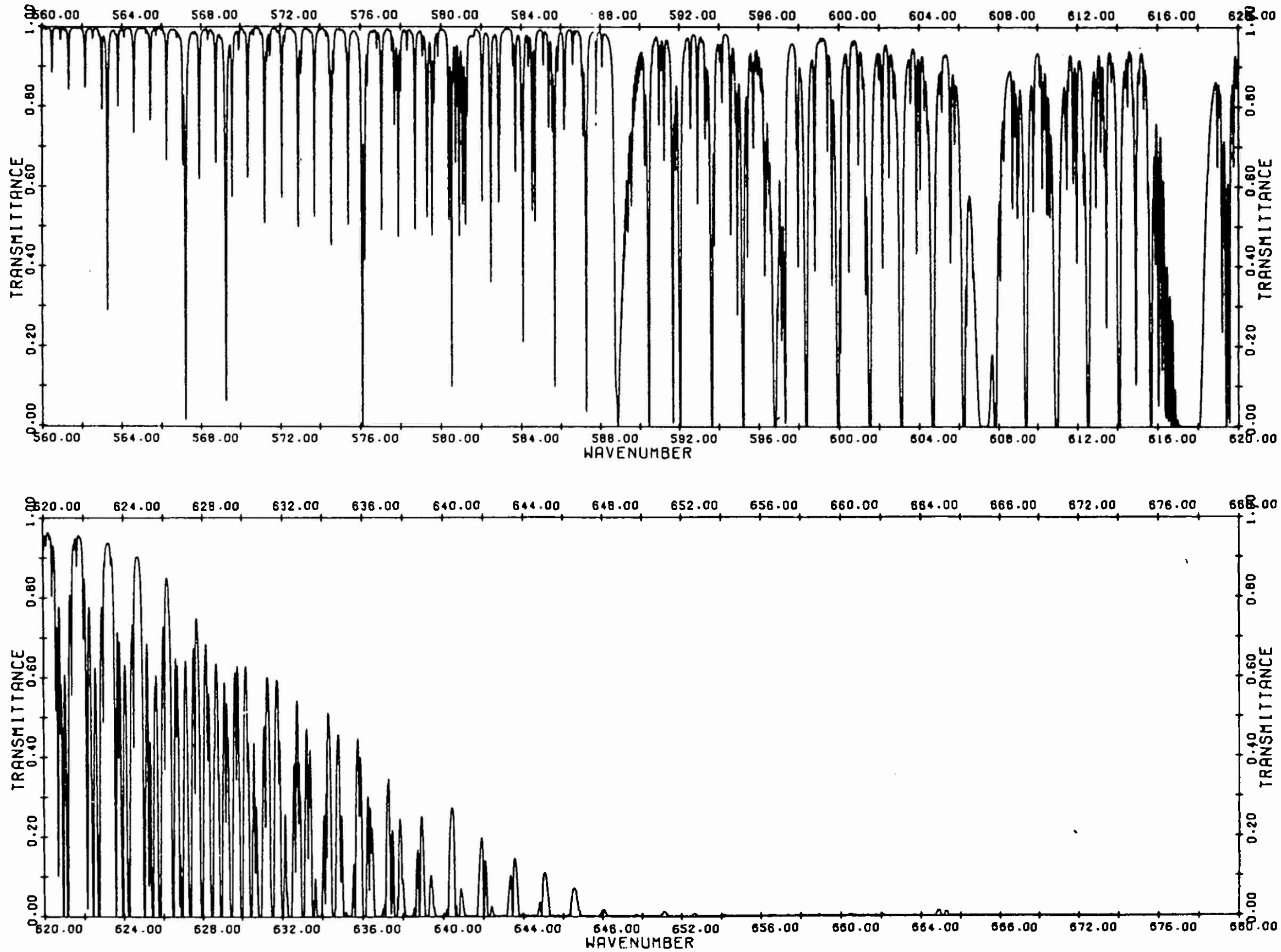


Figure 5c. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

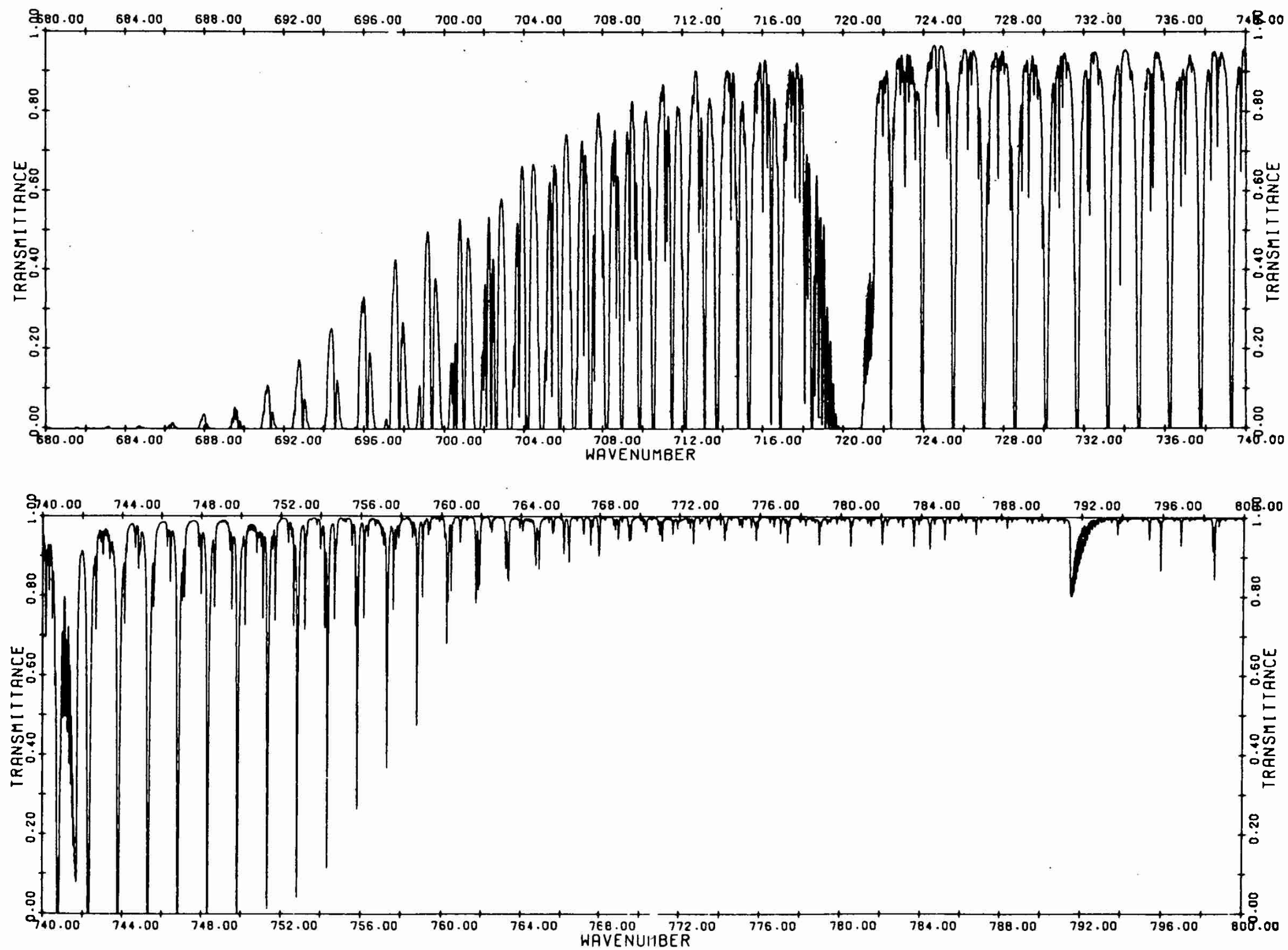


Figure 5d. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

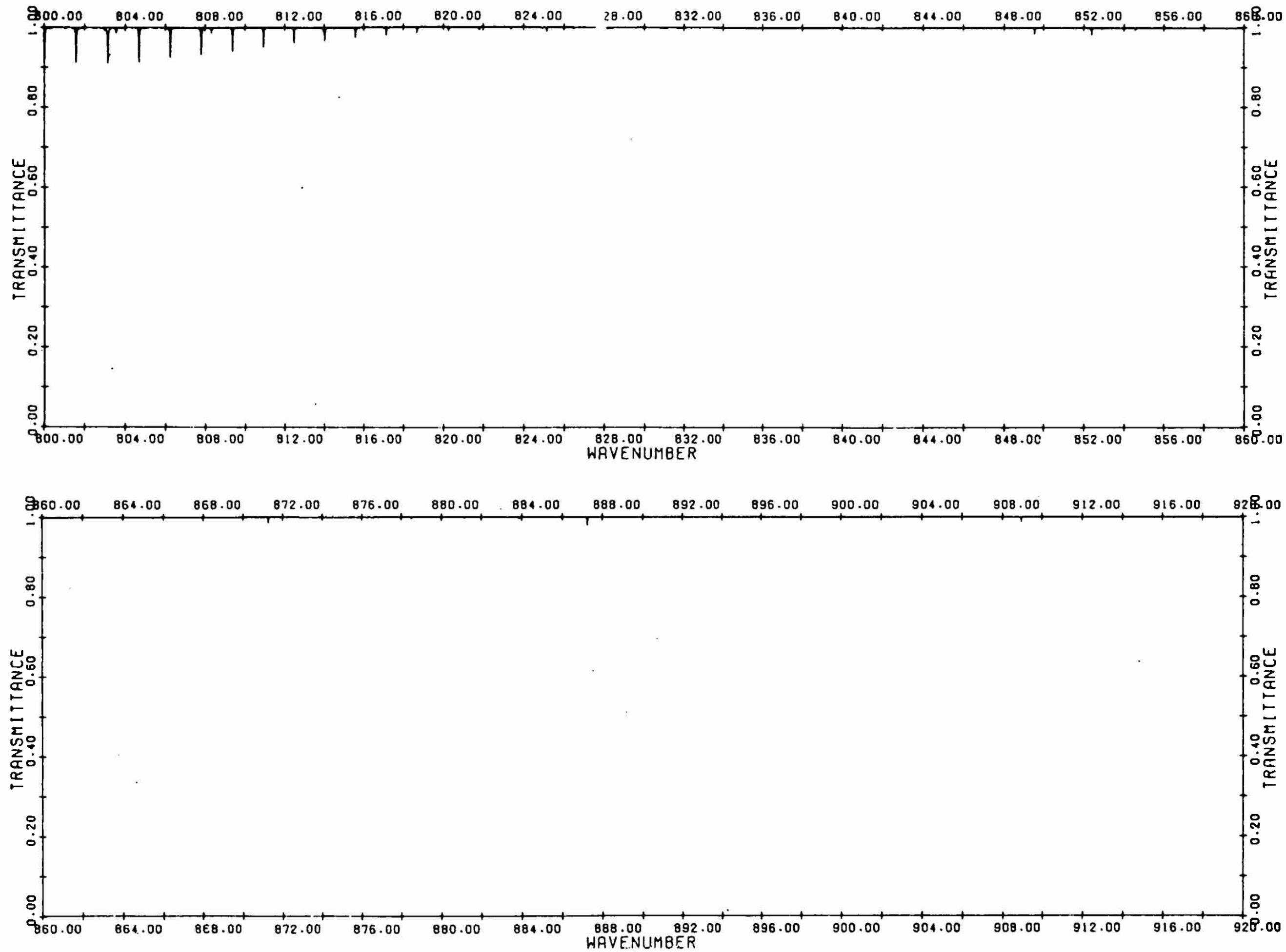


Figure 5e. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

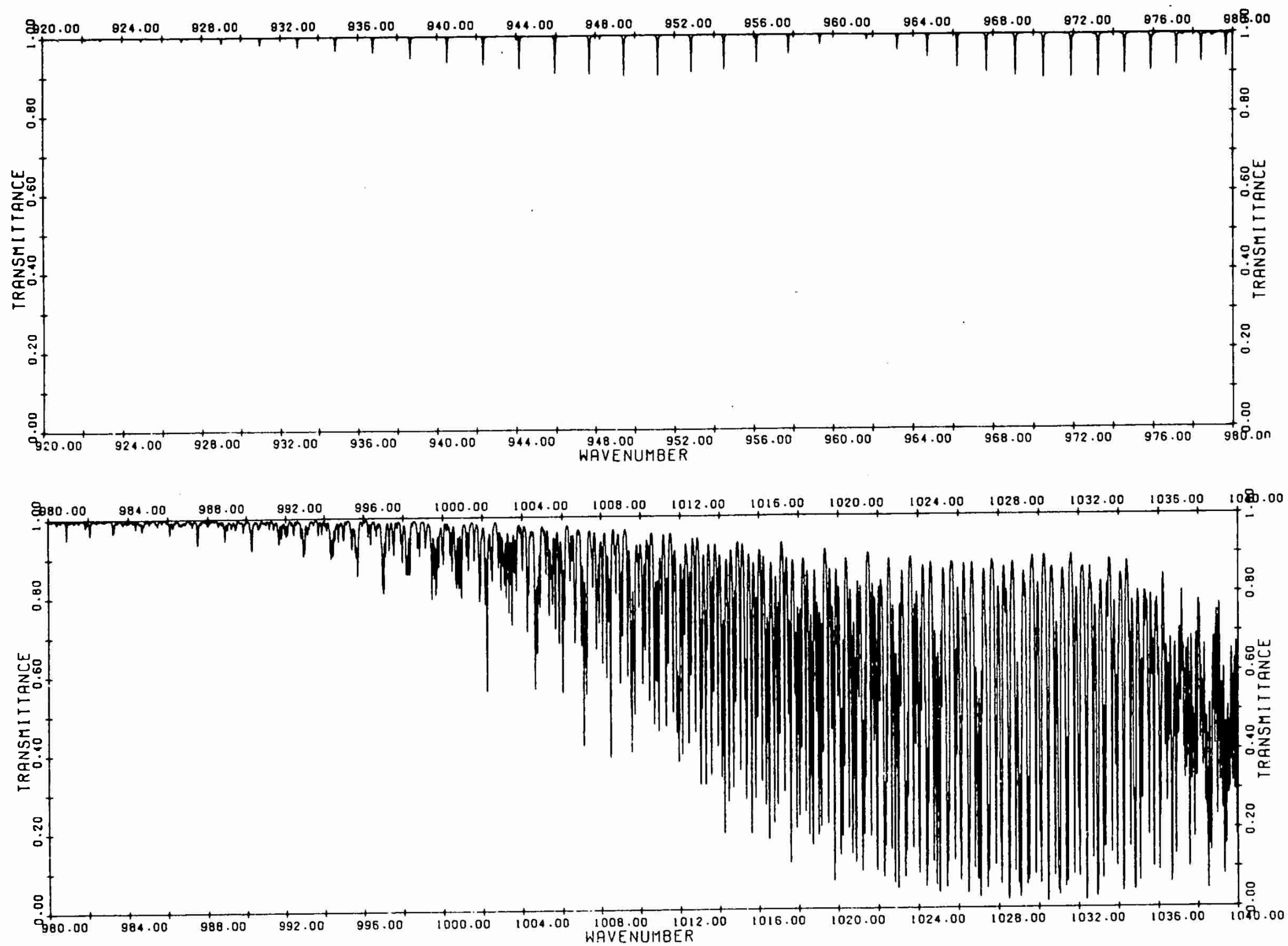


Figure 5f. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

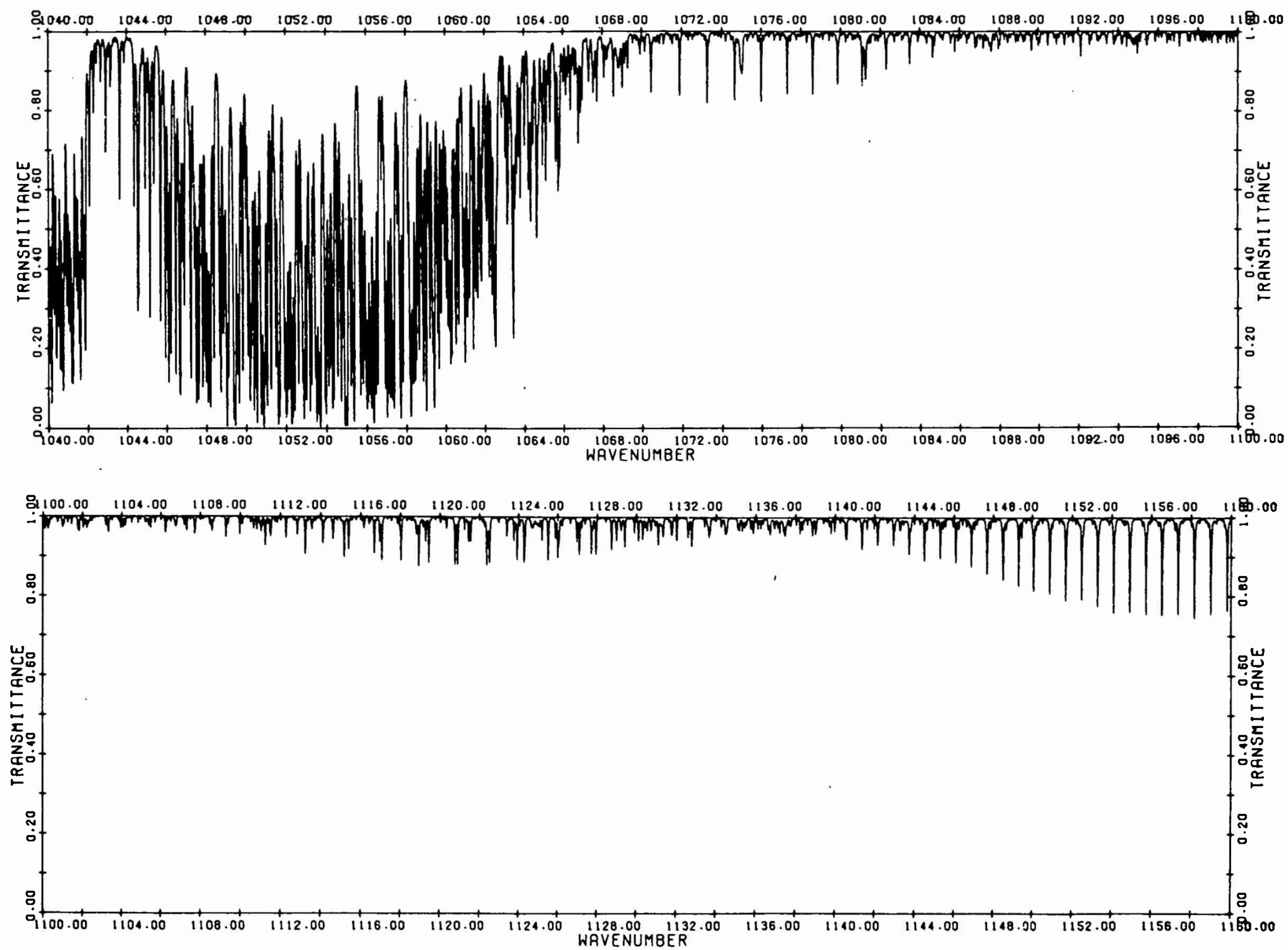


Figure 5g. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

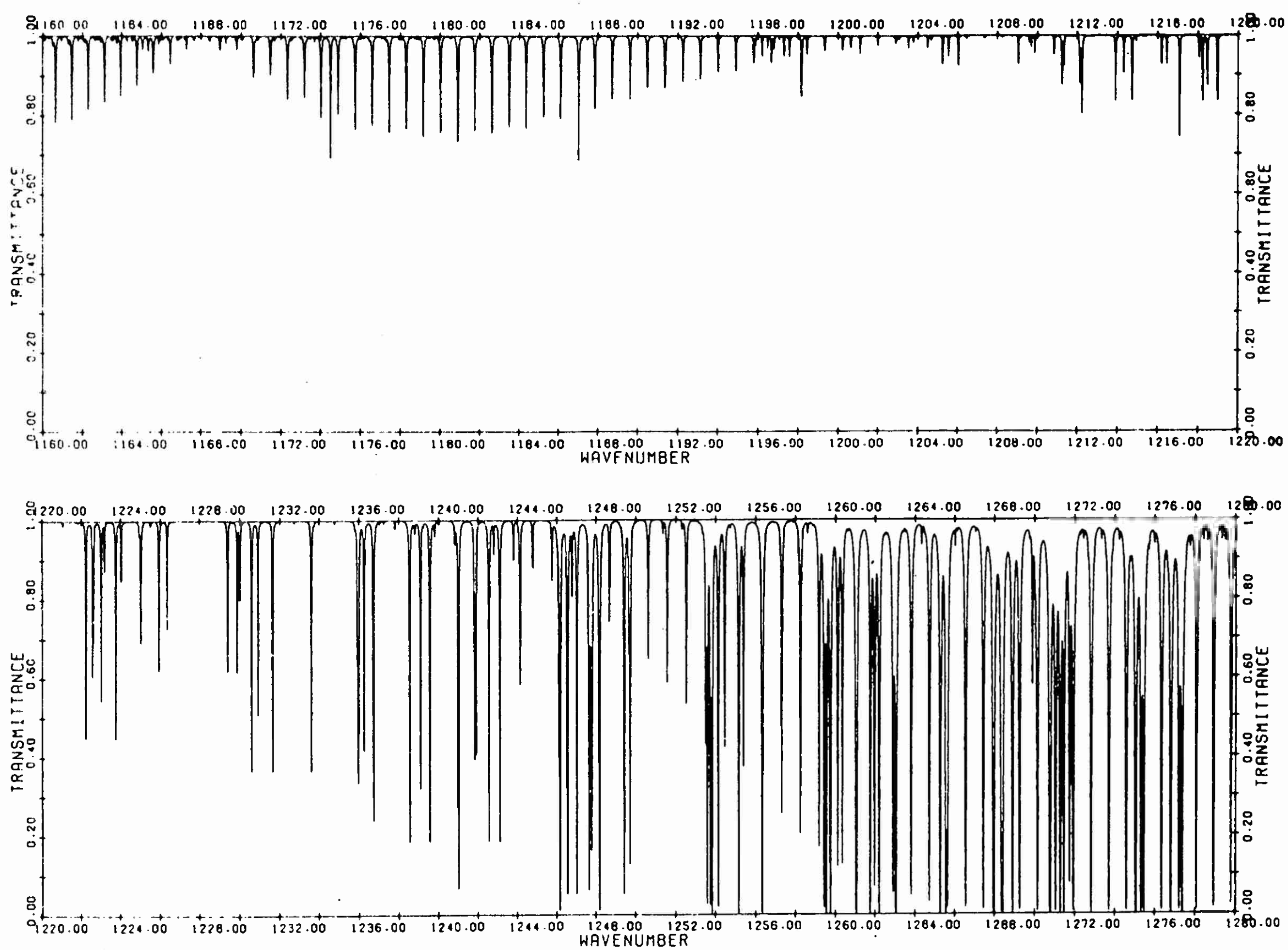


Figure 5h. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

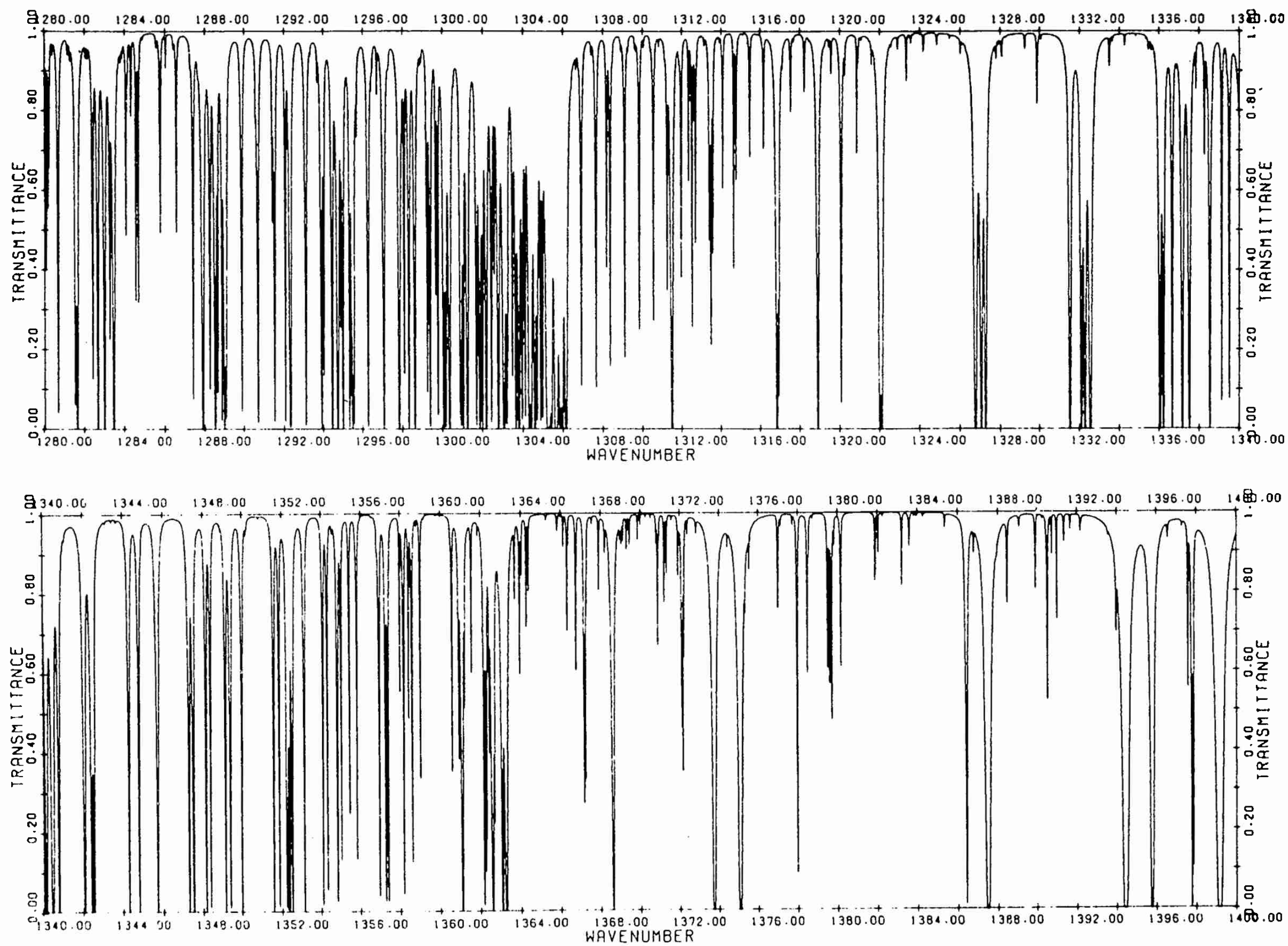


Figure 51. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

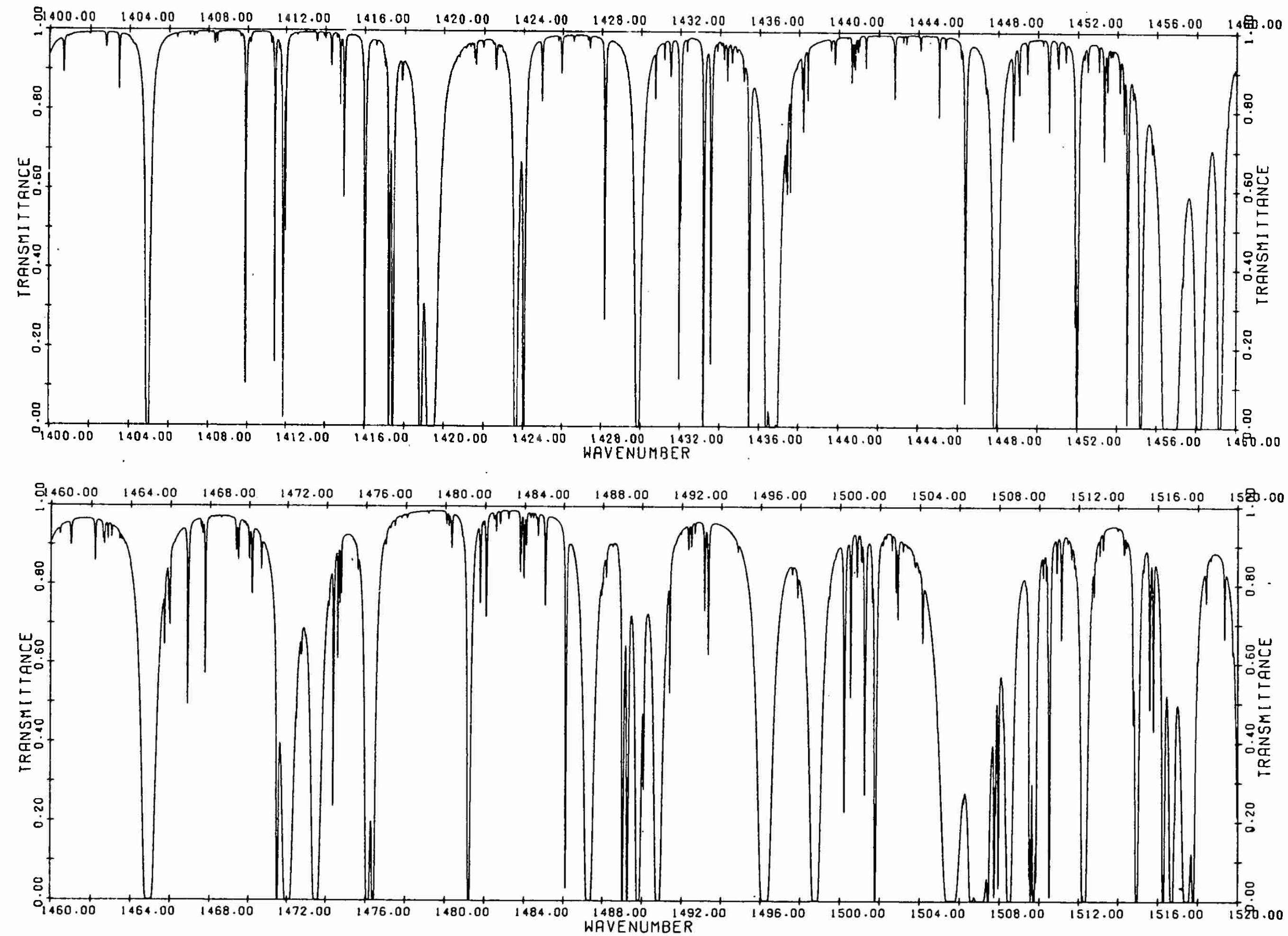


Figure 5j. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

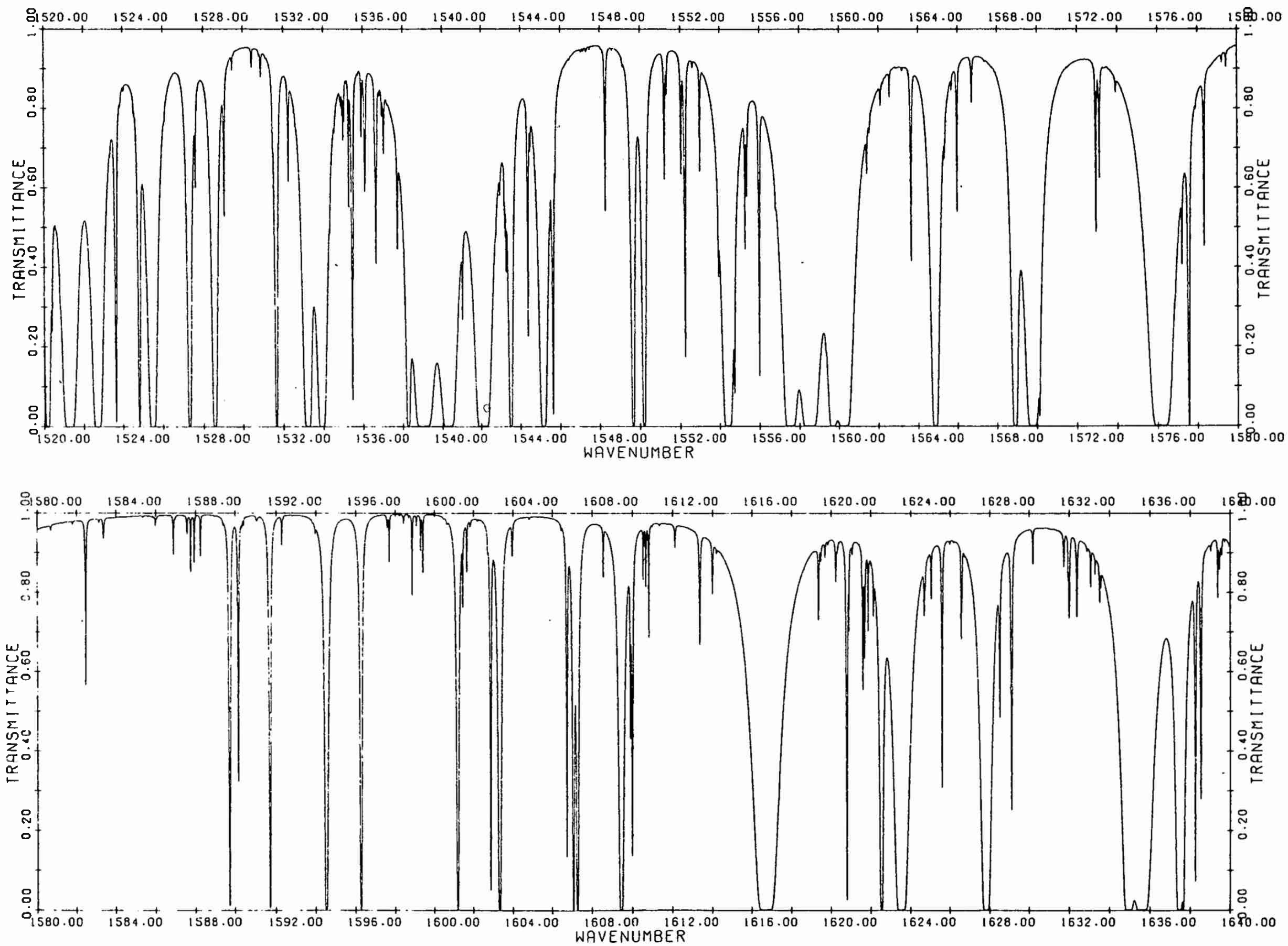


Figure 5k. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

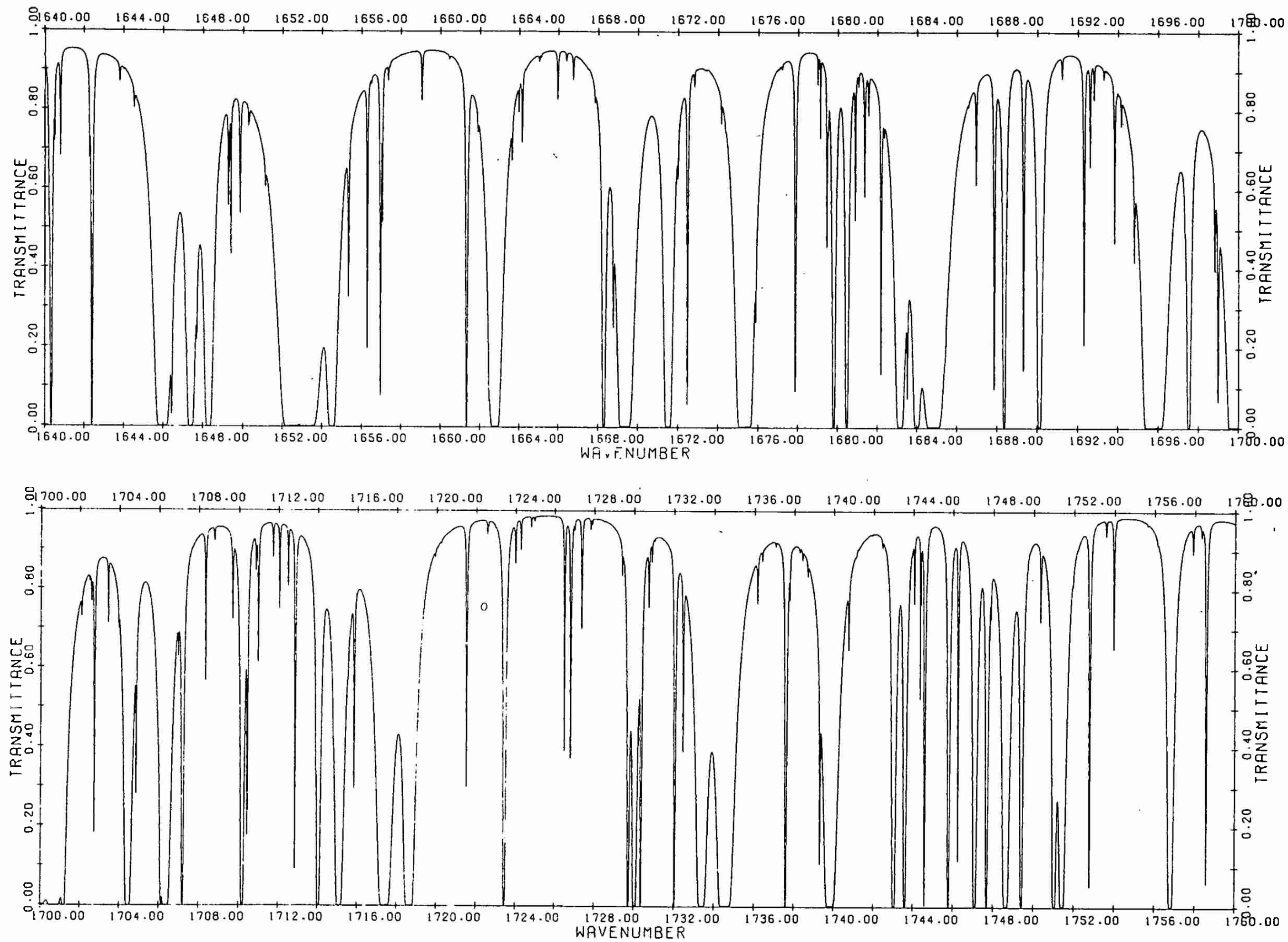


Figure 51. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

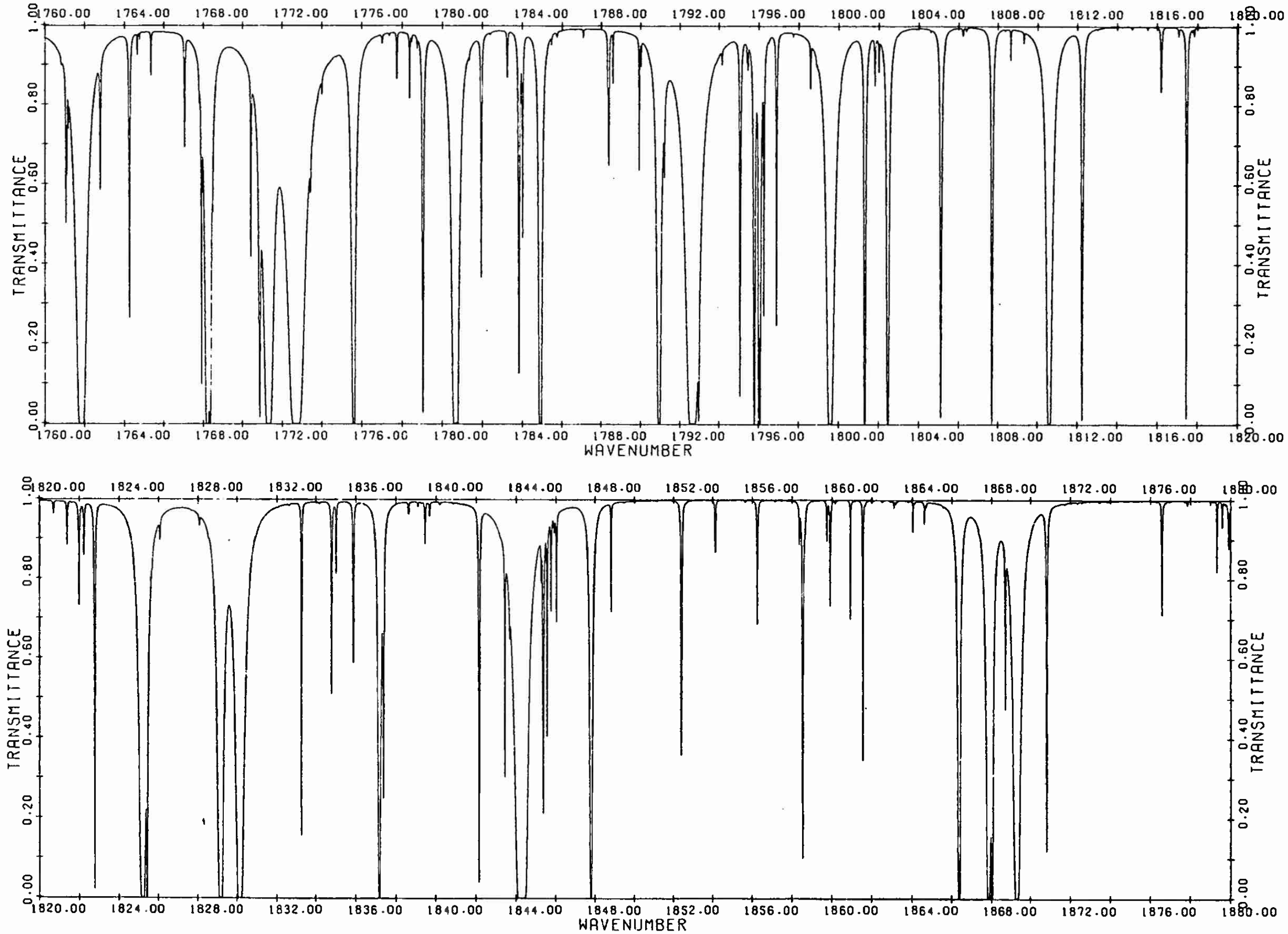


Figure 5m. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

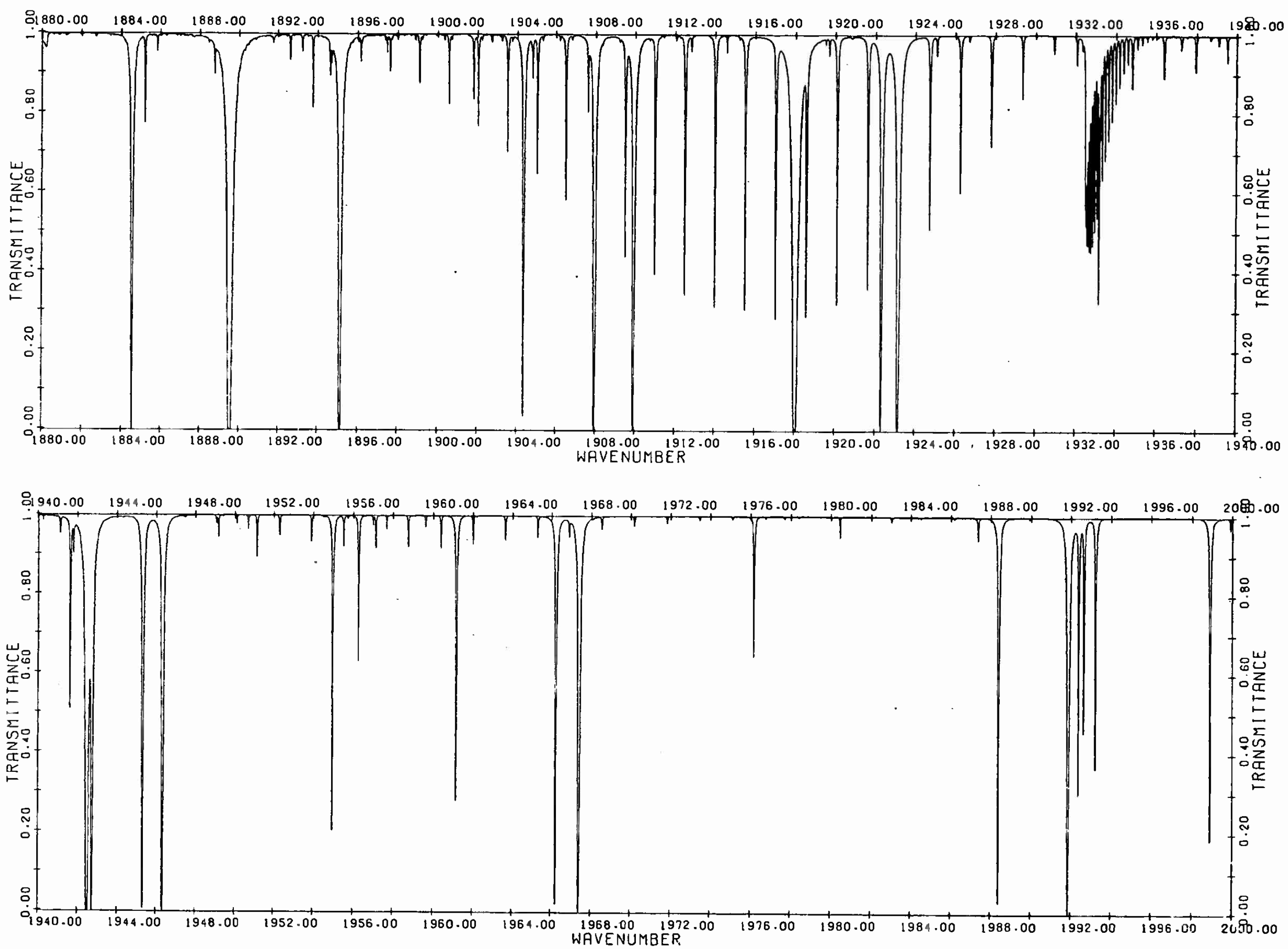


Figure 5n. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

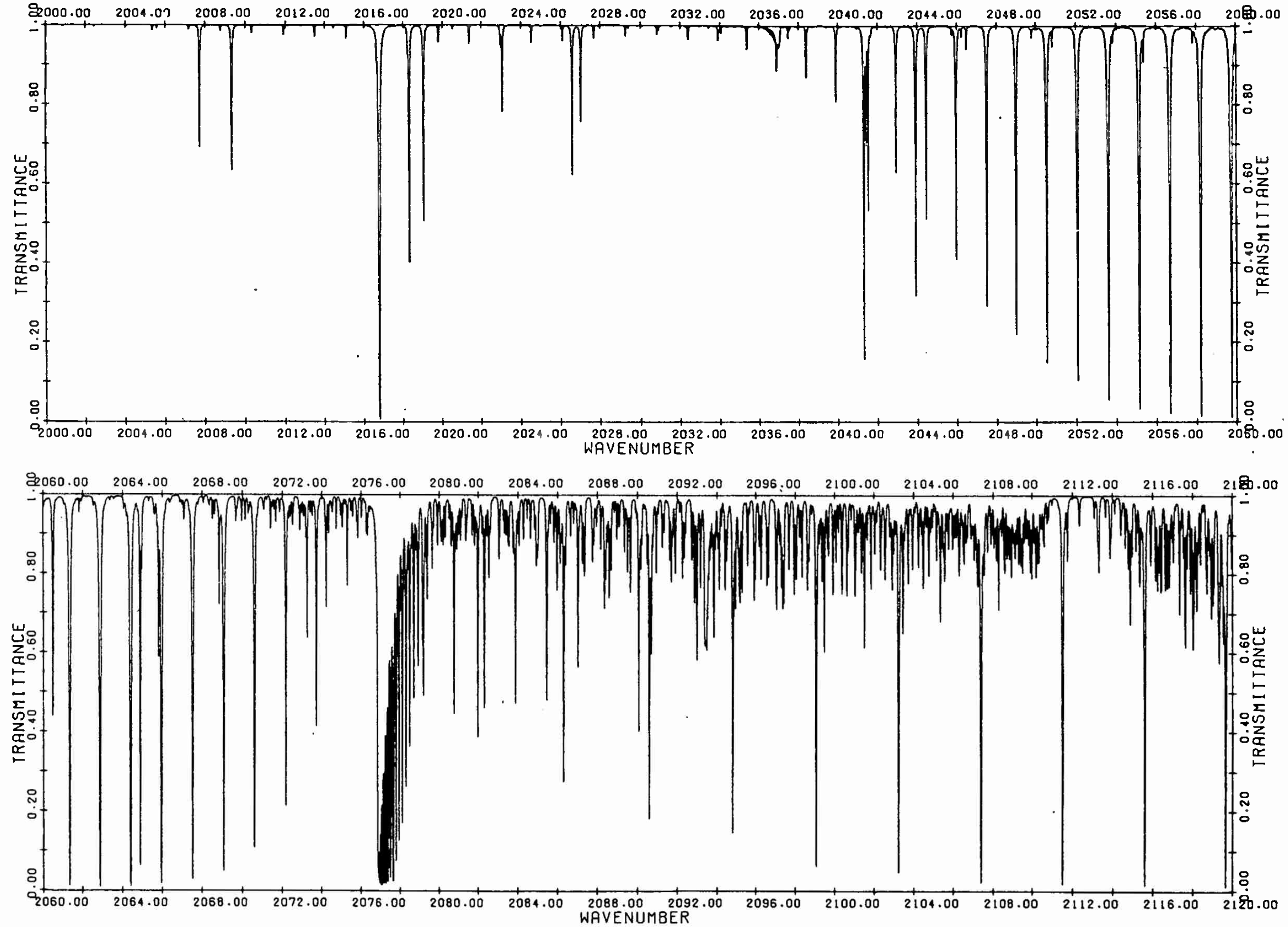


Figure 5o. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

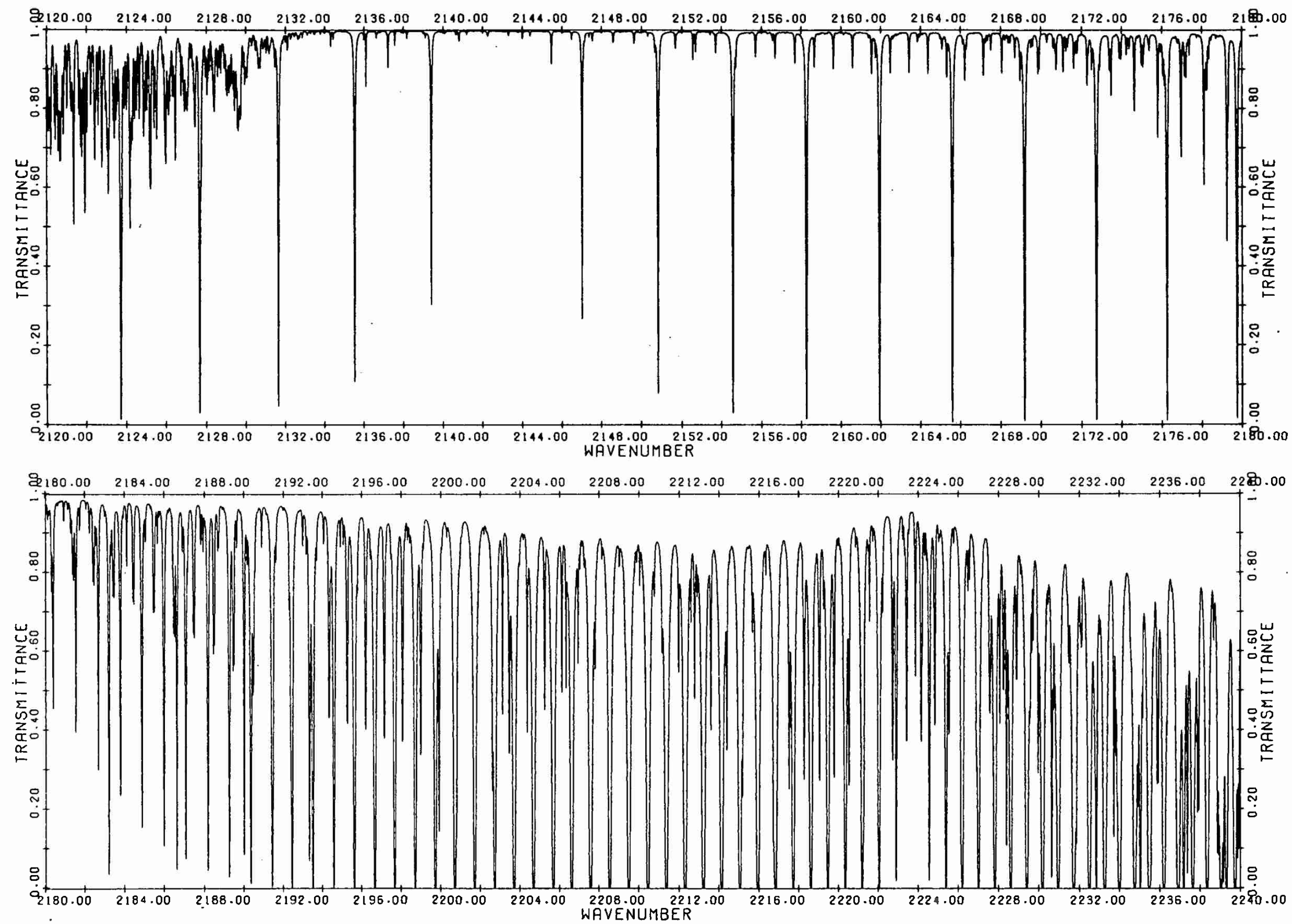


Figure 5p. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

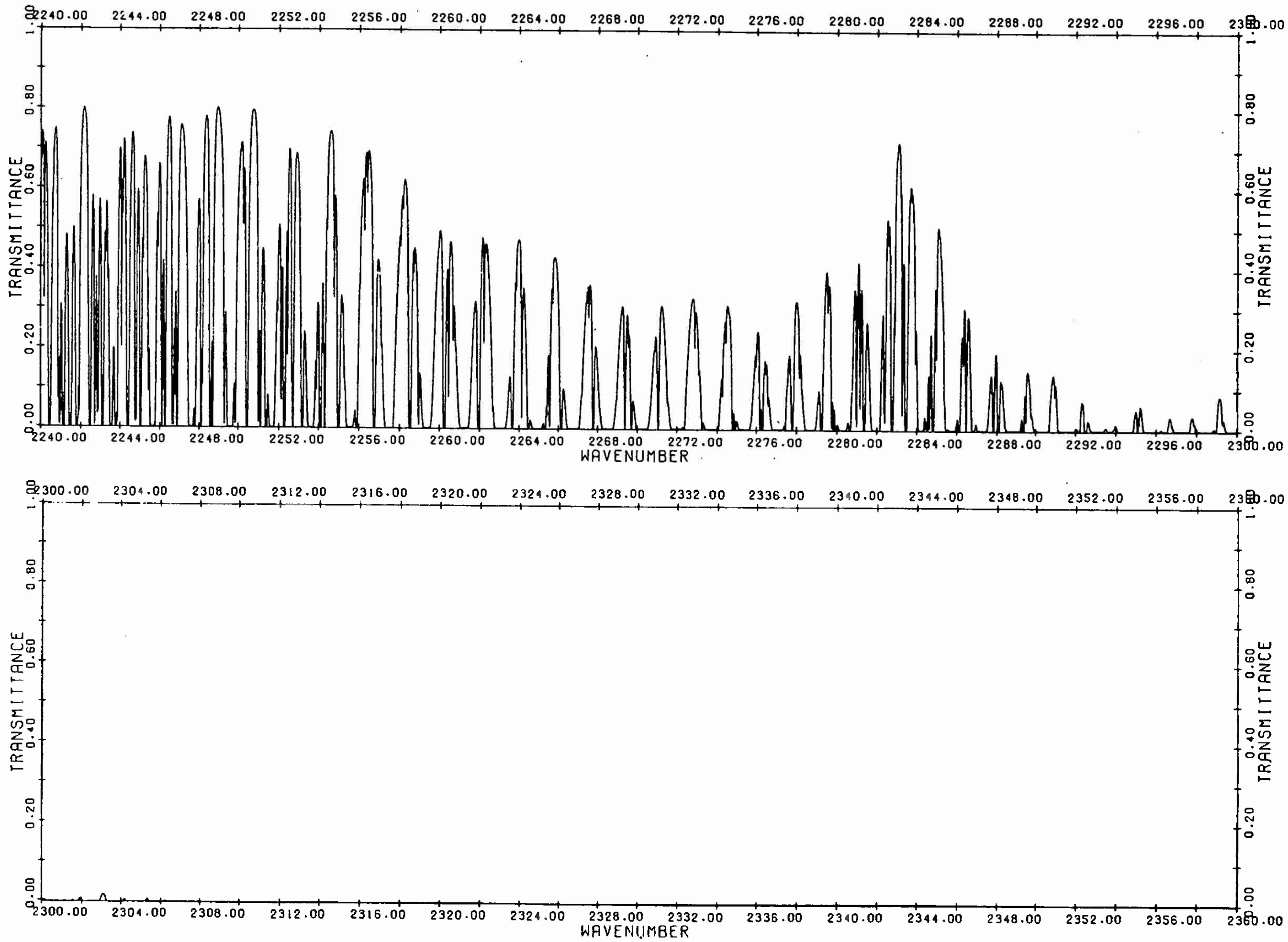


Figure 5q. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

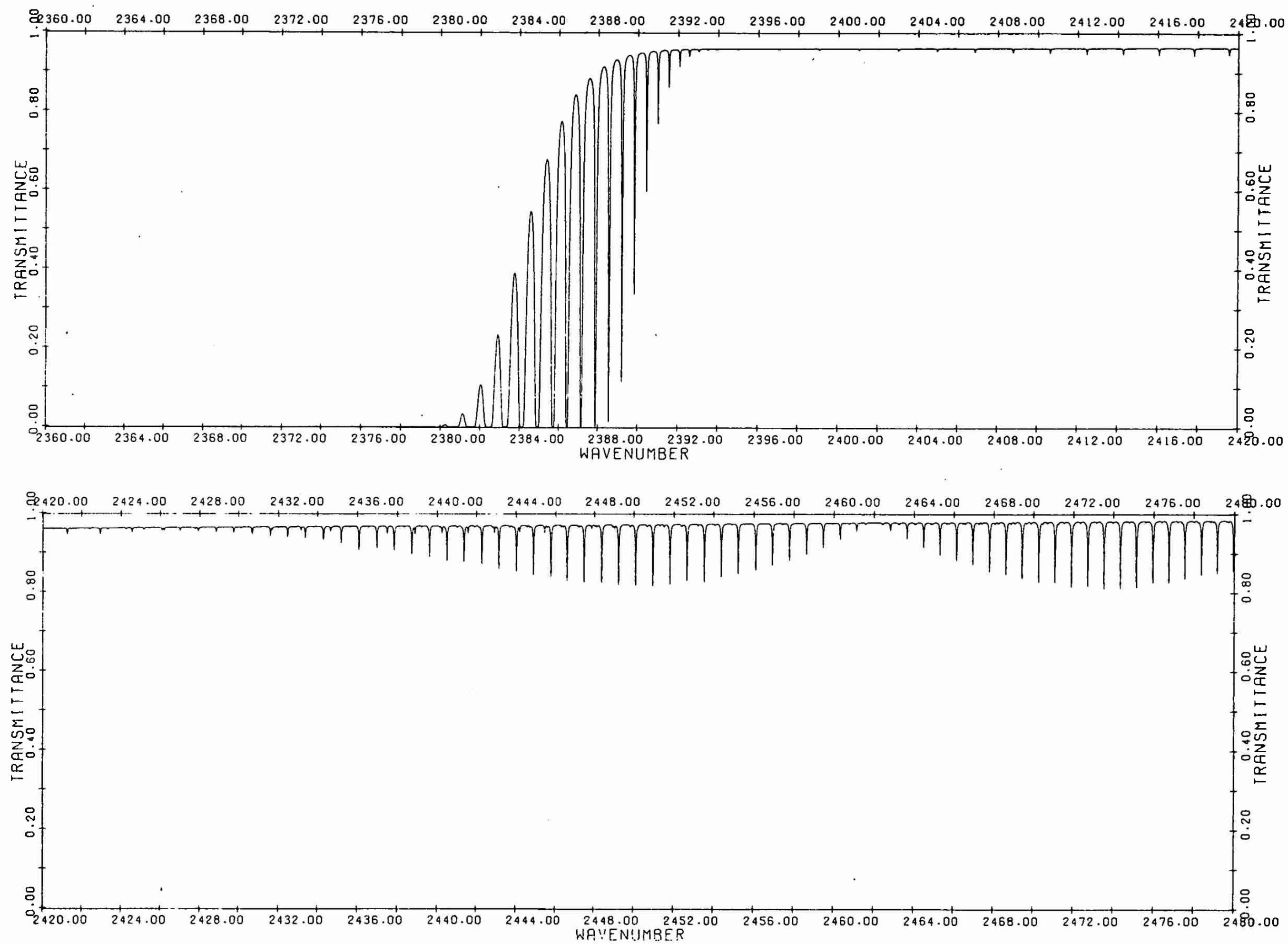


Figure 5r. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

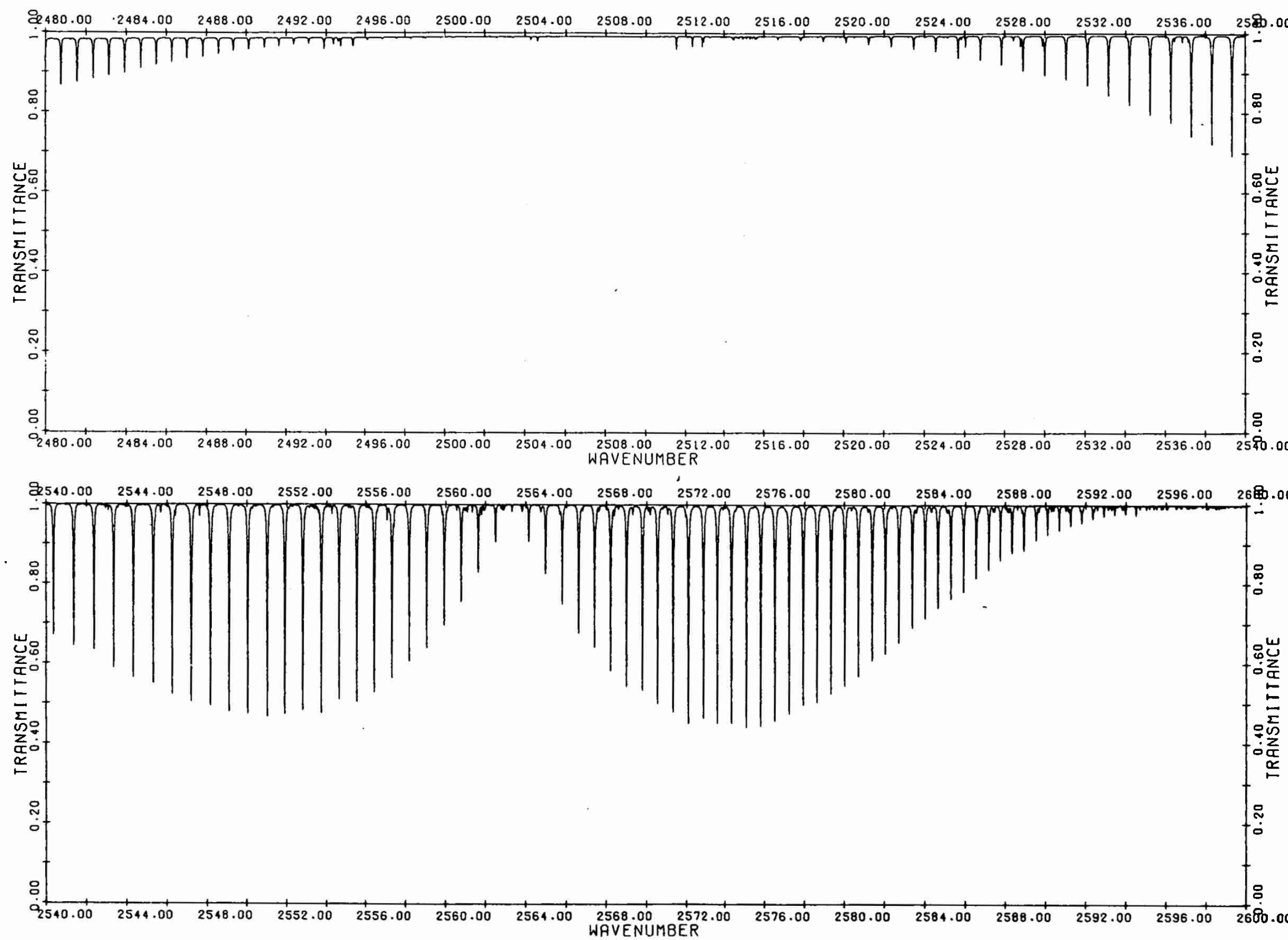


Figure 5s. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

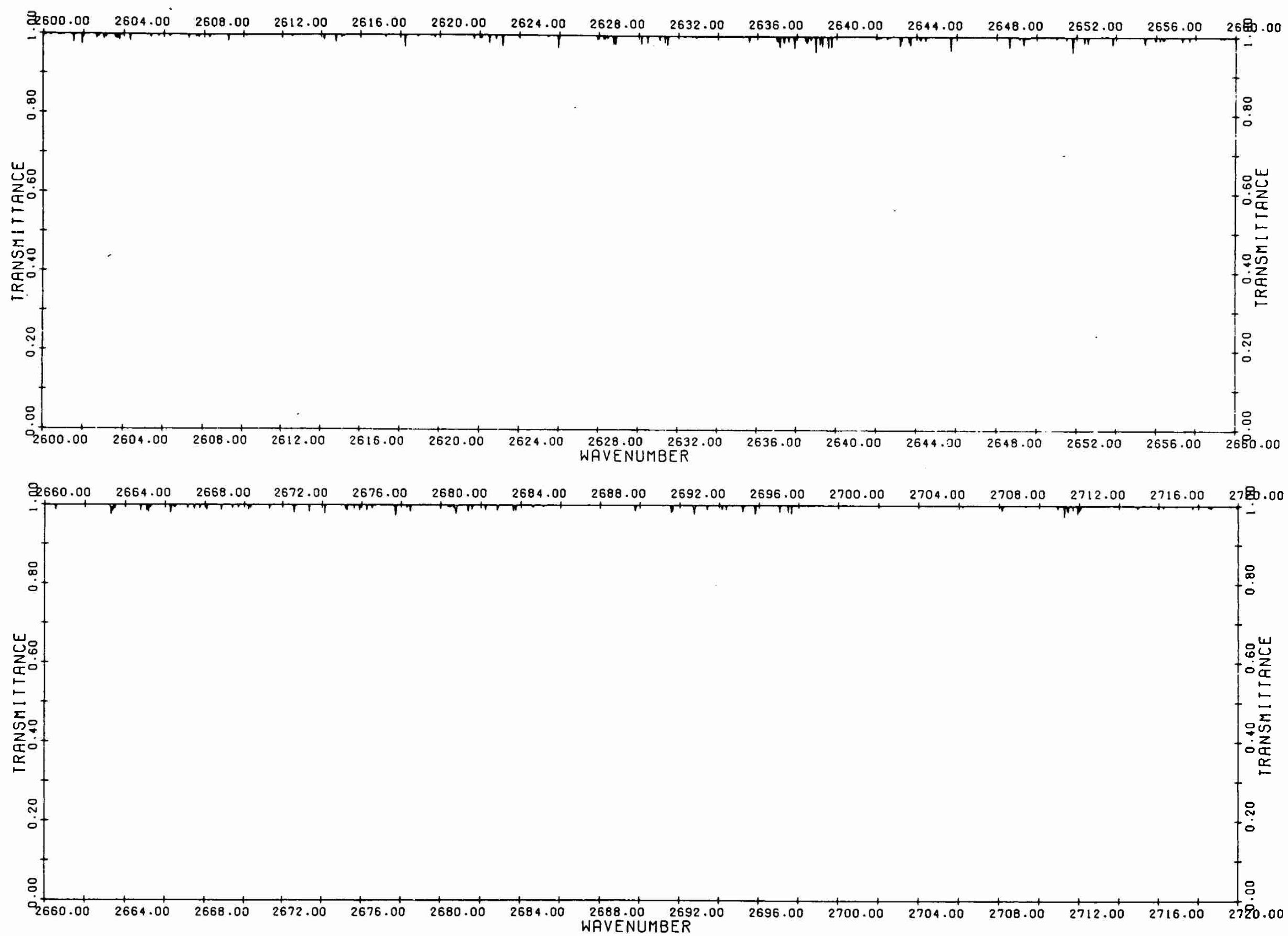


Figure 5t. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

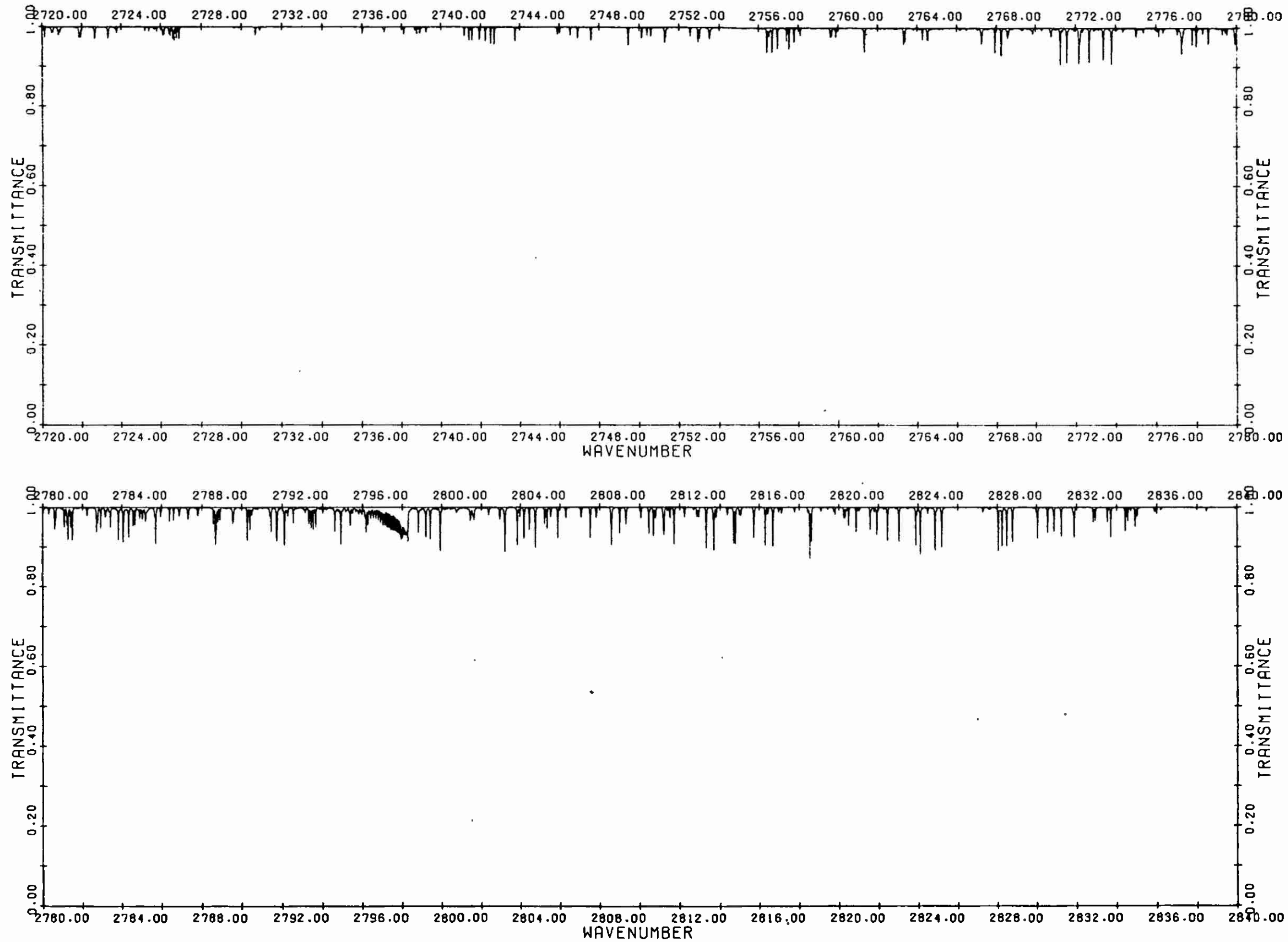


Figure 5u. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

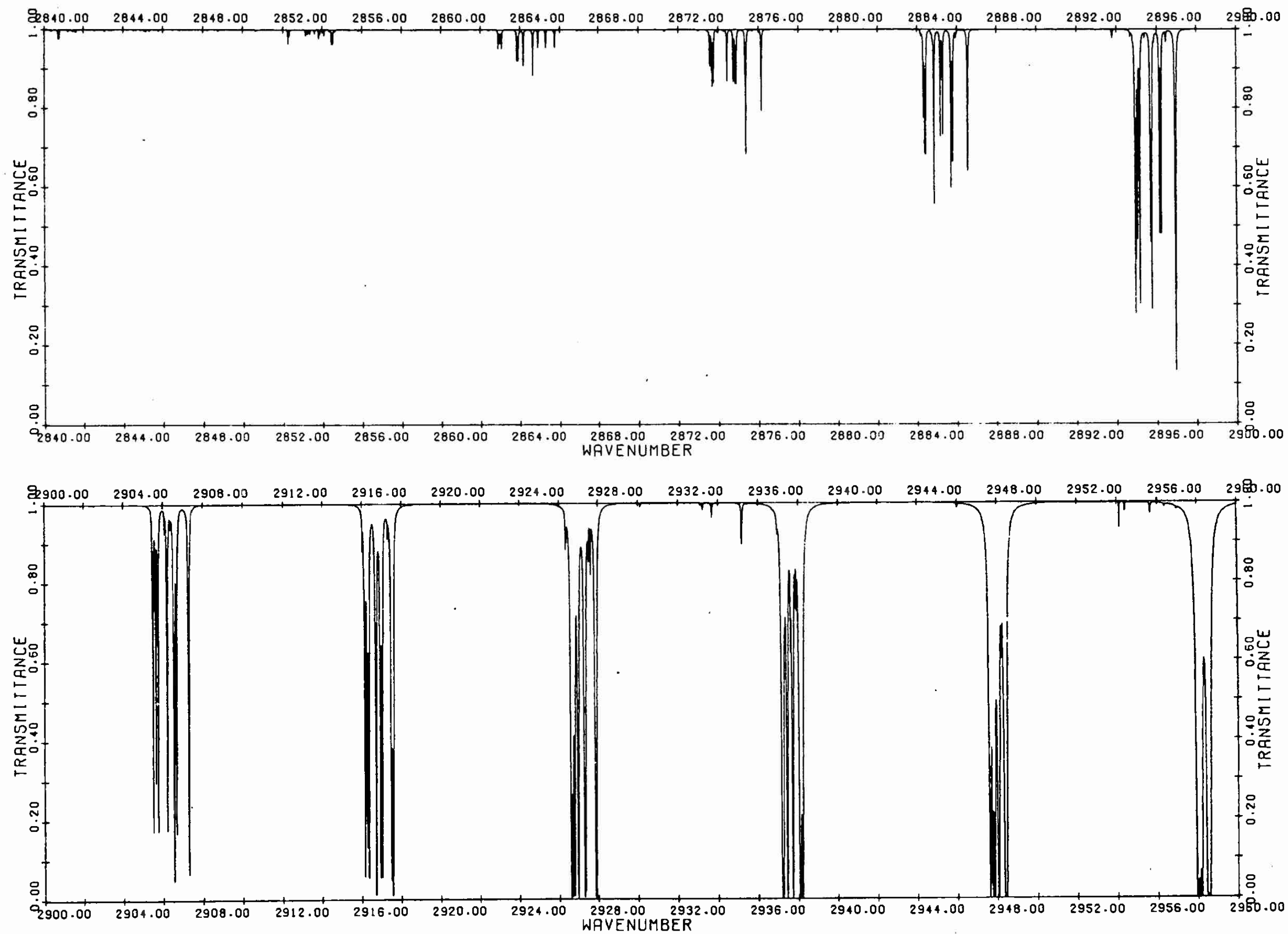


Figure 5v. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

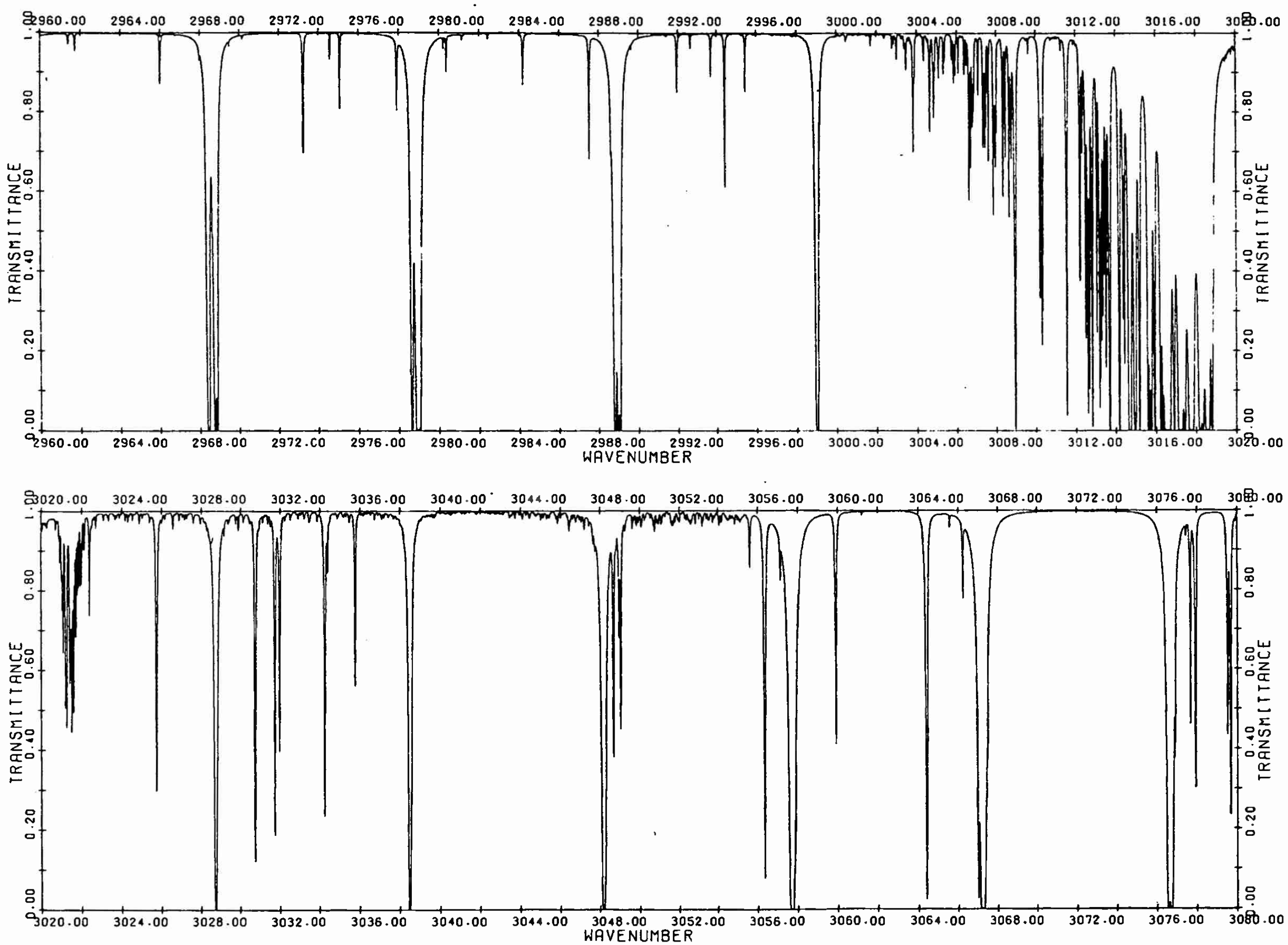


Figure 5w. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

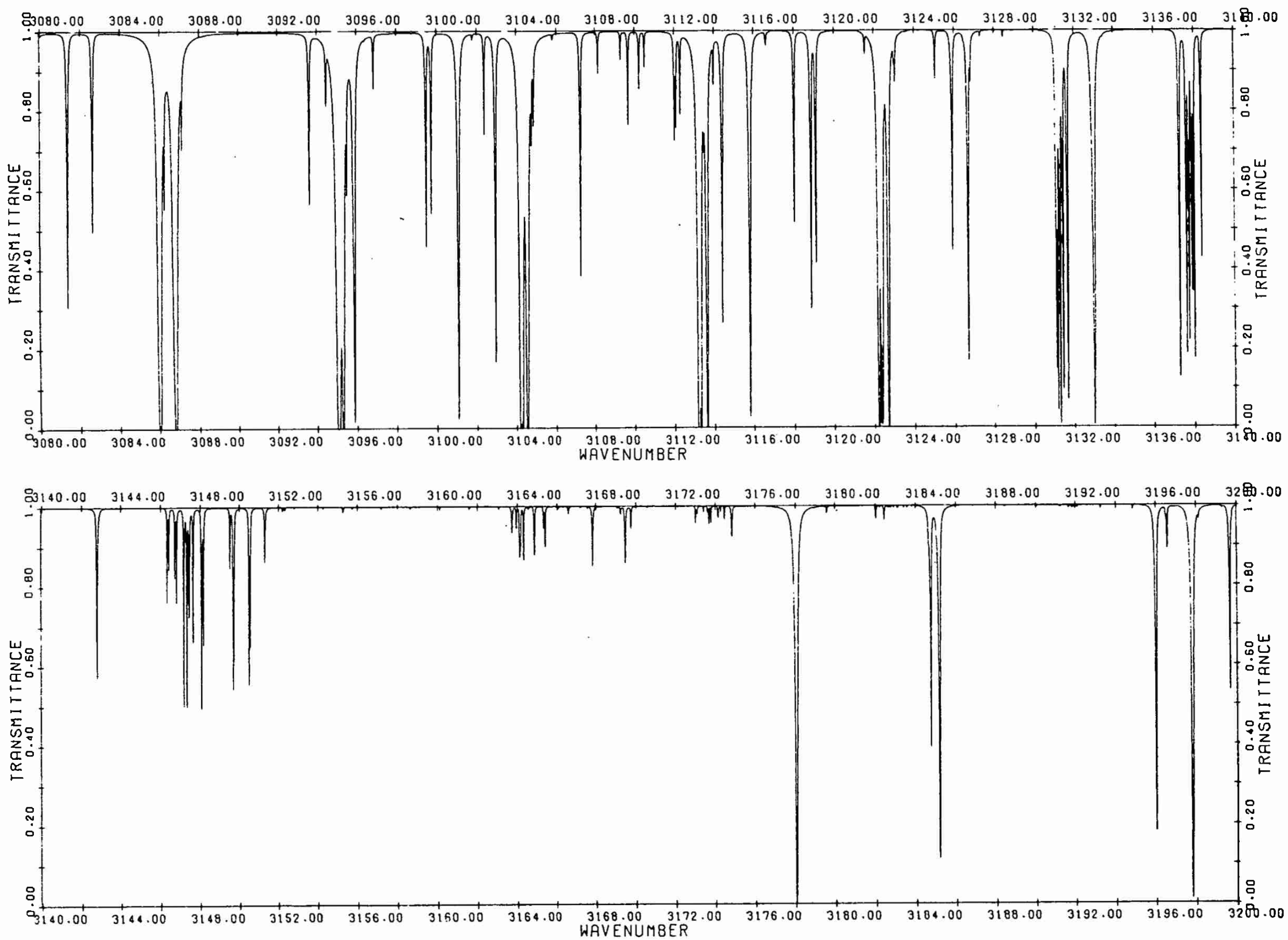


Figure 5x. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

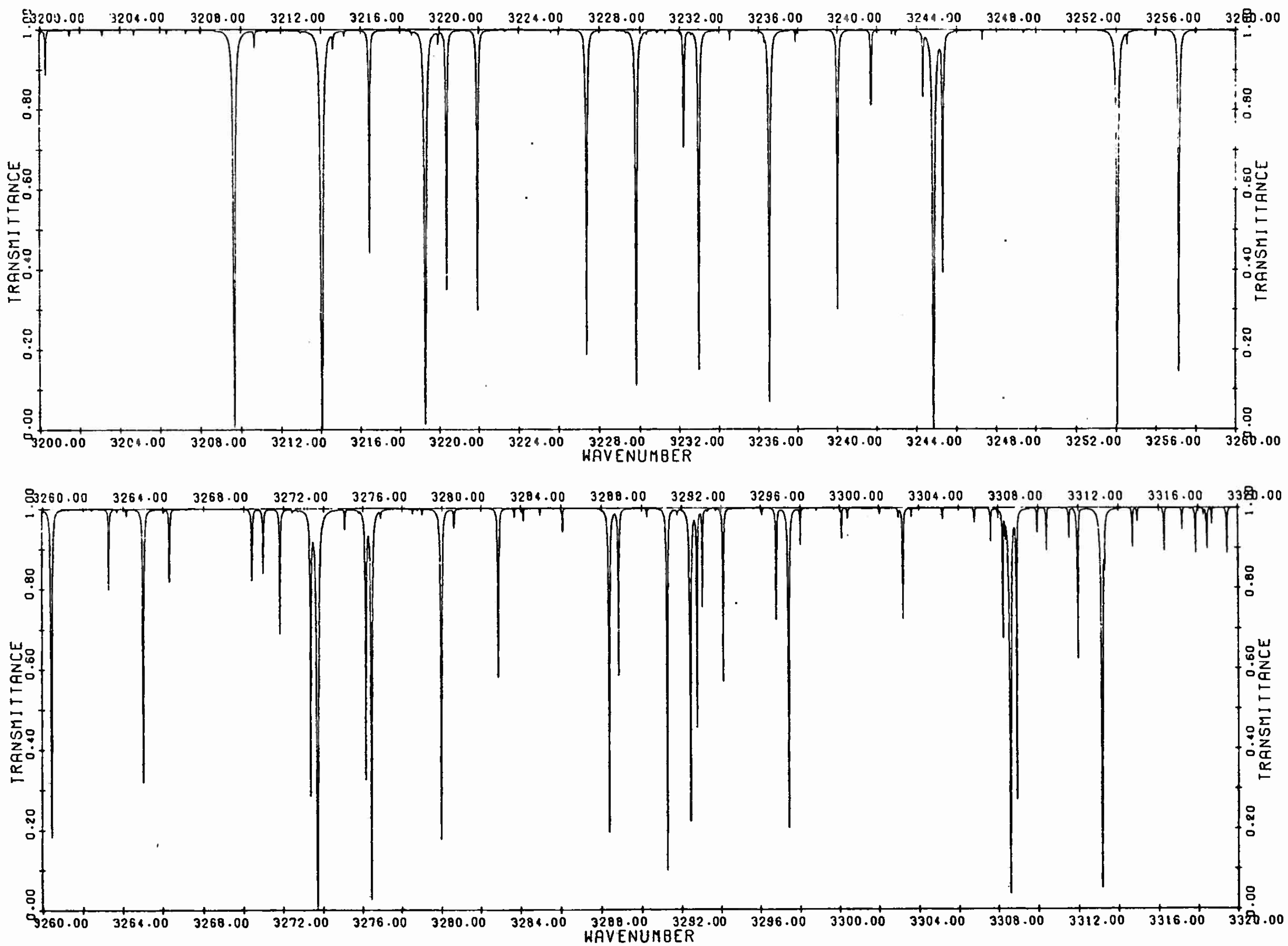


Figure 5y. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

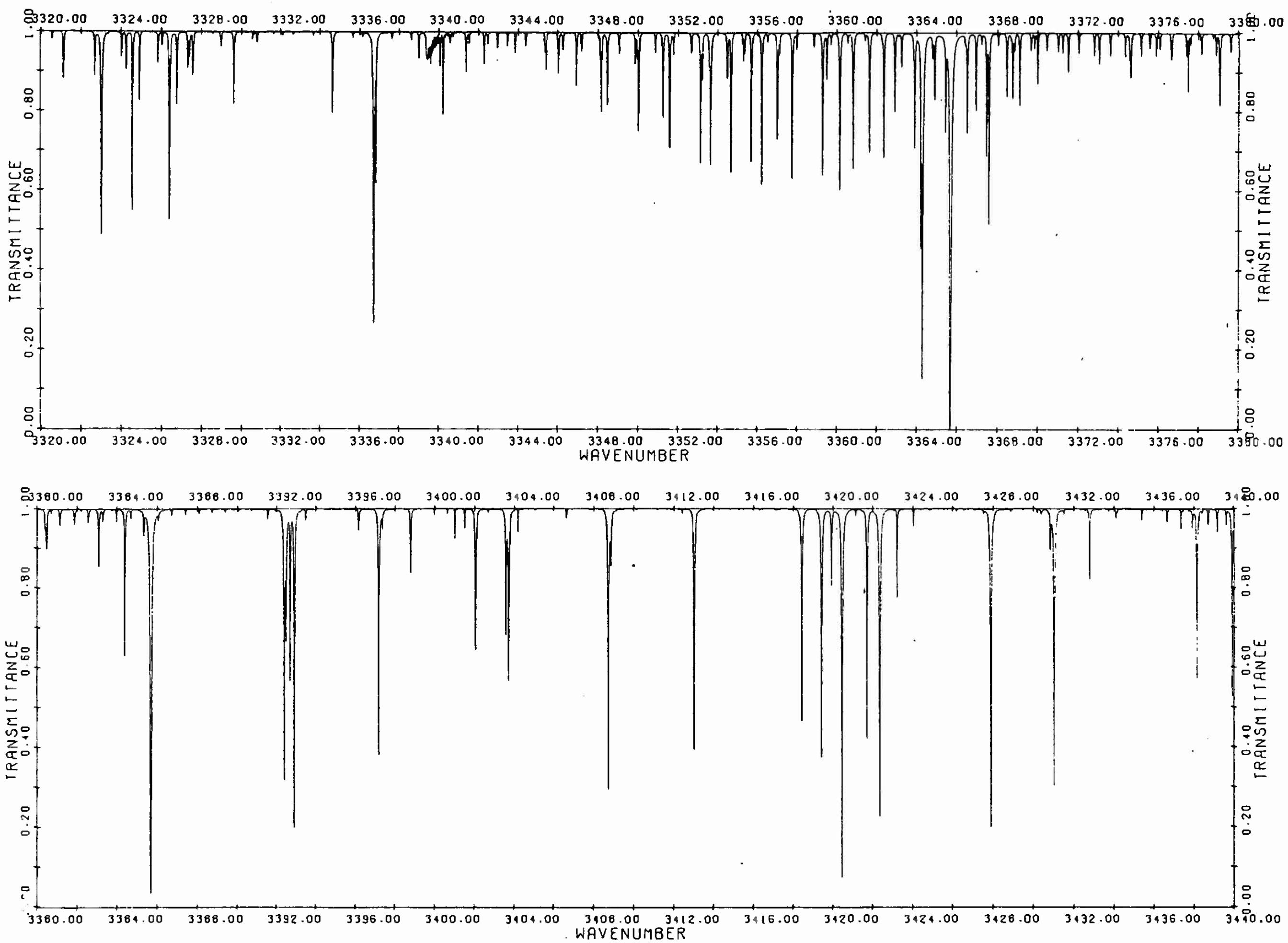


Figure 5z. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

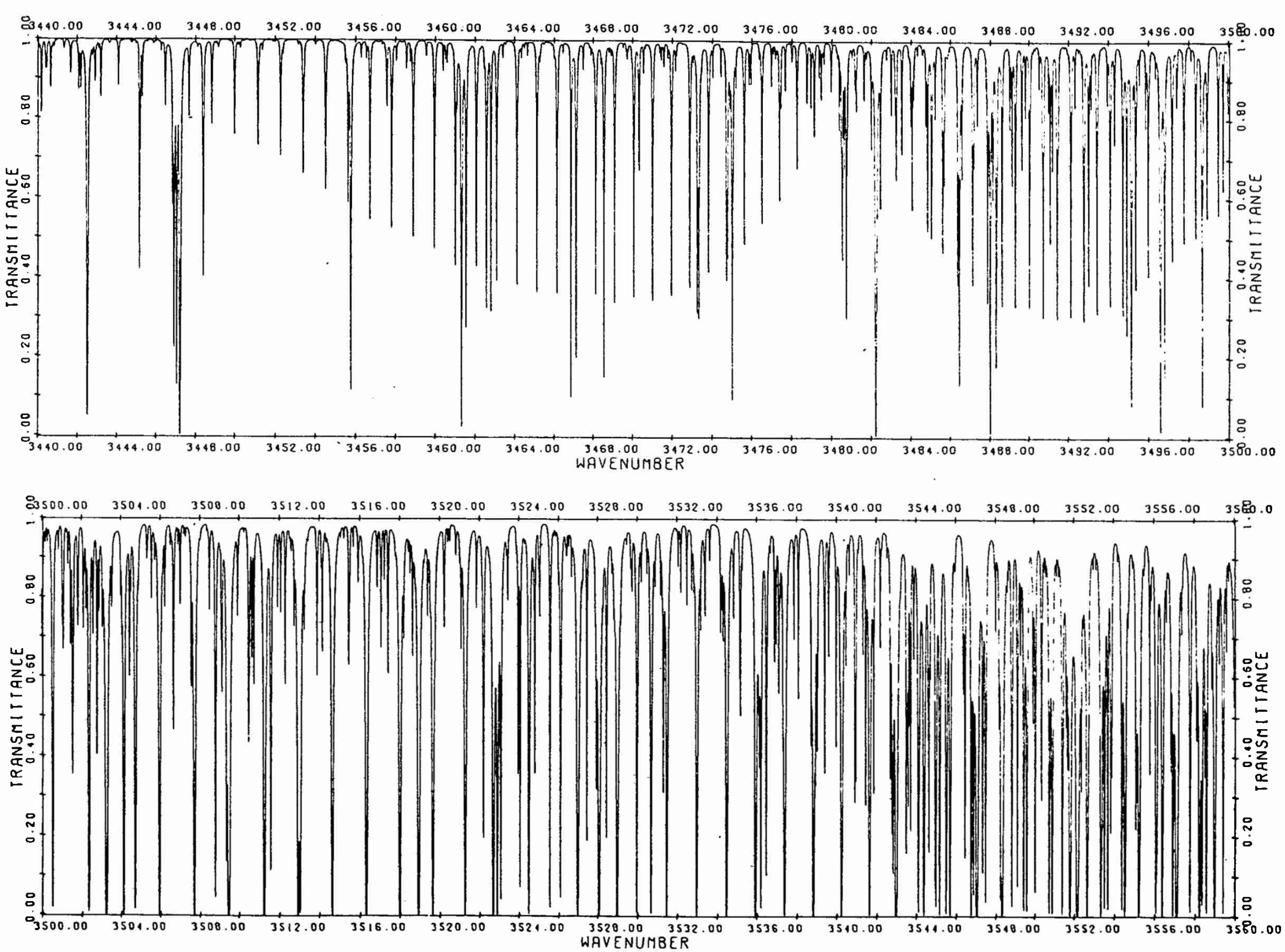


Figure 5aa. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

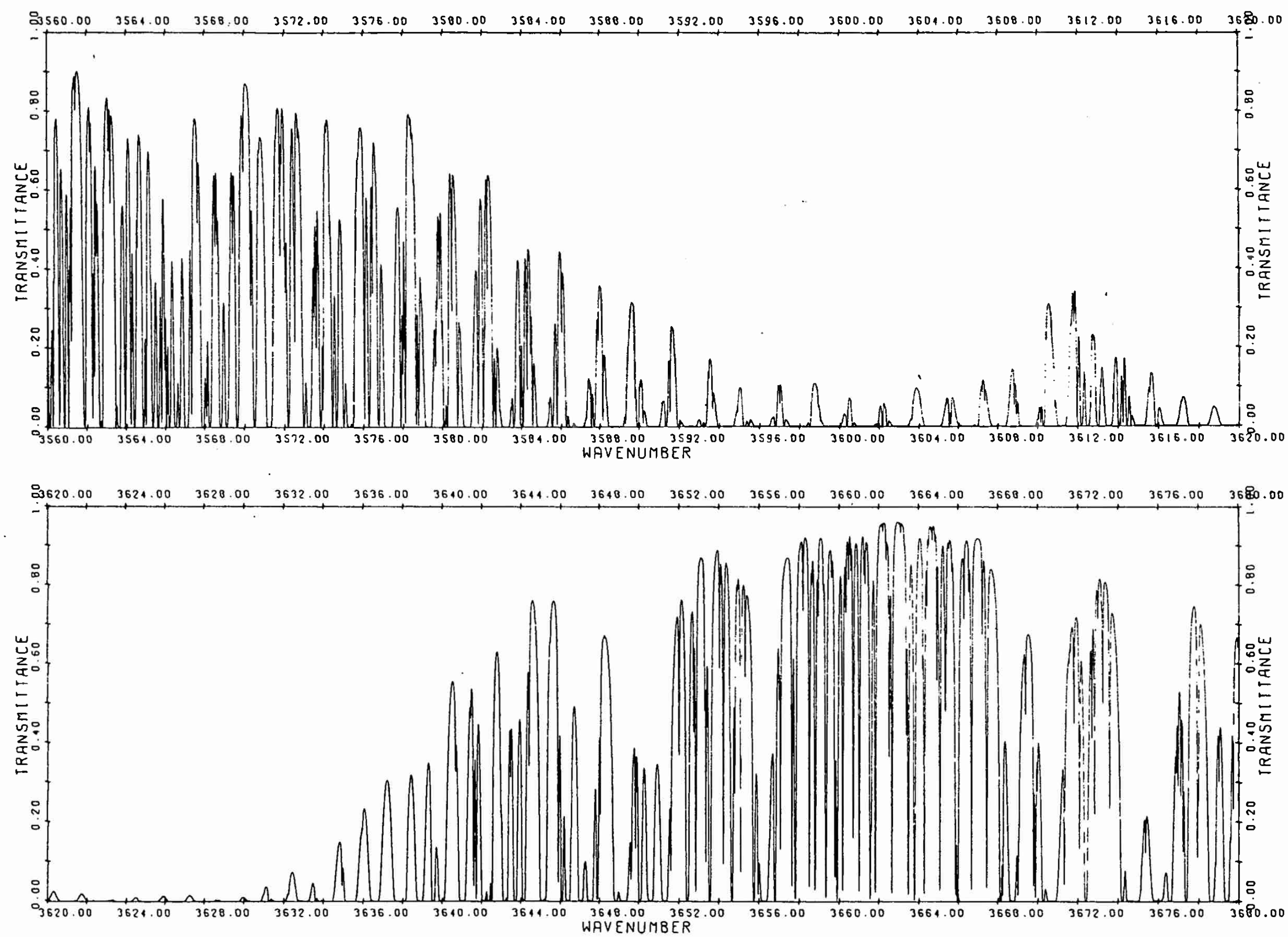


Figure 5ab. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

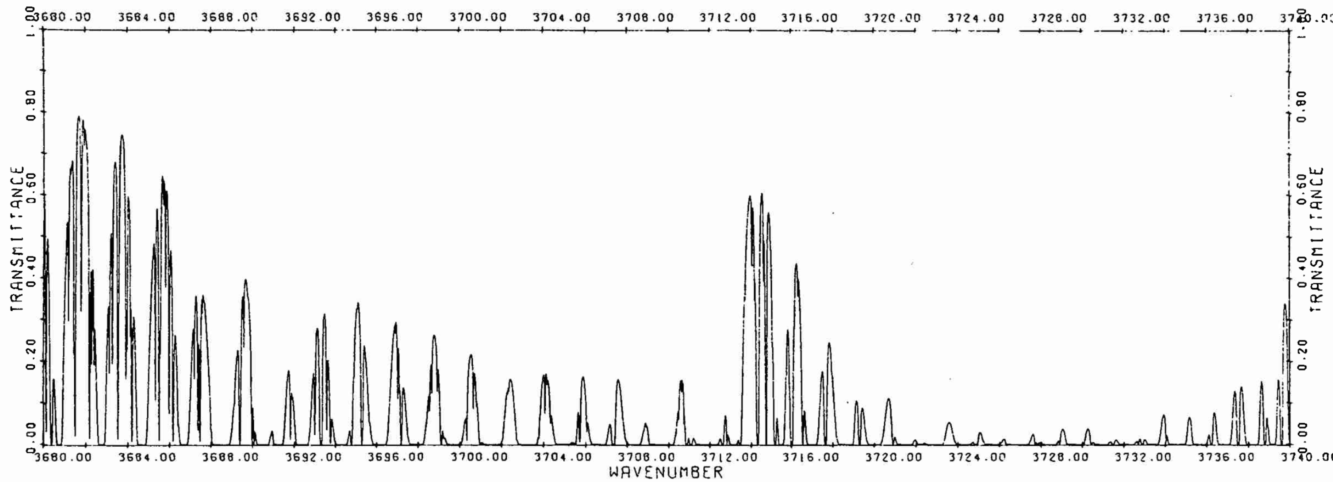


Figure 5ac. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

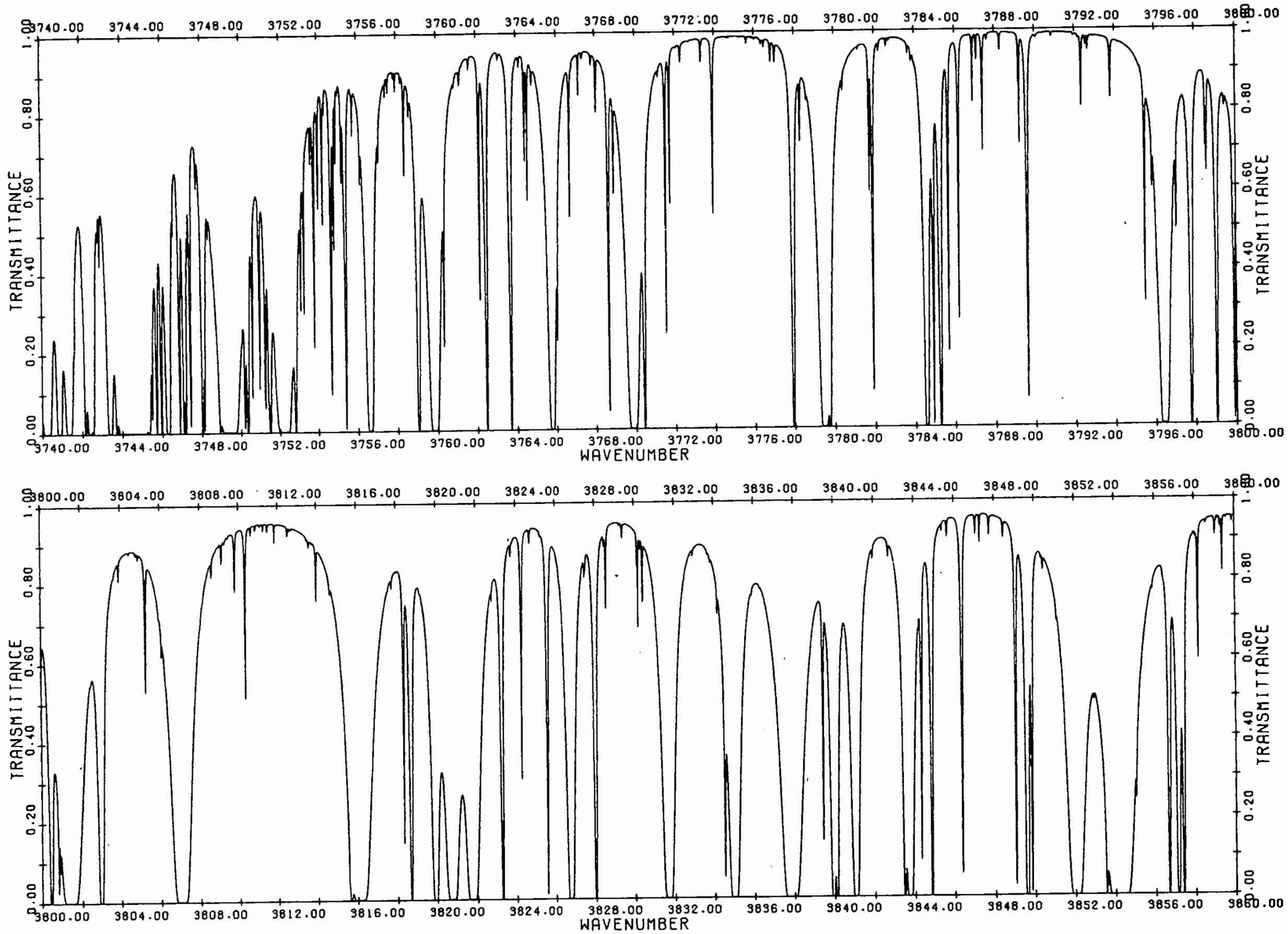


Figure 5ad. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

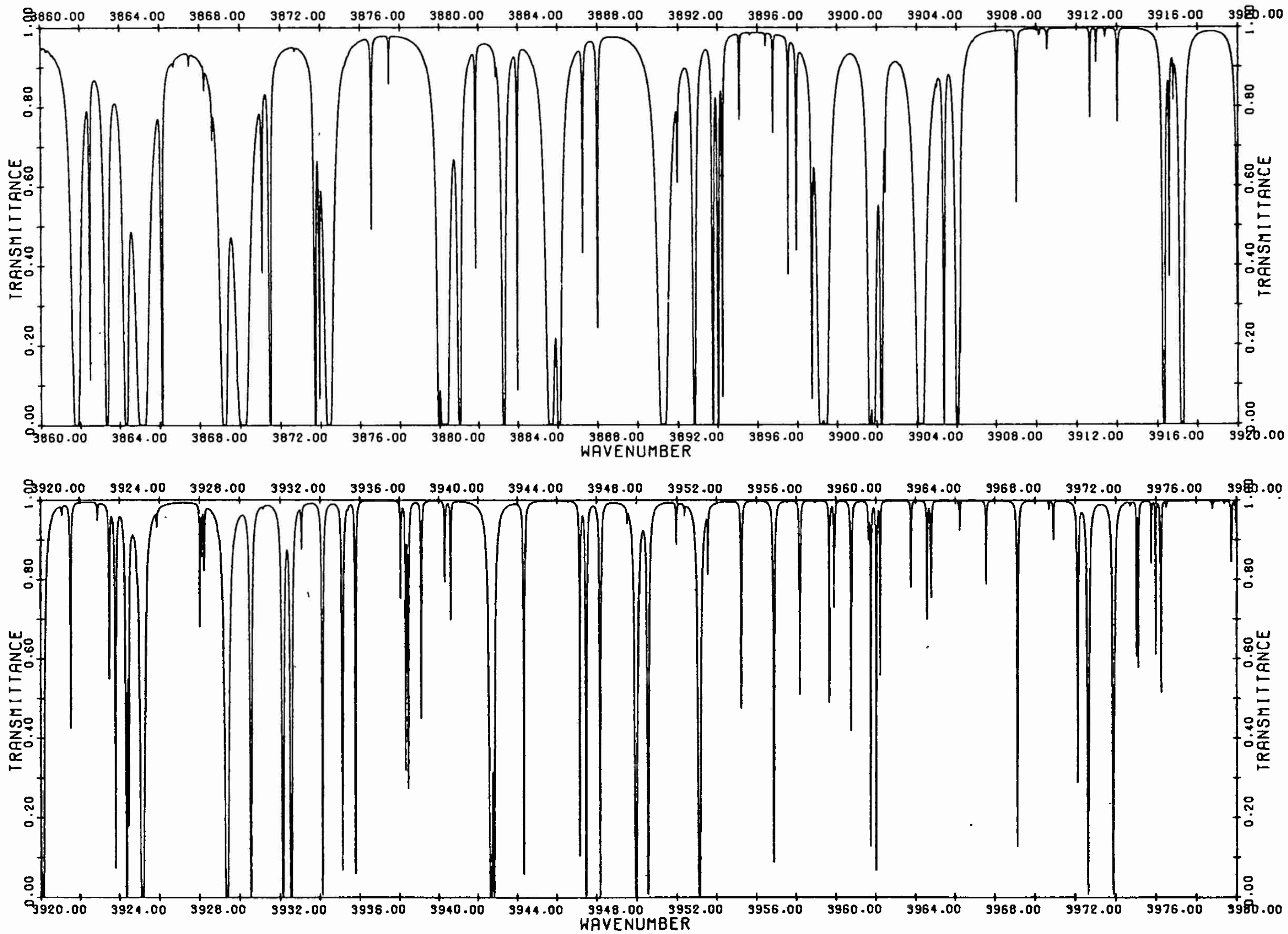
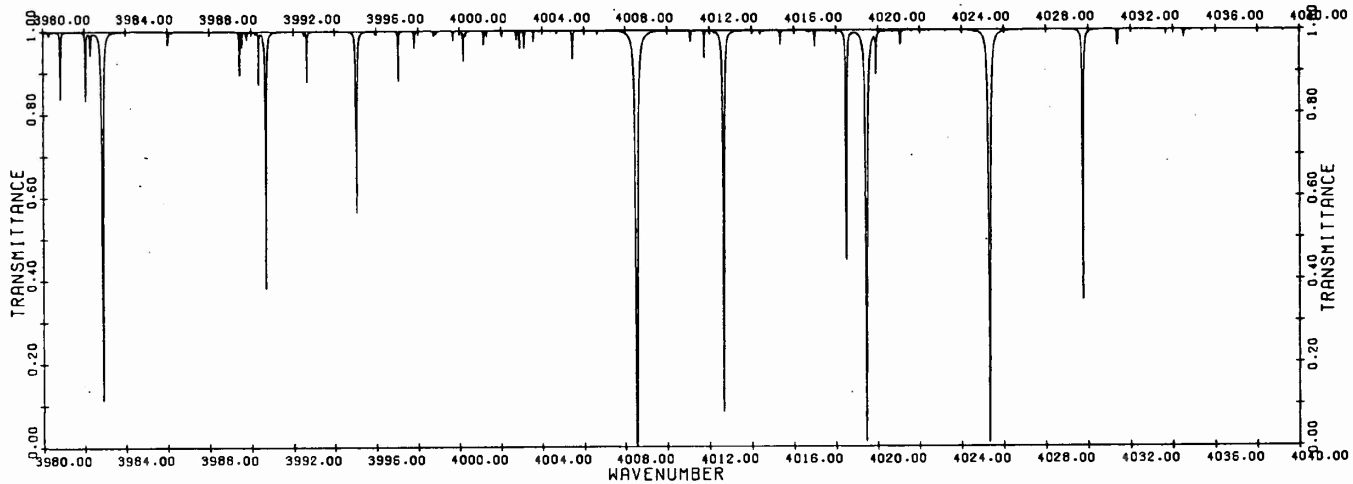


Figure 5ae. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude



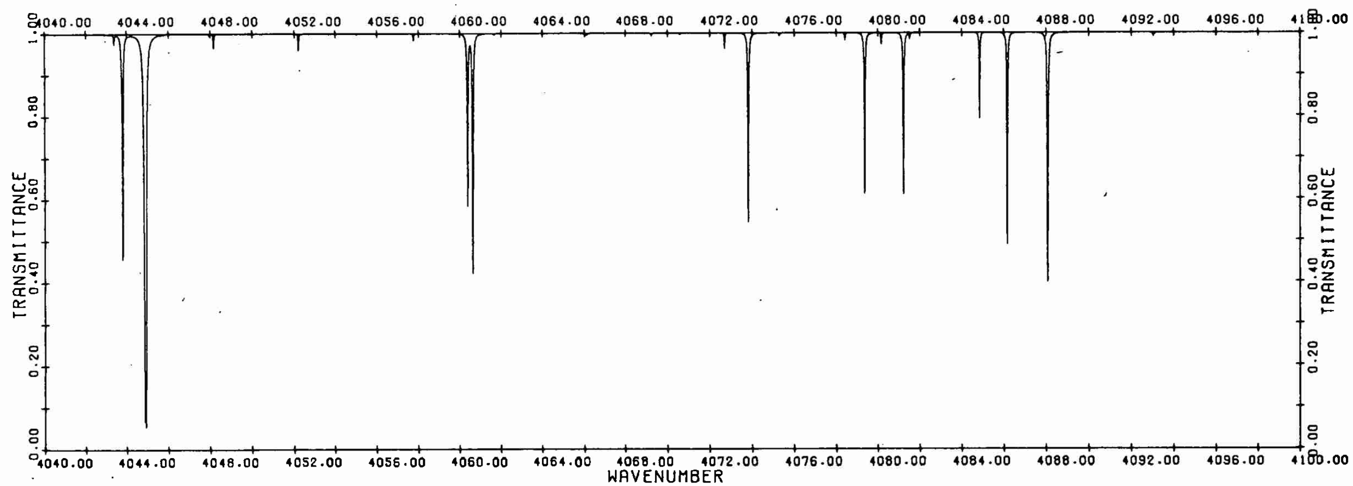


Figure 5af. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

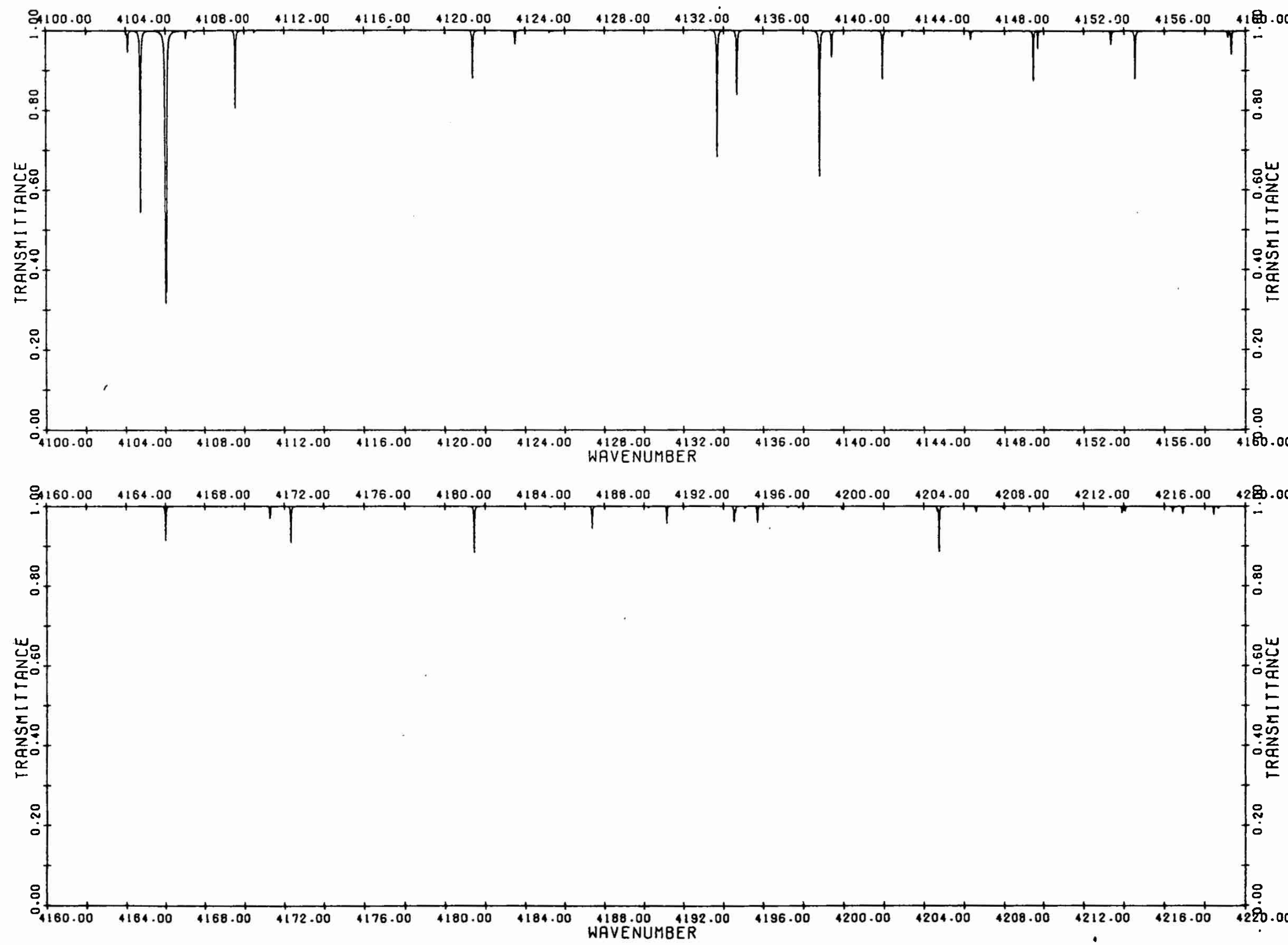


Figure 5ag. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

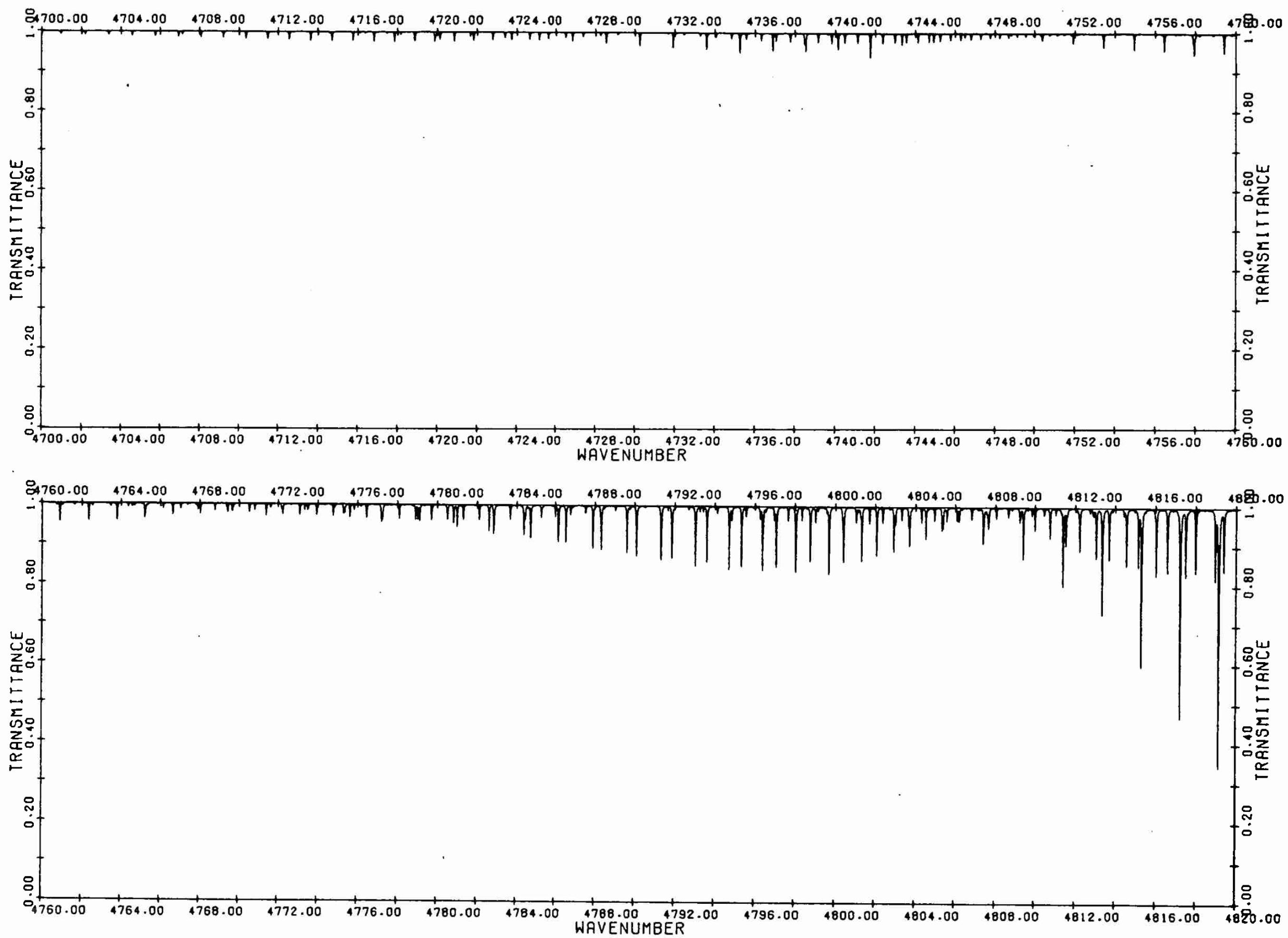


Figure 5al. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

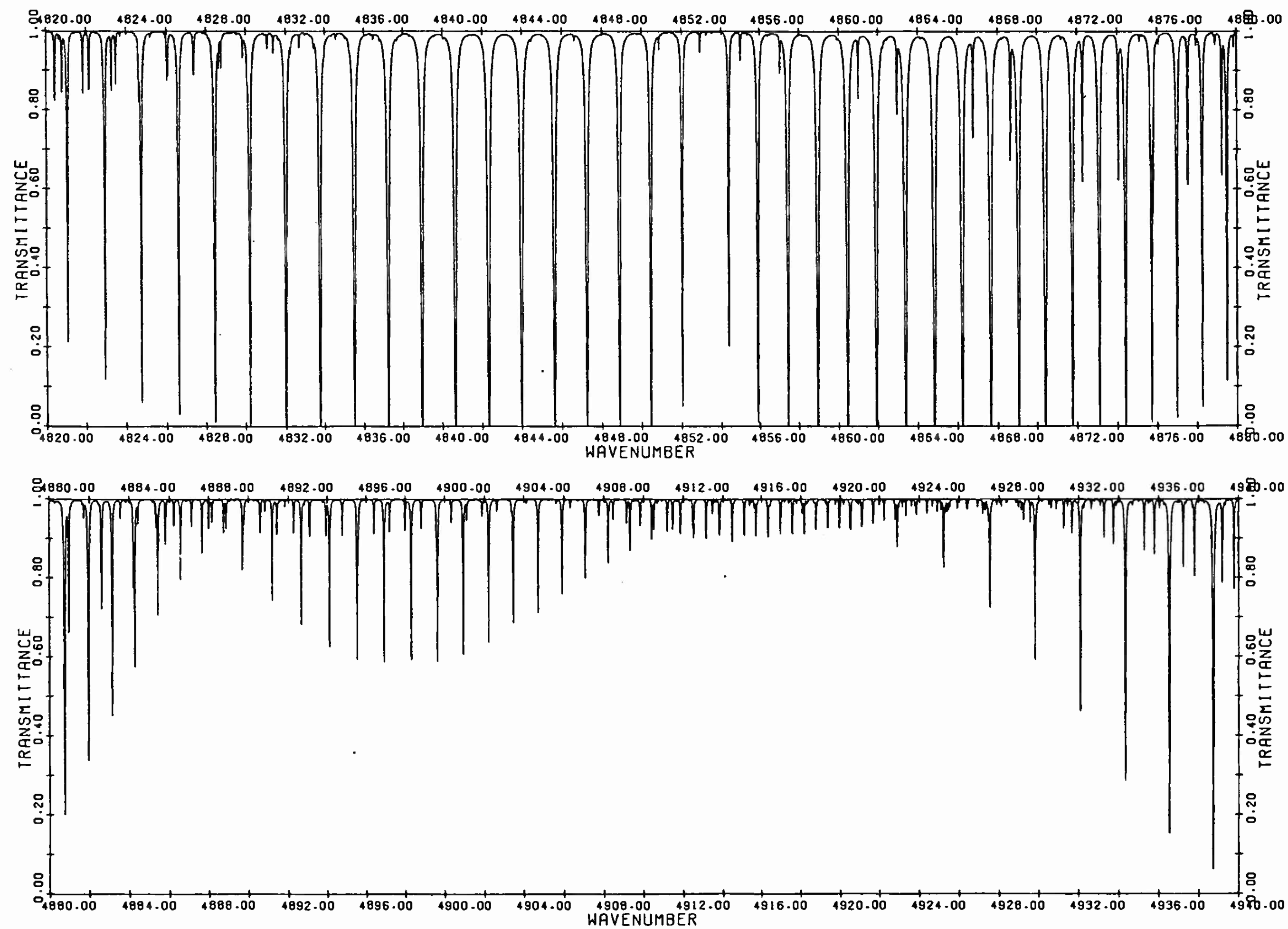


Figure 5am. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

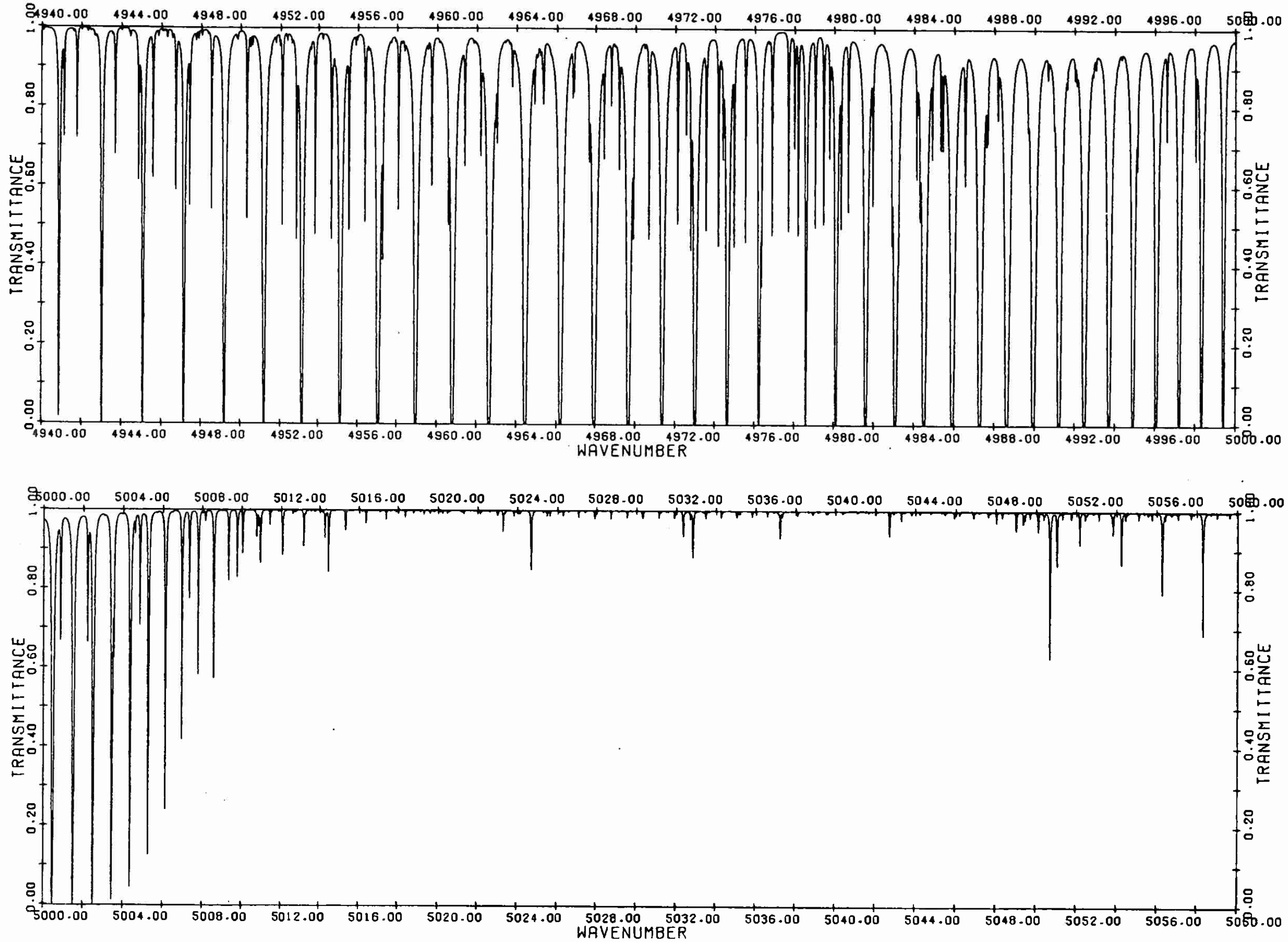
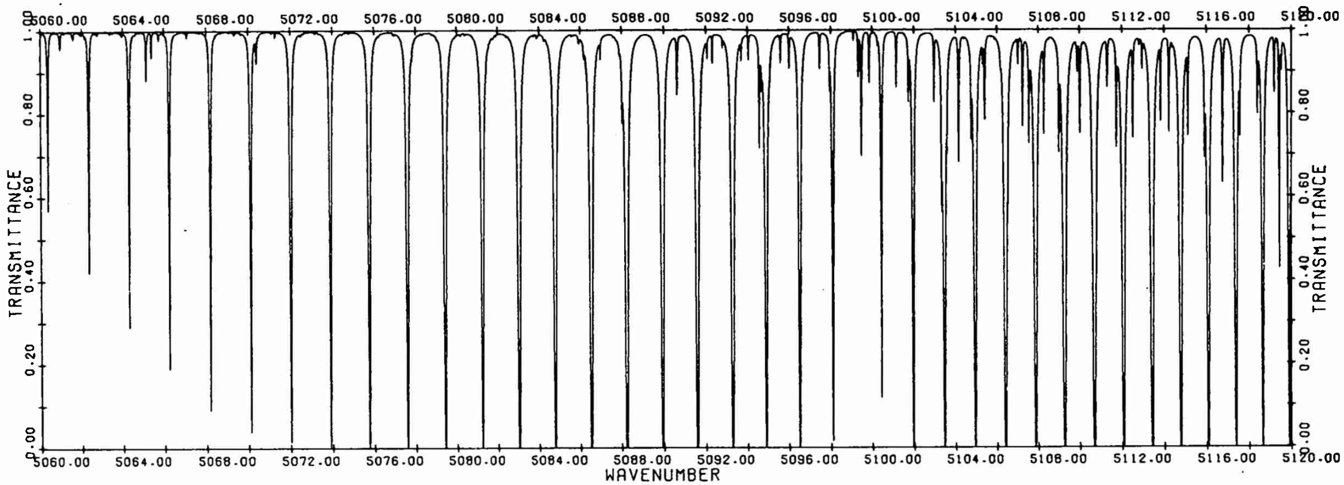


Figure 5an. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude



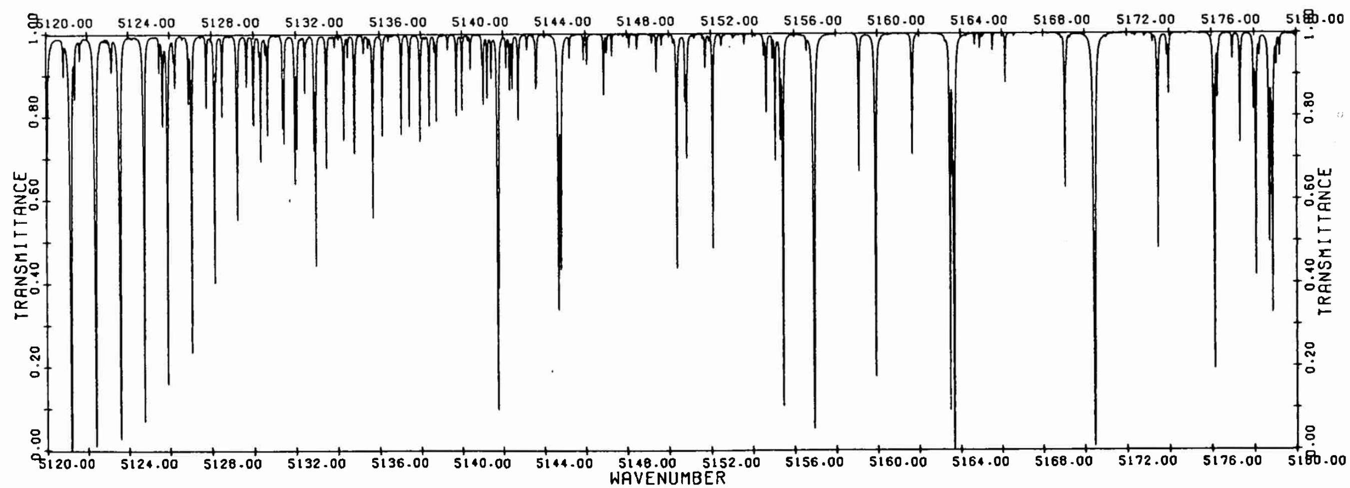


Figure 5ao. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

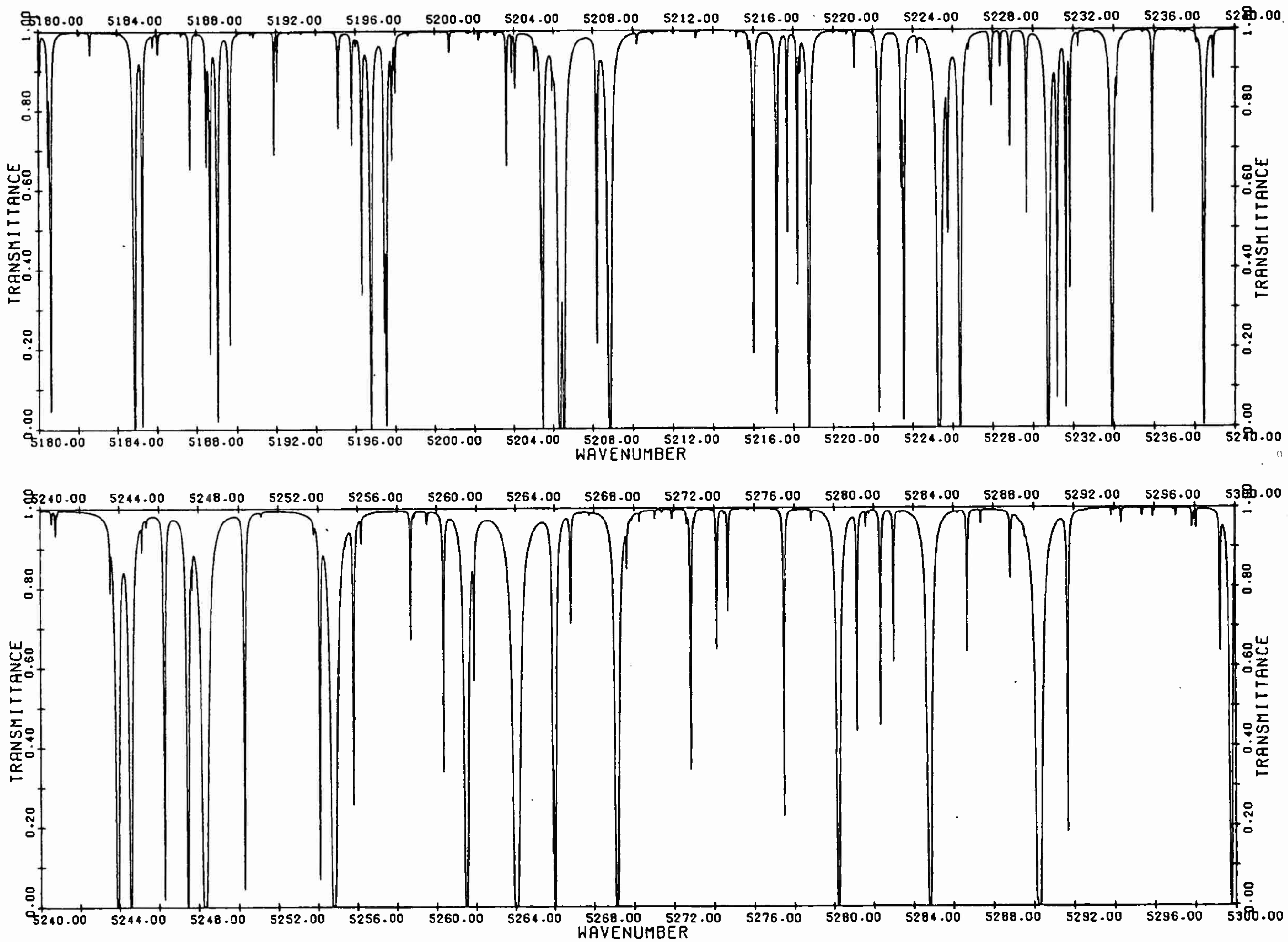


Figure 5ap. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

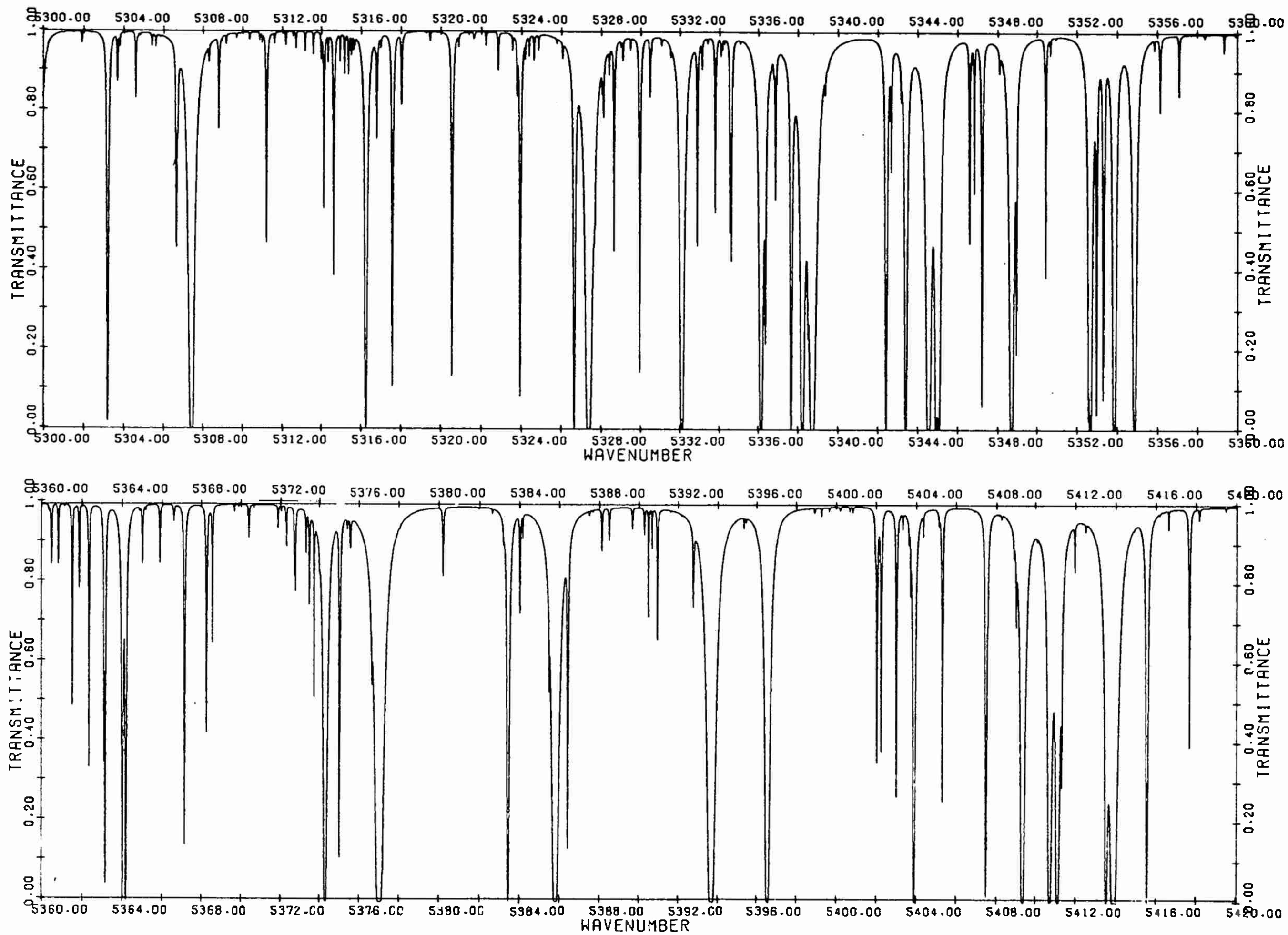


Figure 5aq. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

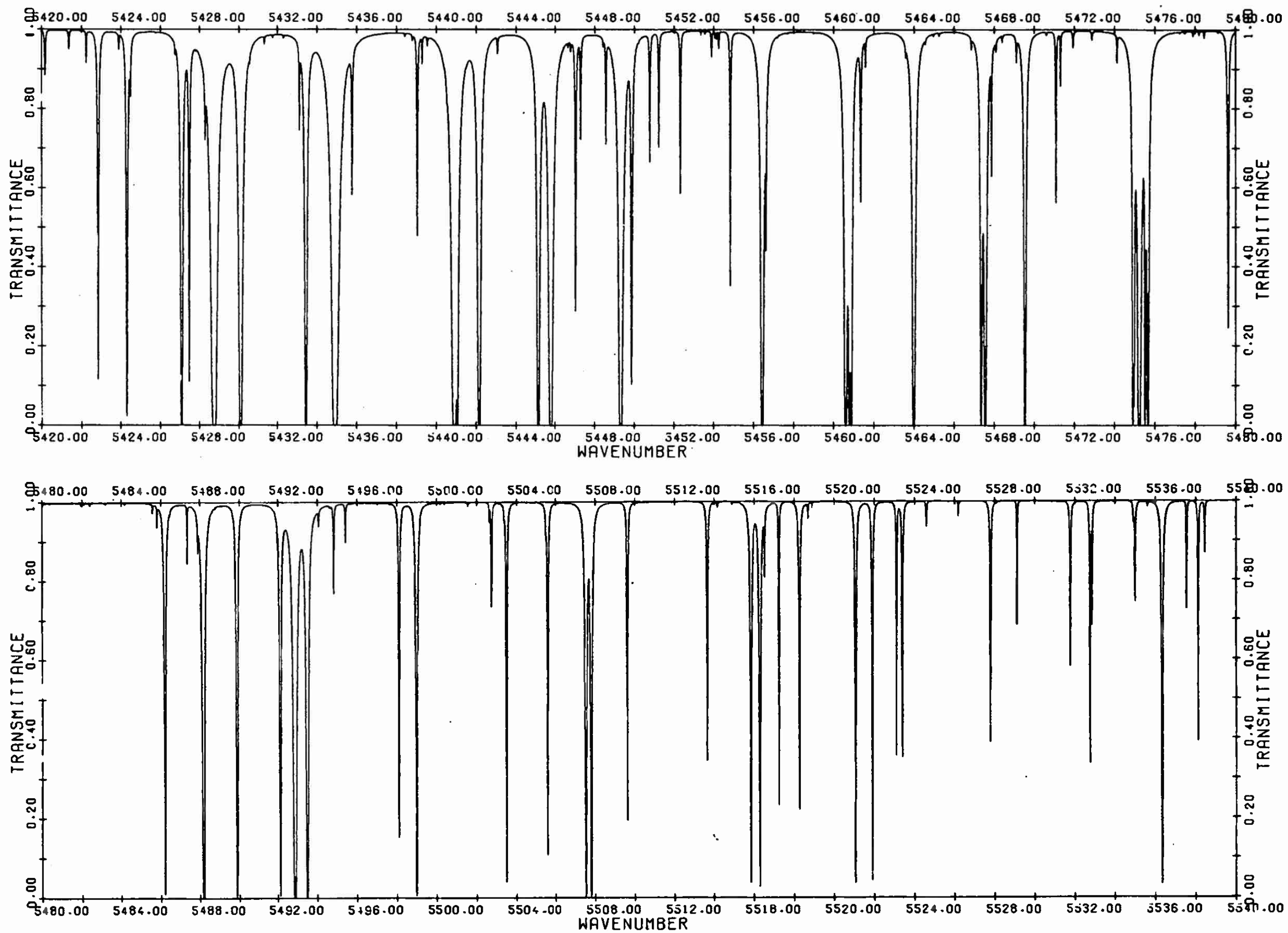


Figure 5ar. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

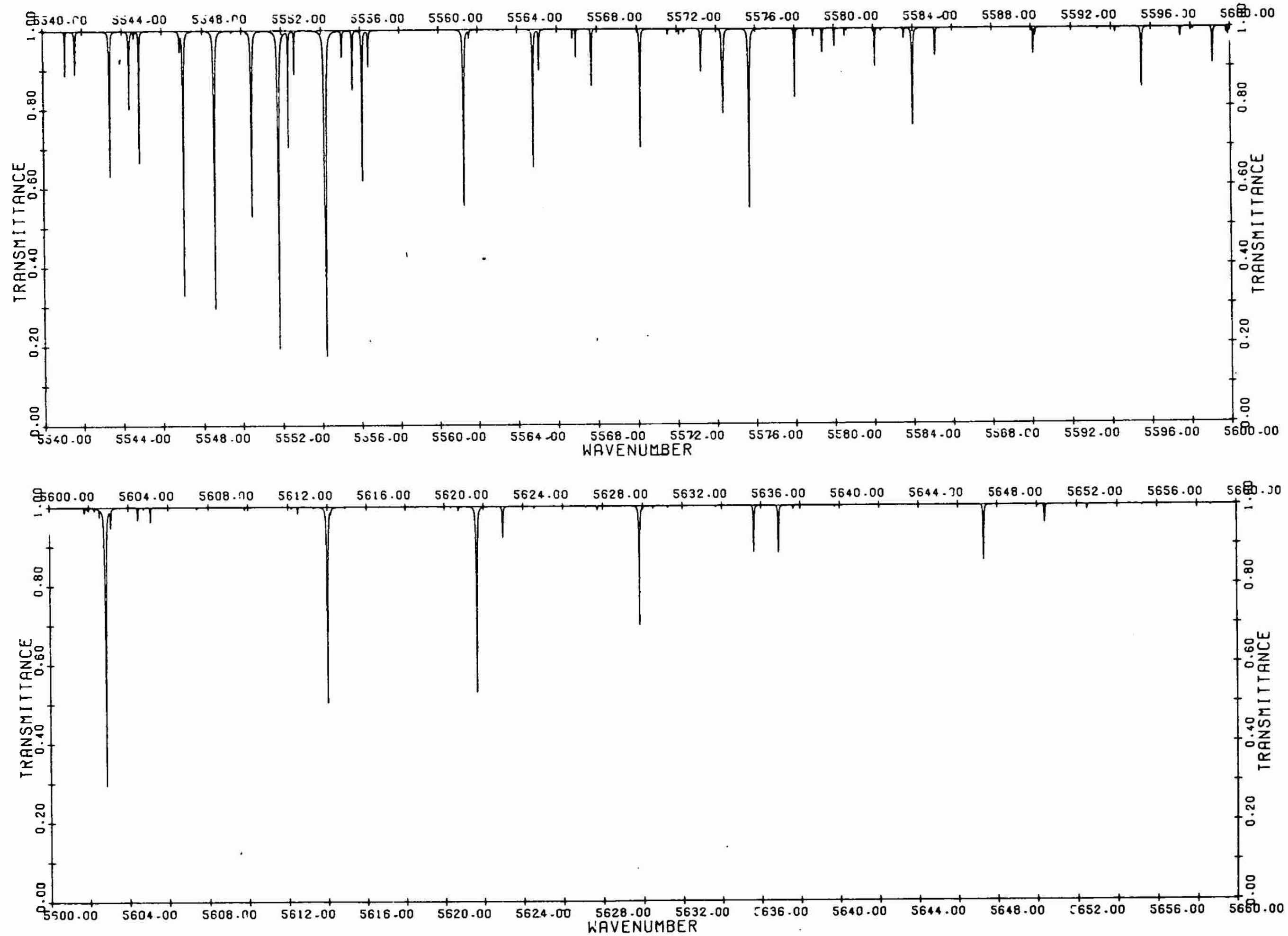


Figure 5as. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

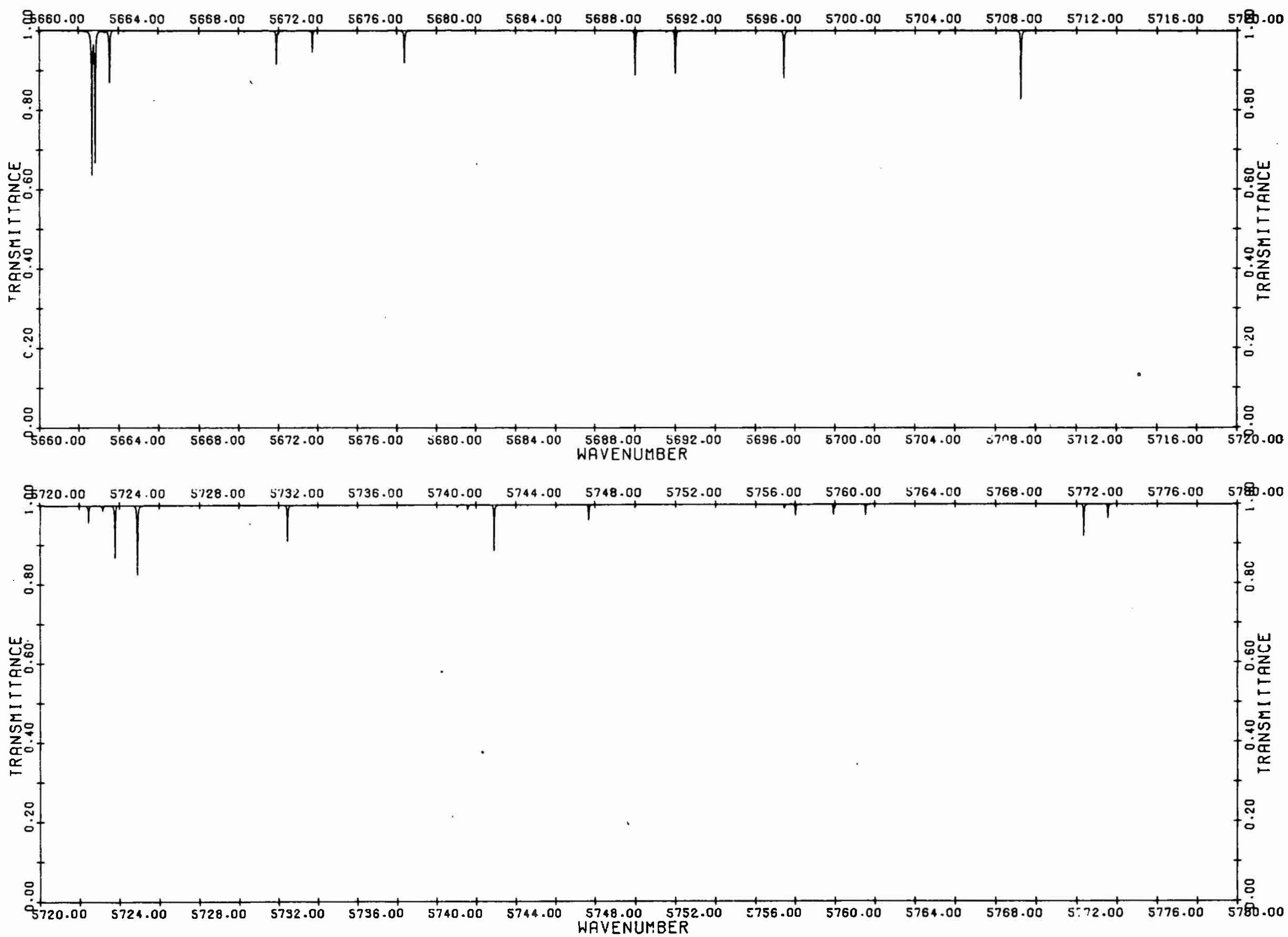


Figure 5at. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

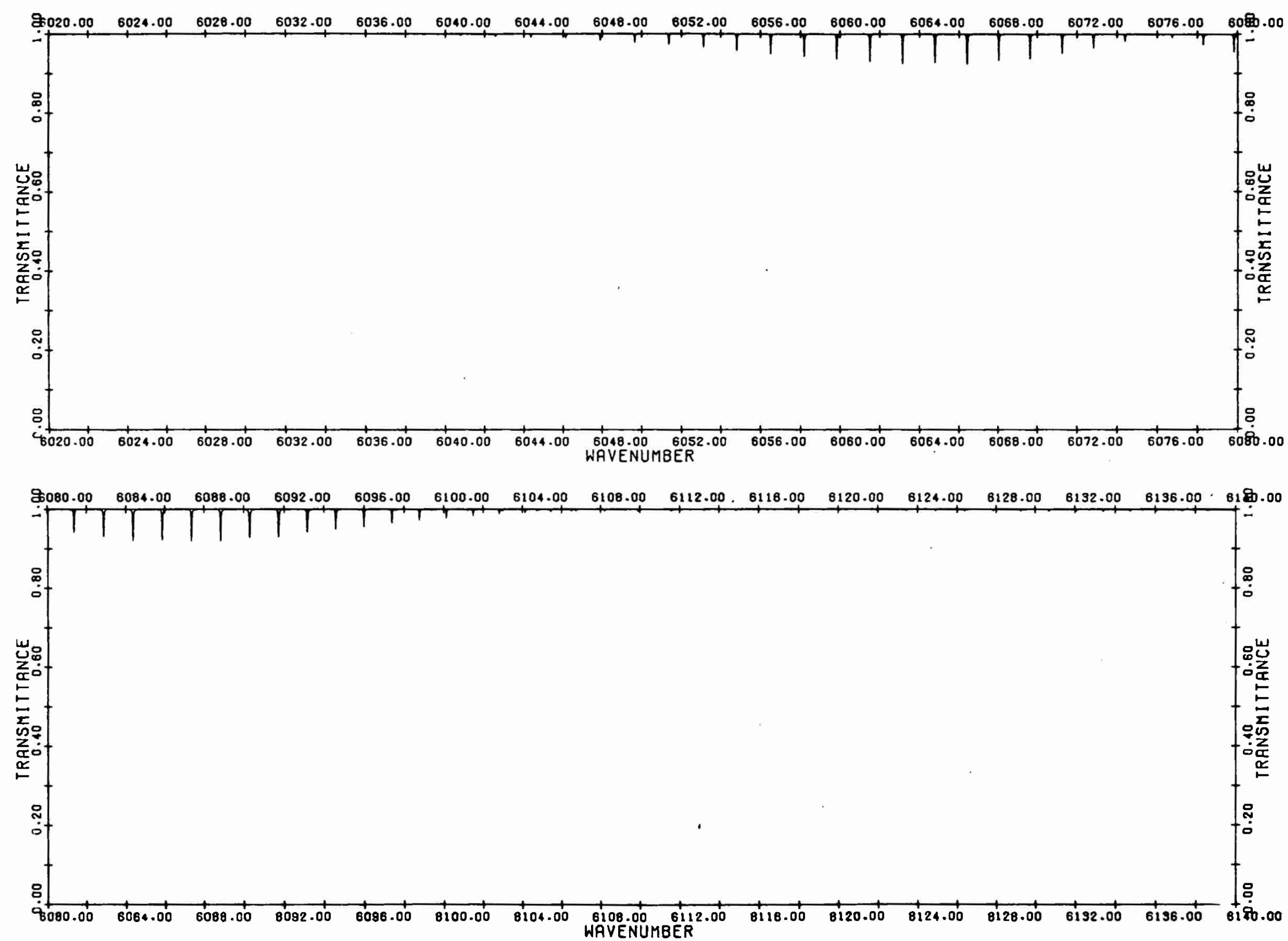


Figure 5aw. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

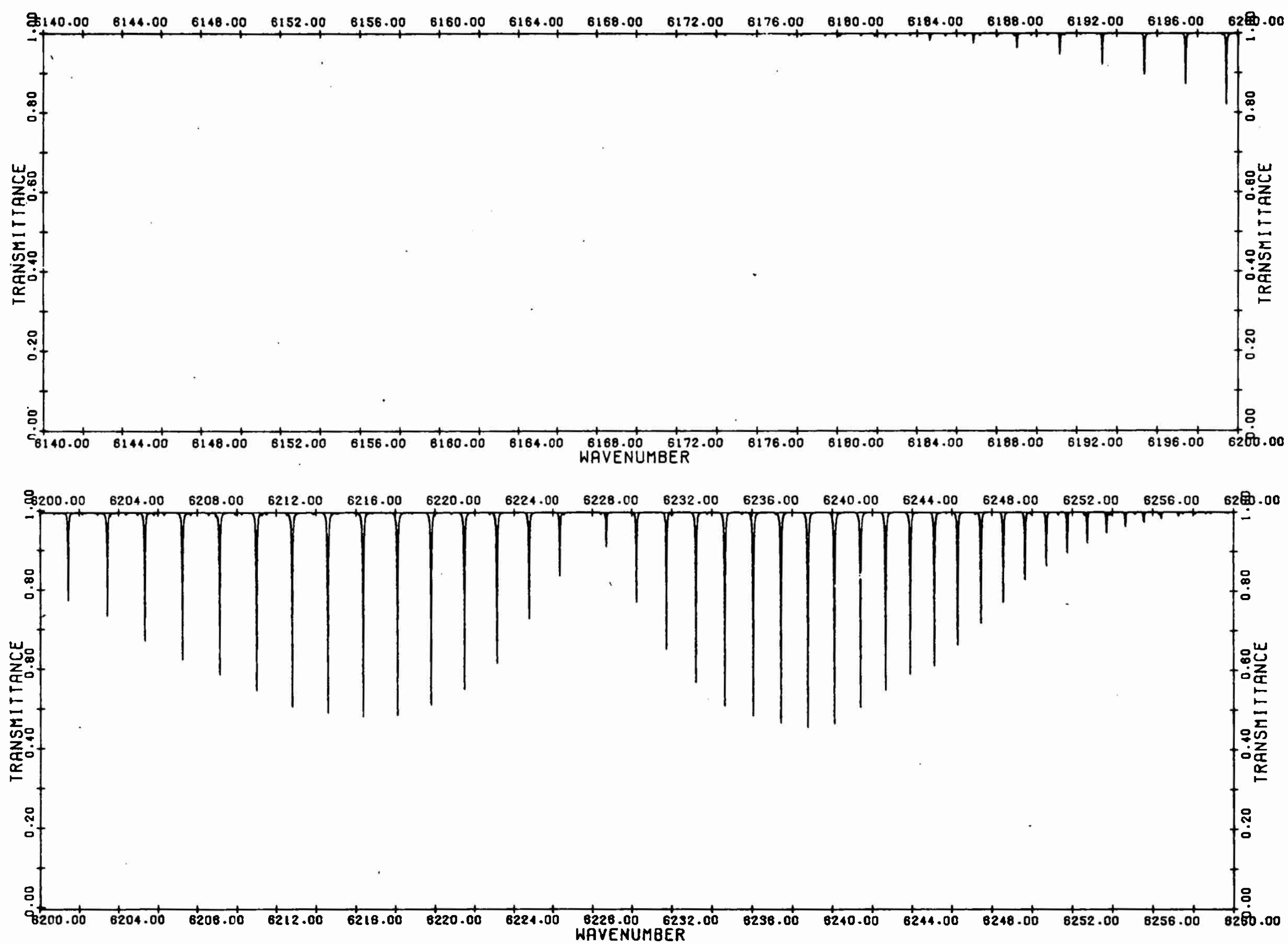


Figure 5ax. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

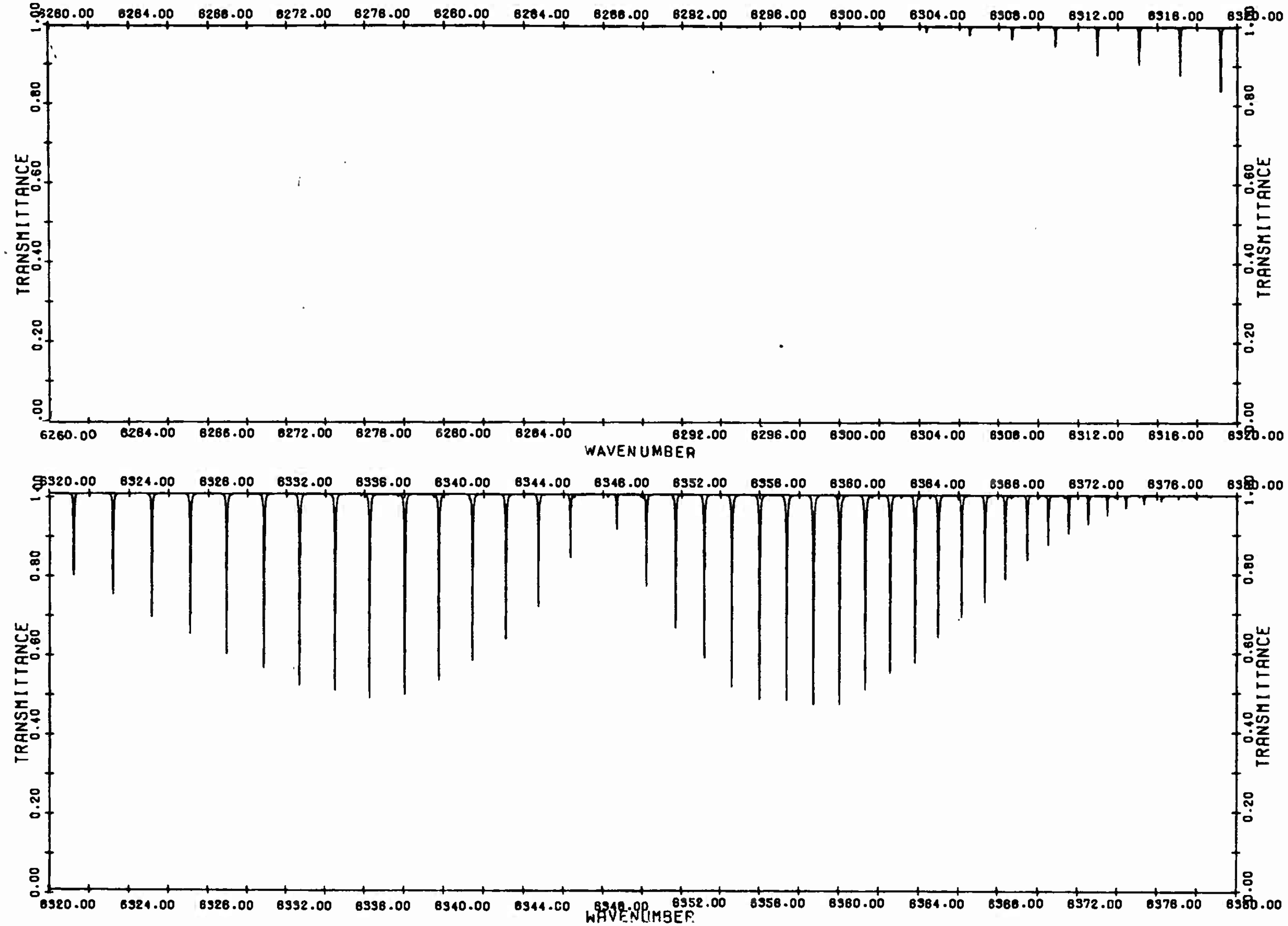


Figure 5ay. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

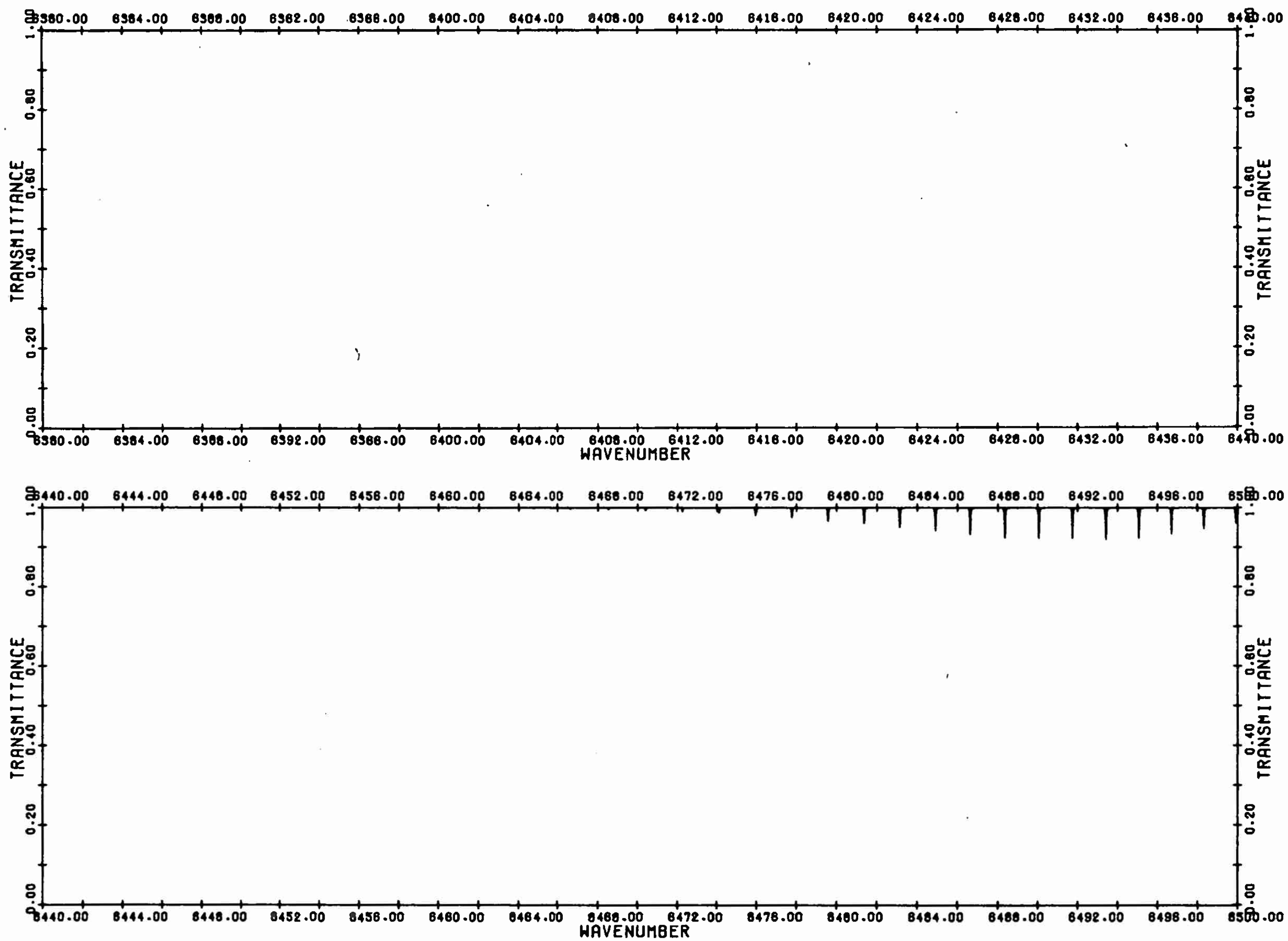


Figure 5az. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

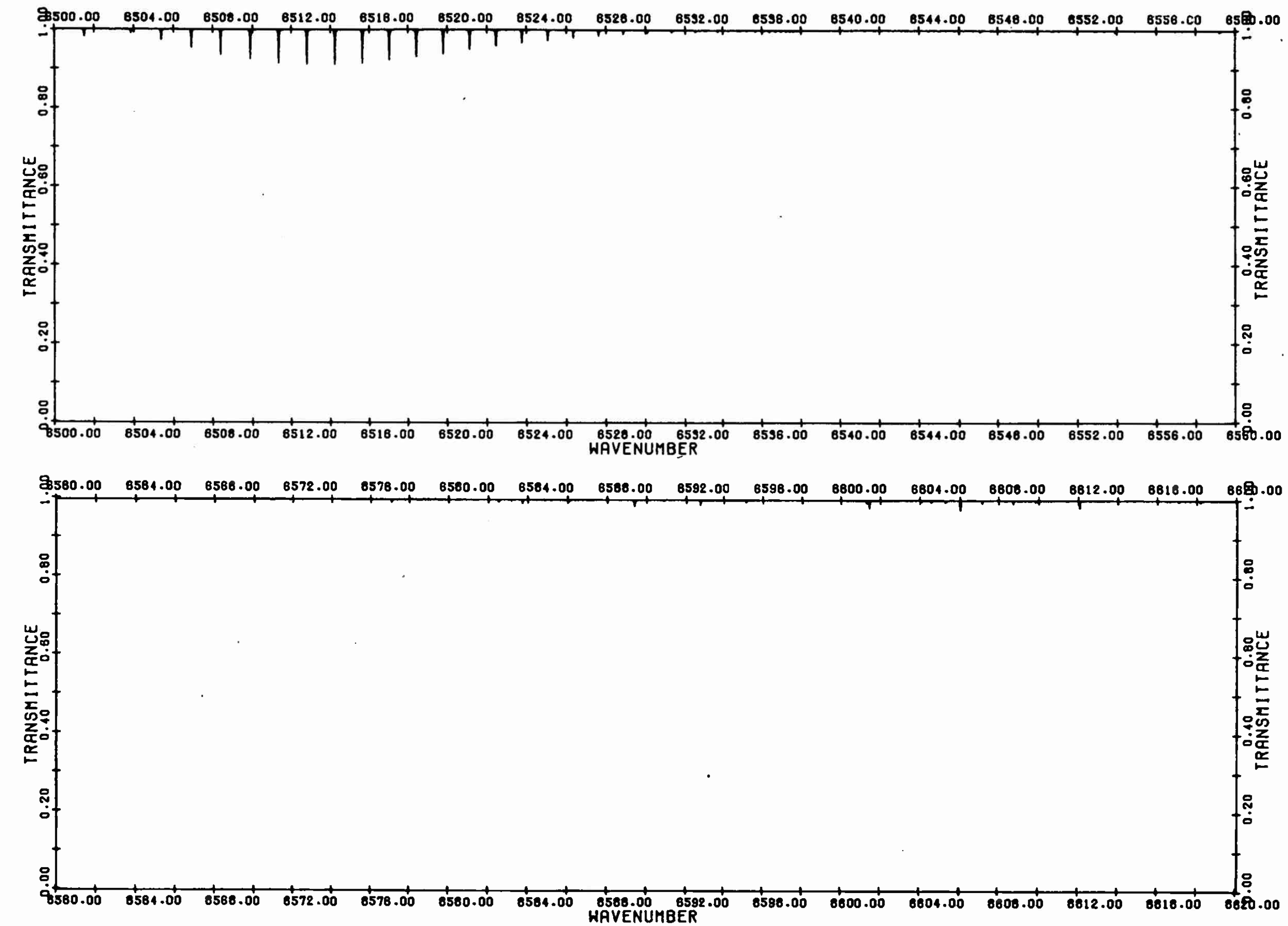


Figure 5ba. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

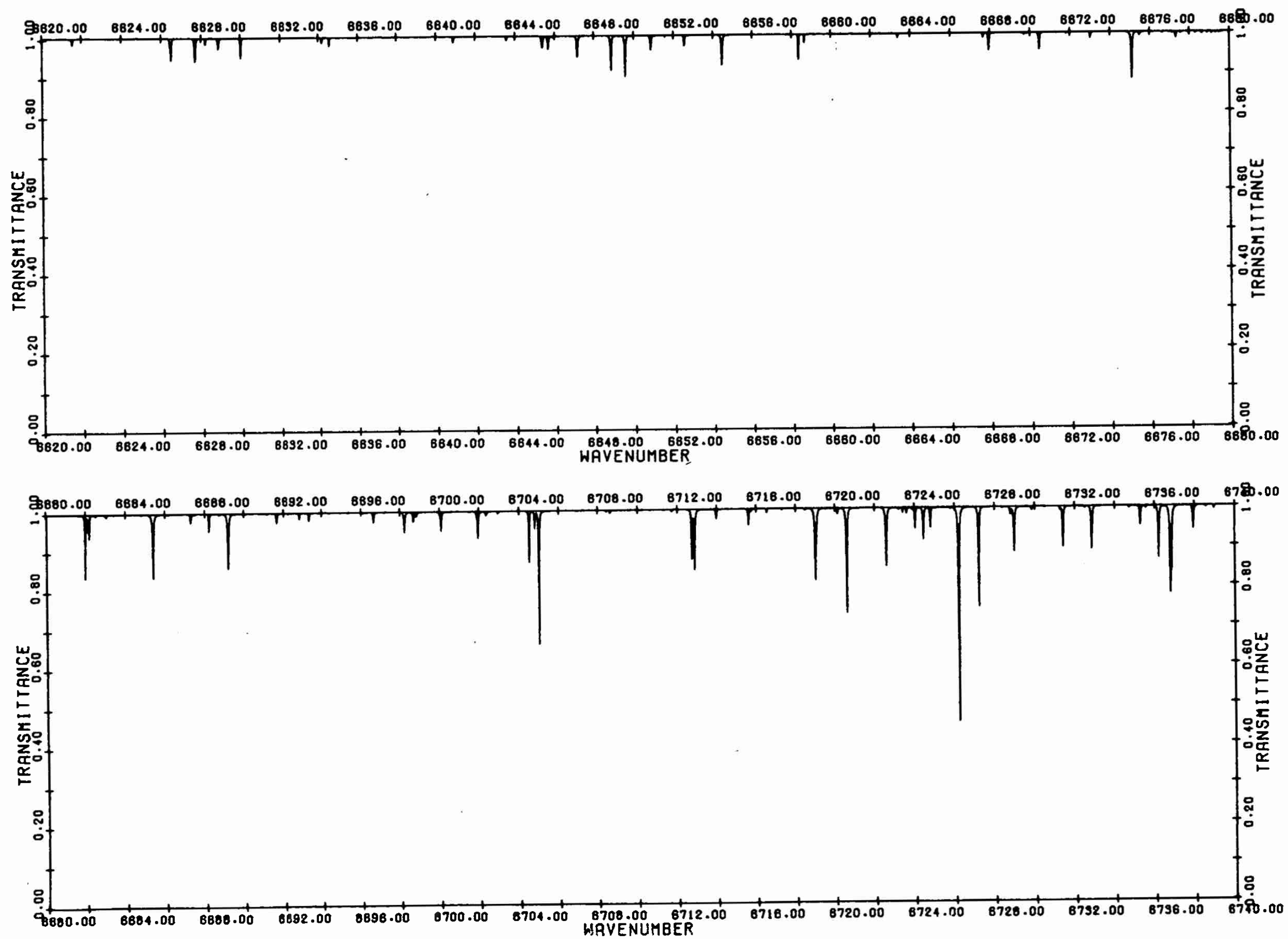


Figure 5bb. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

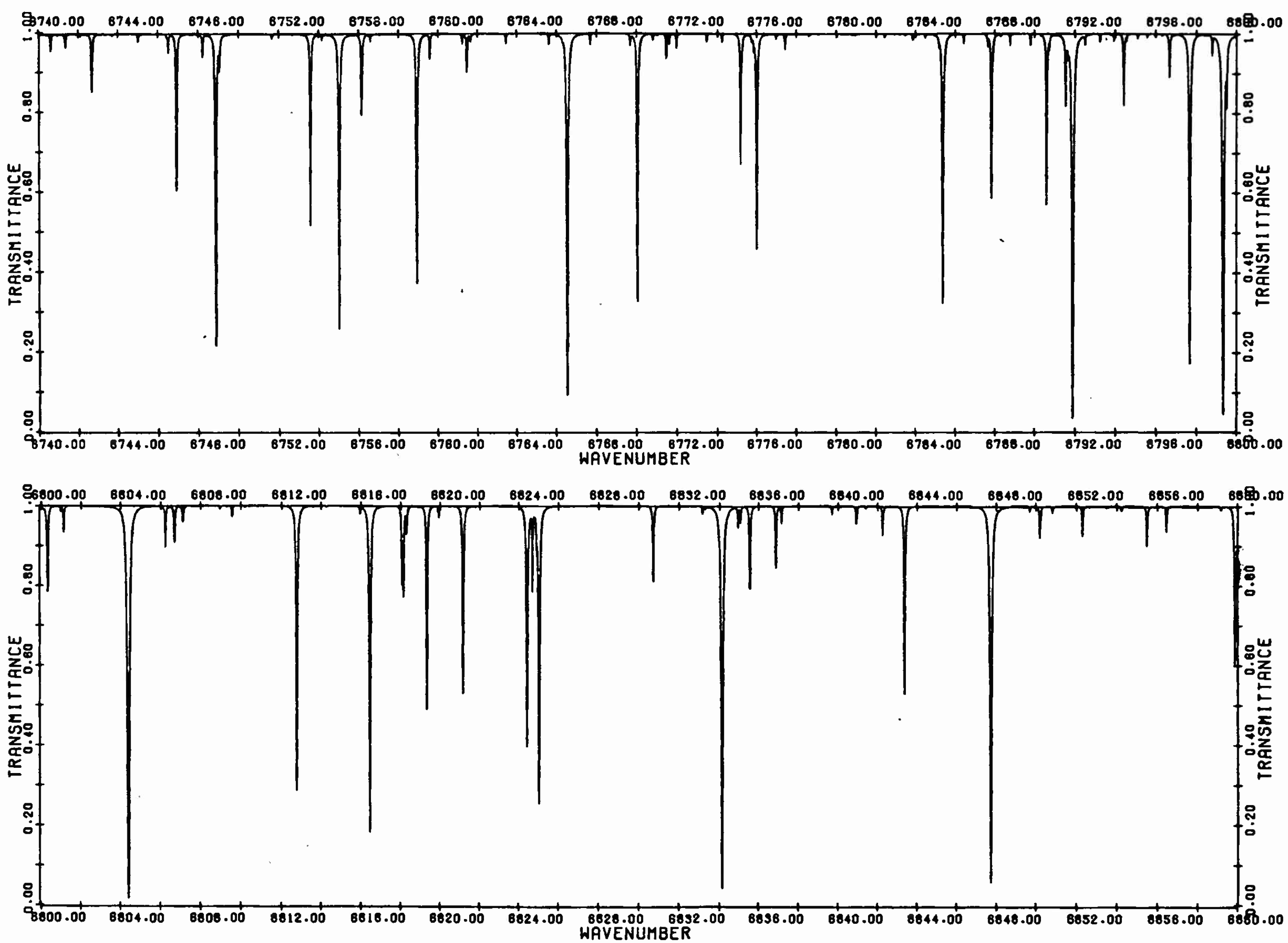


Figure 5bc. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

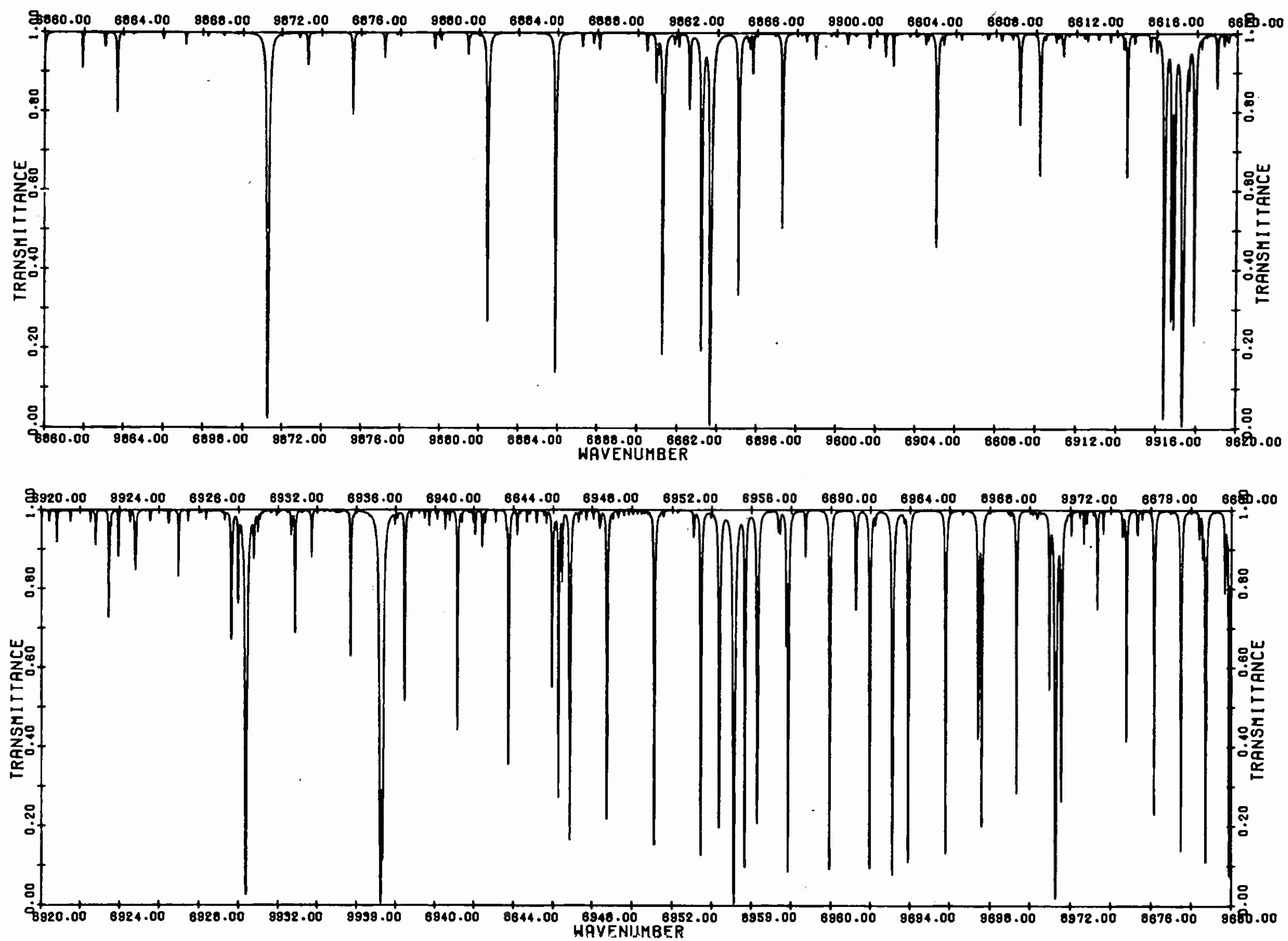


Figure 5bd. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

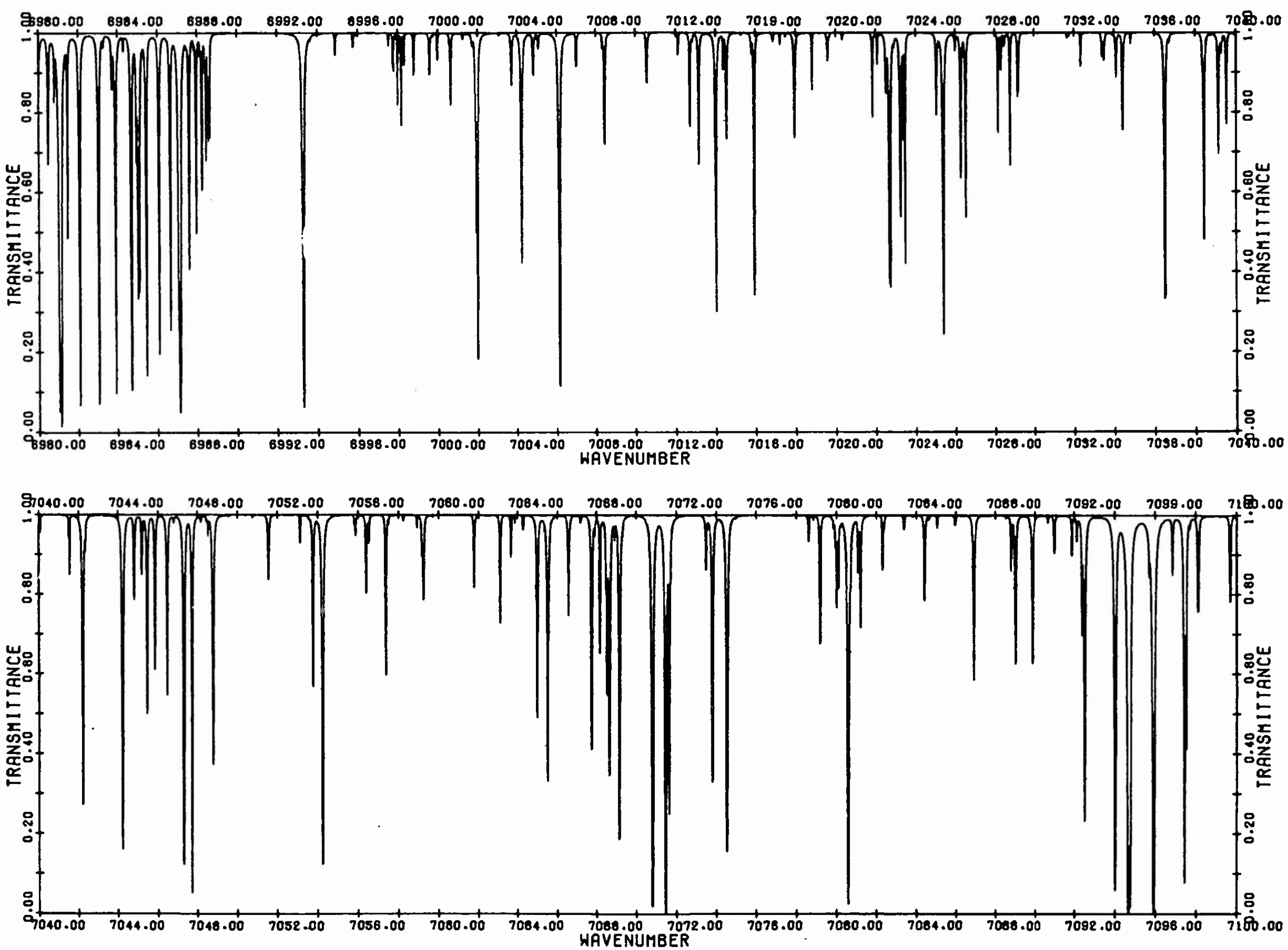


Figure 5be. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

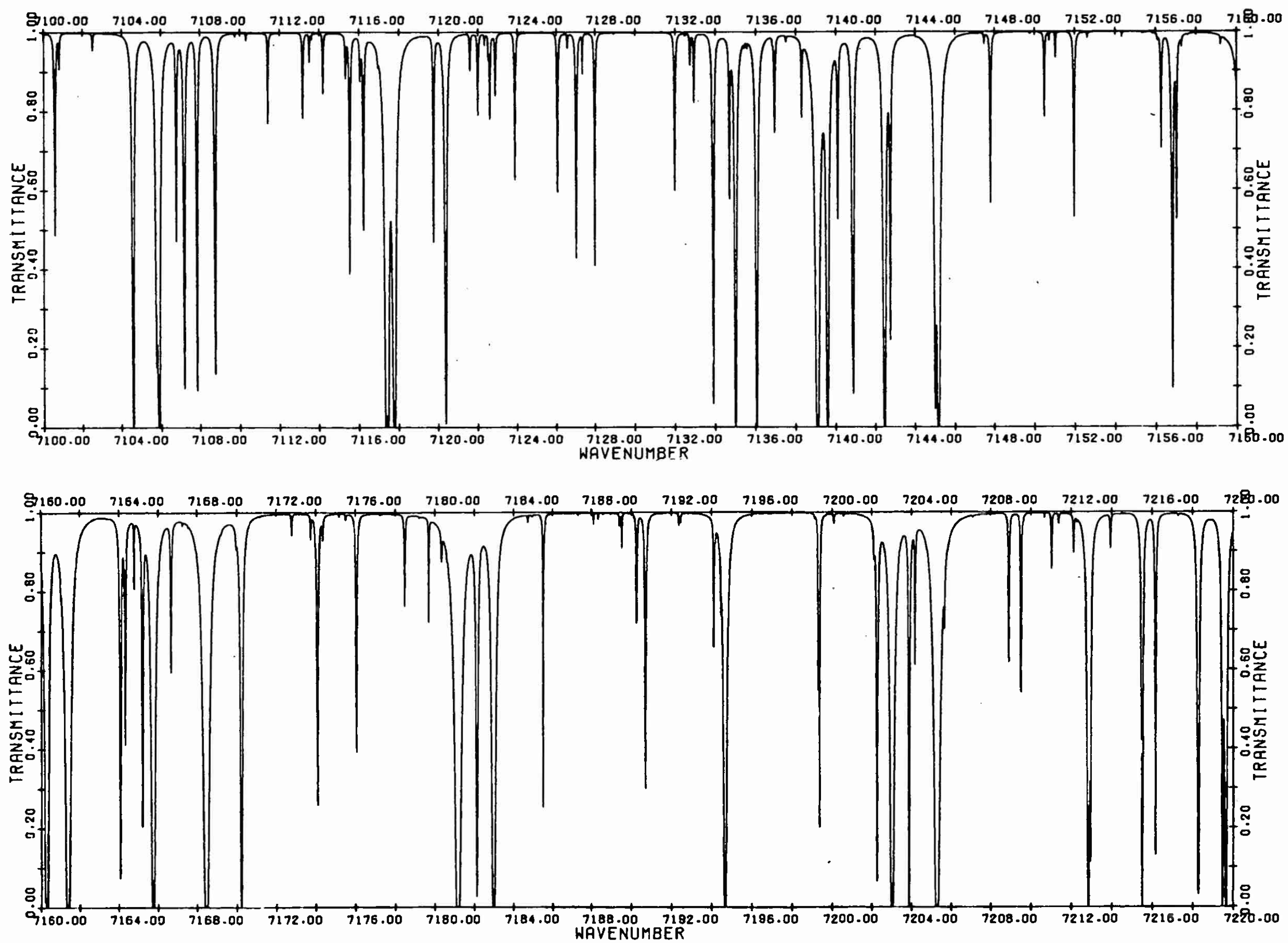


Figure 5bf. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

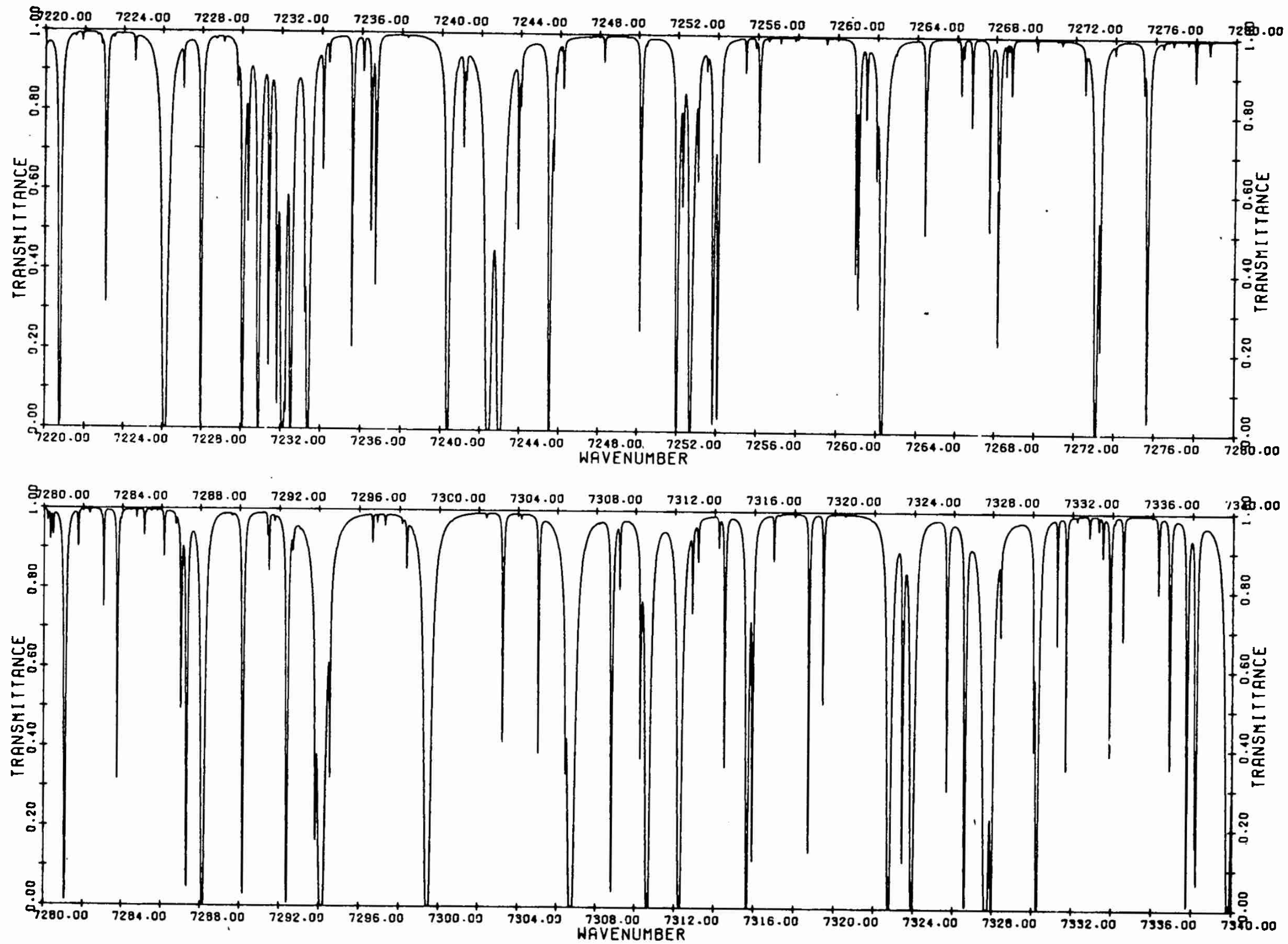


Figure 5bg. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

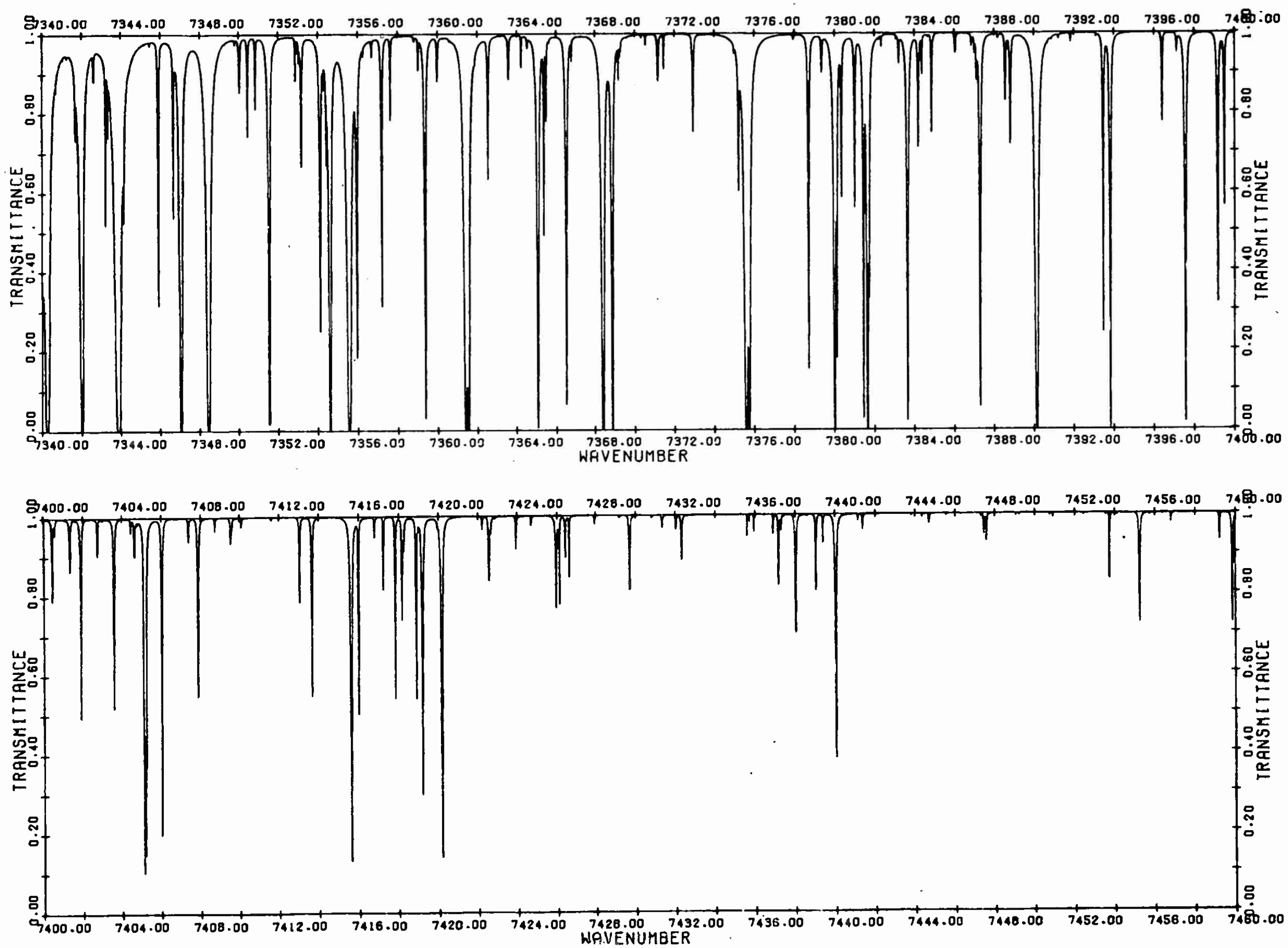


Figure 5bh. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

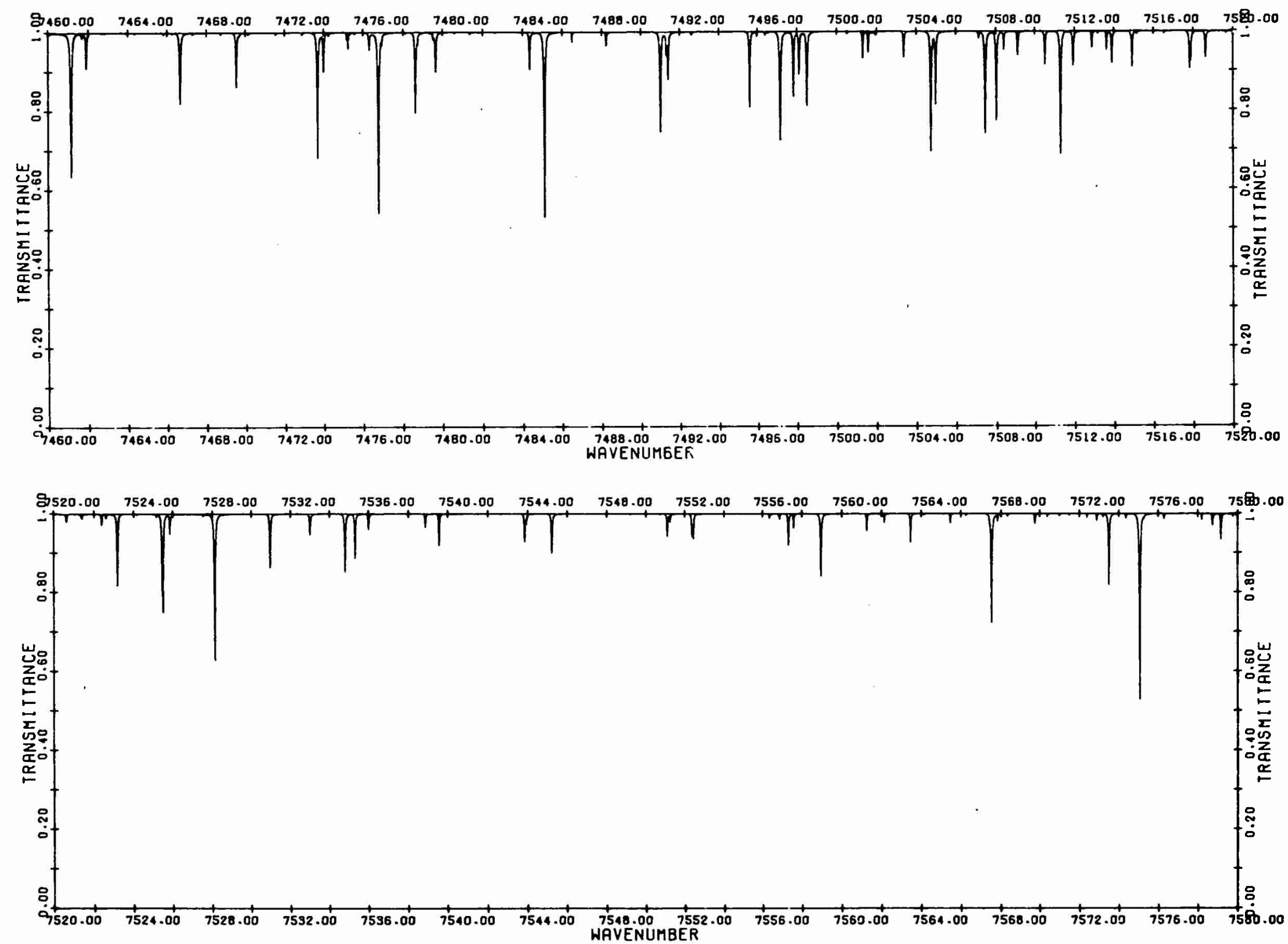


Figure 5bi. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

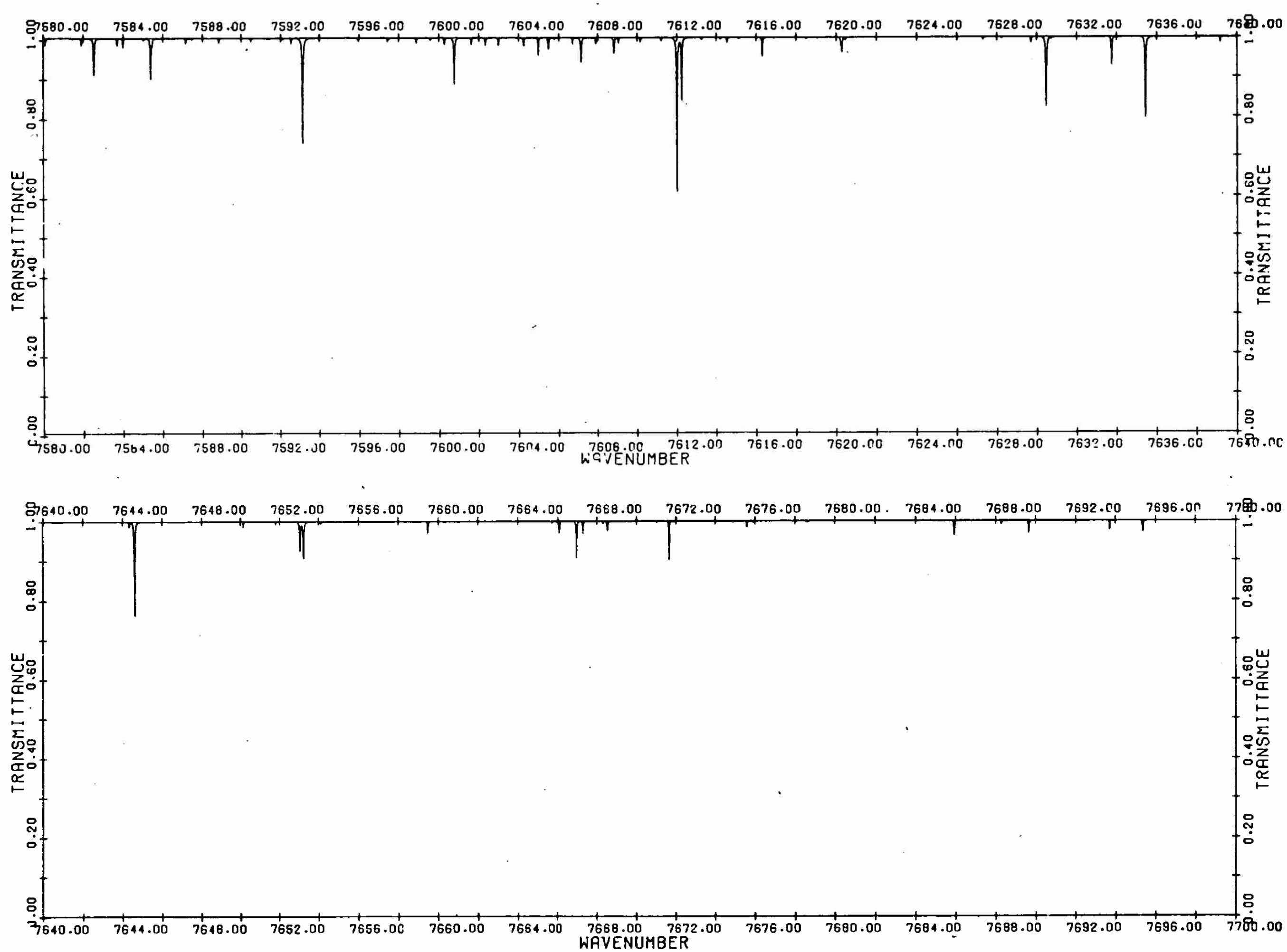


Figure 5bj. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

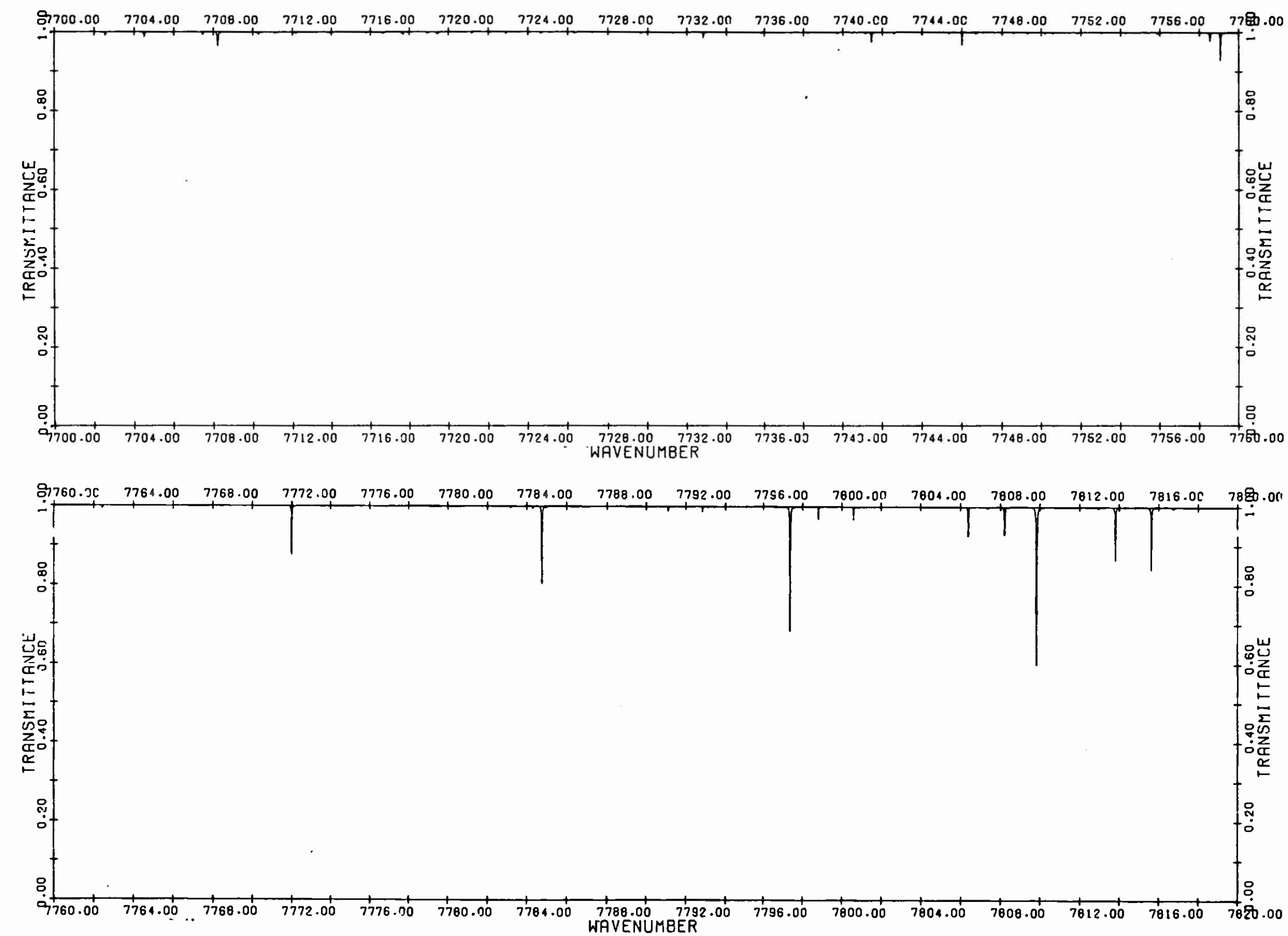


Figure 5bk. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

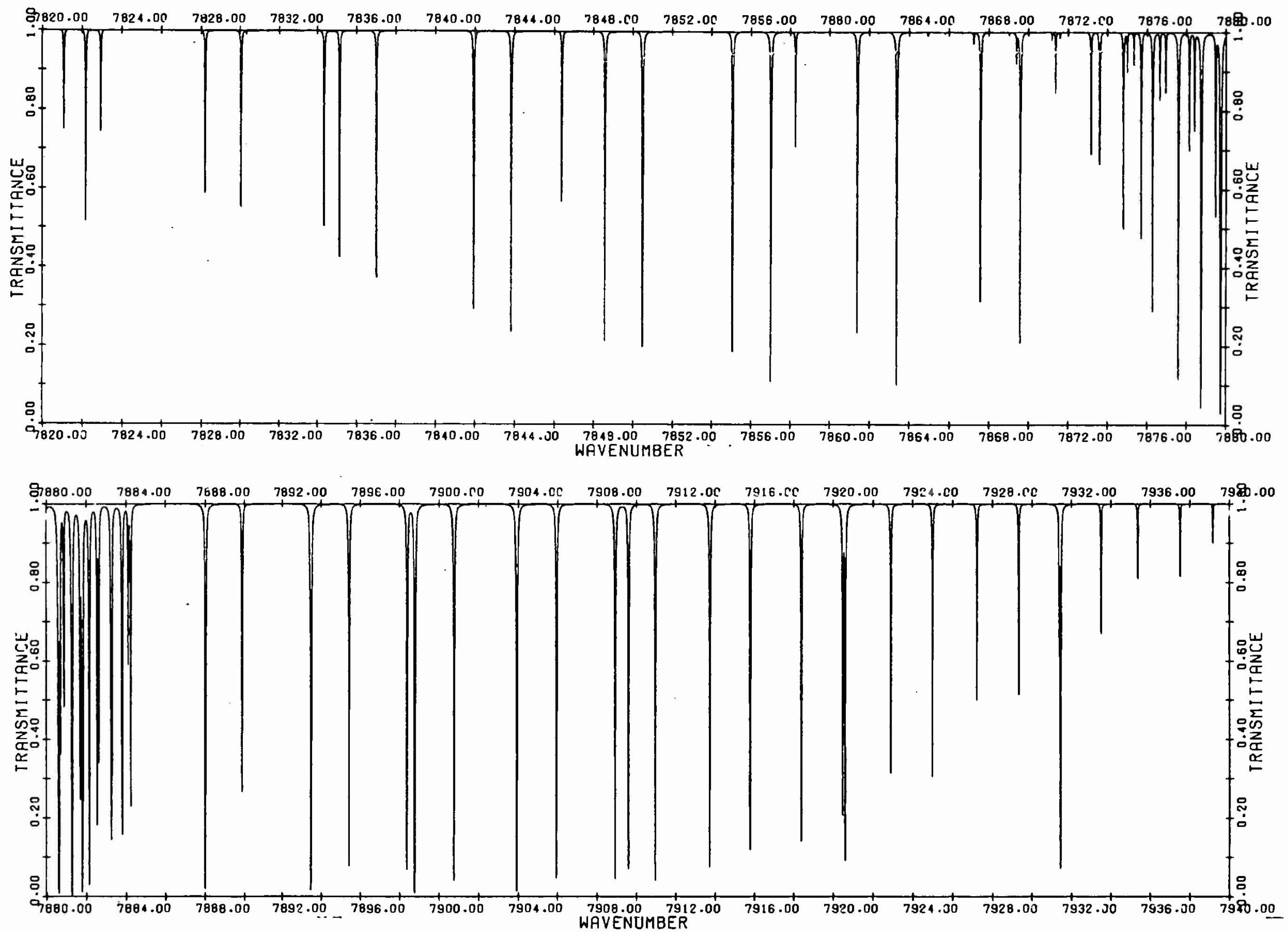


Figure 5b1. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

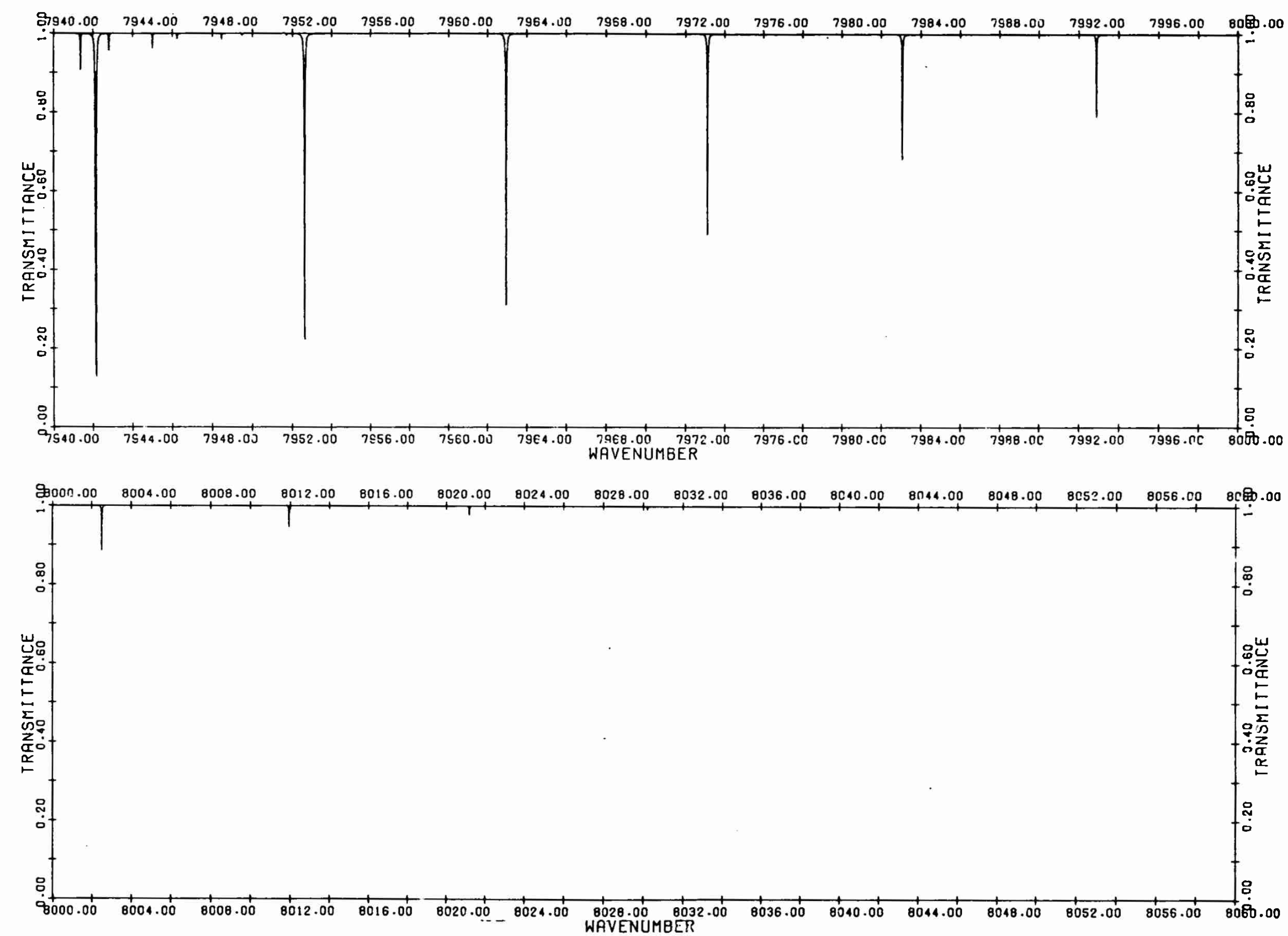


Figure 5bm. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

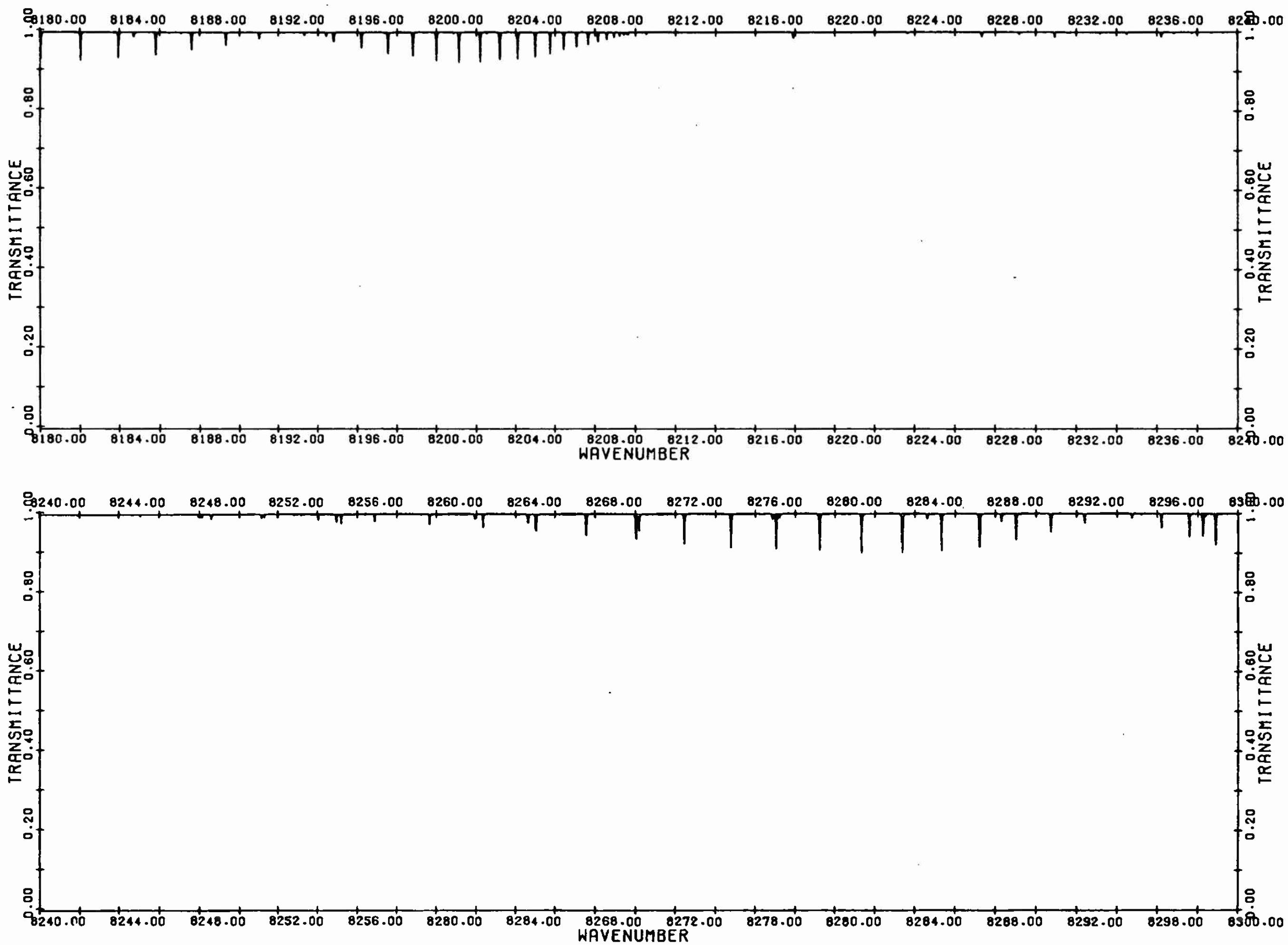


Figure 5bo. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

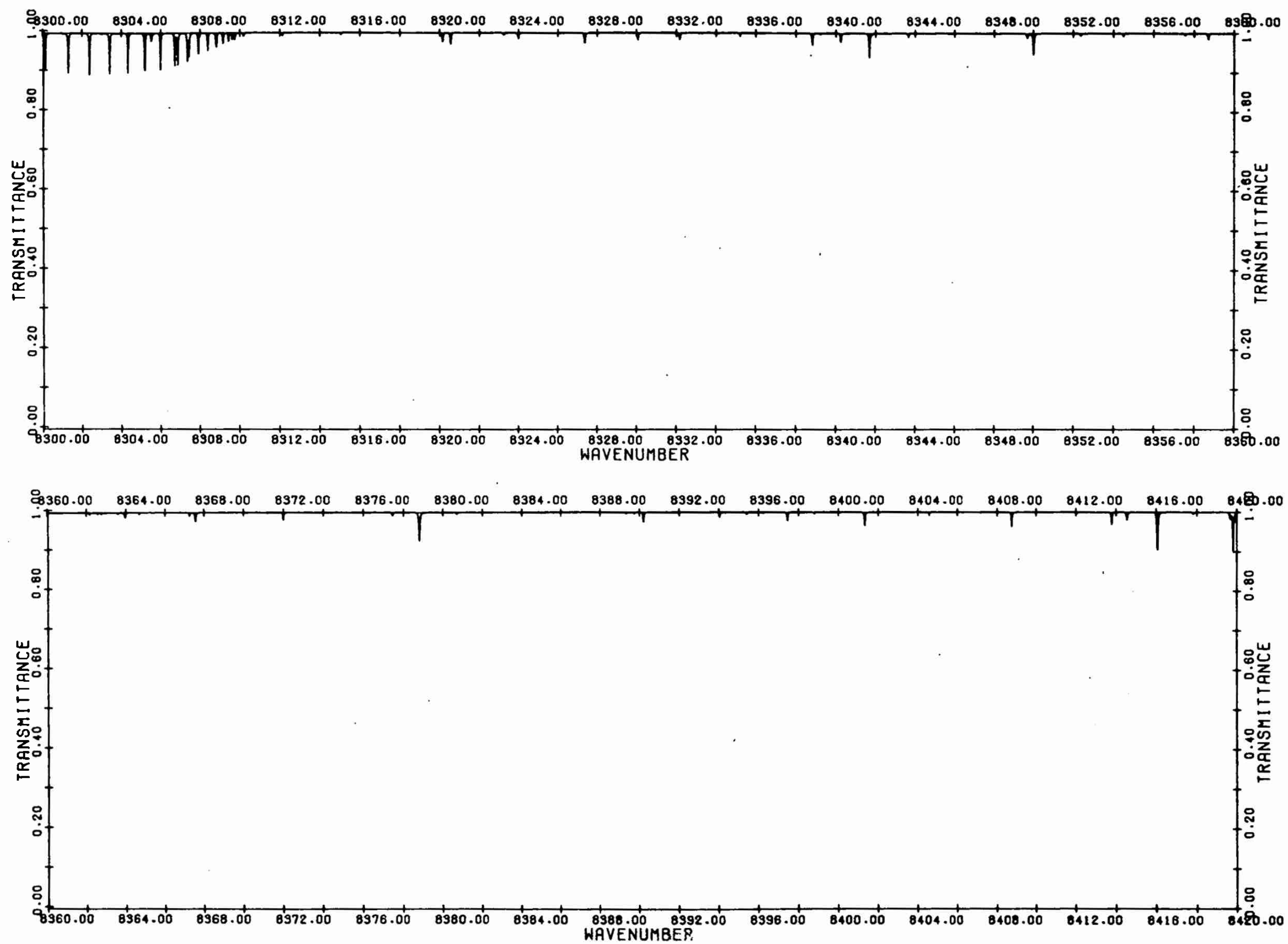


Figure 5bp. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

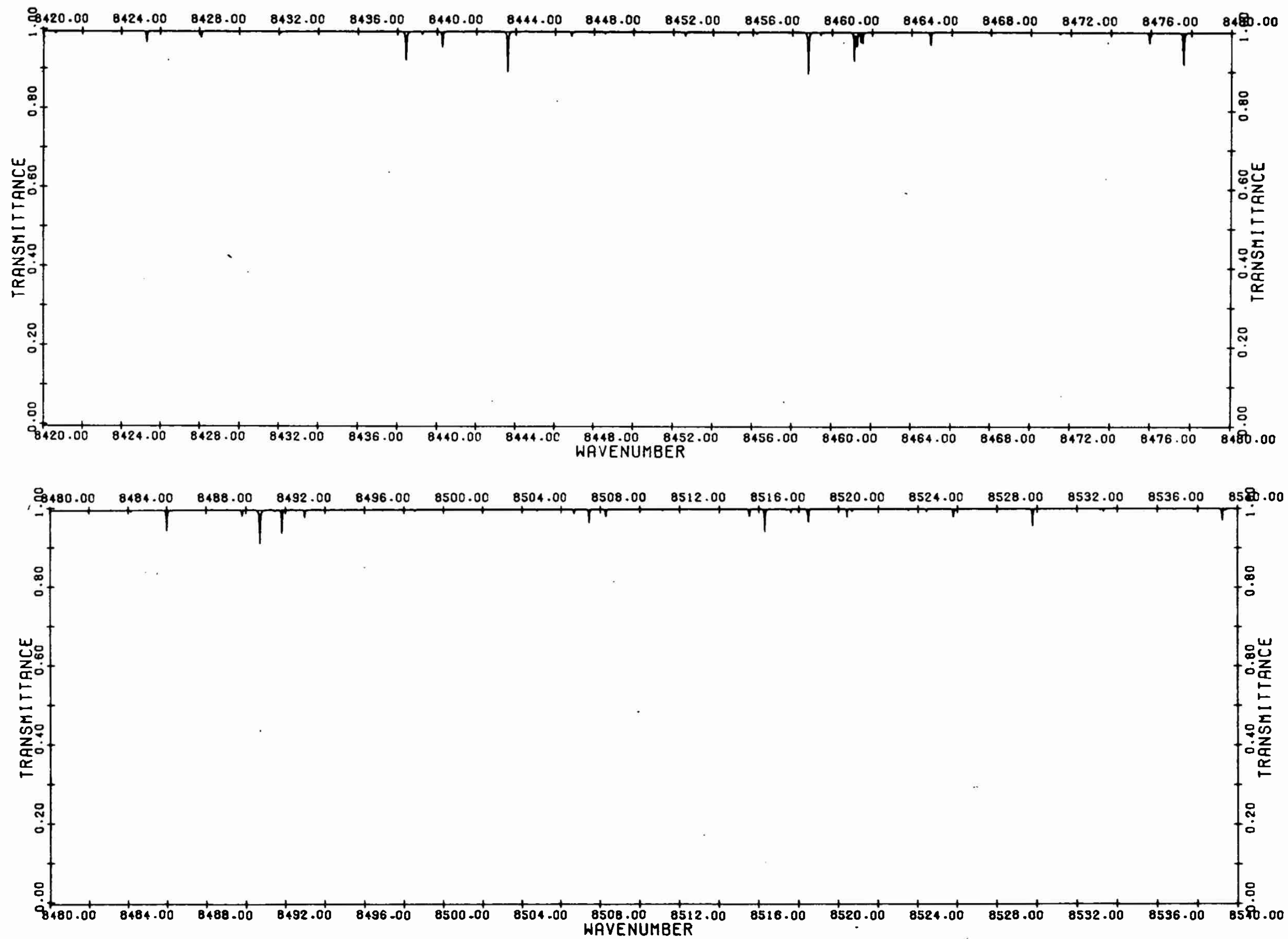


Figure 5bq. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

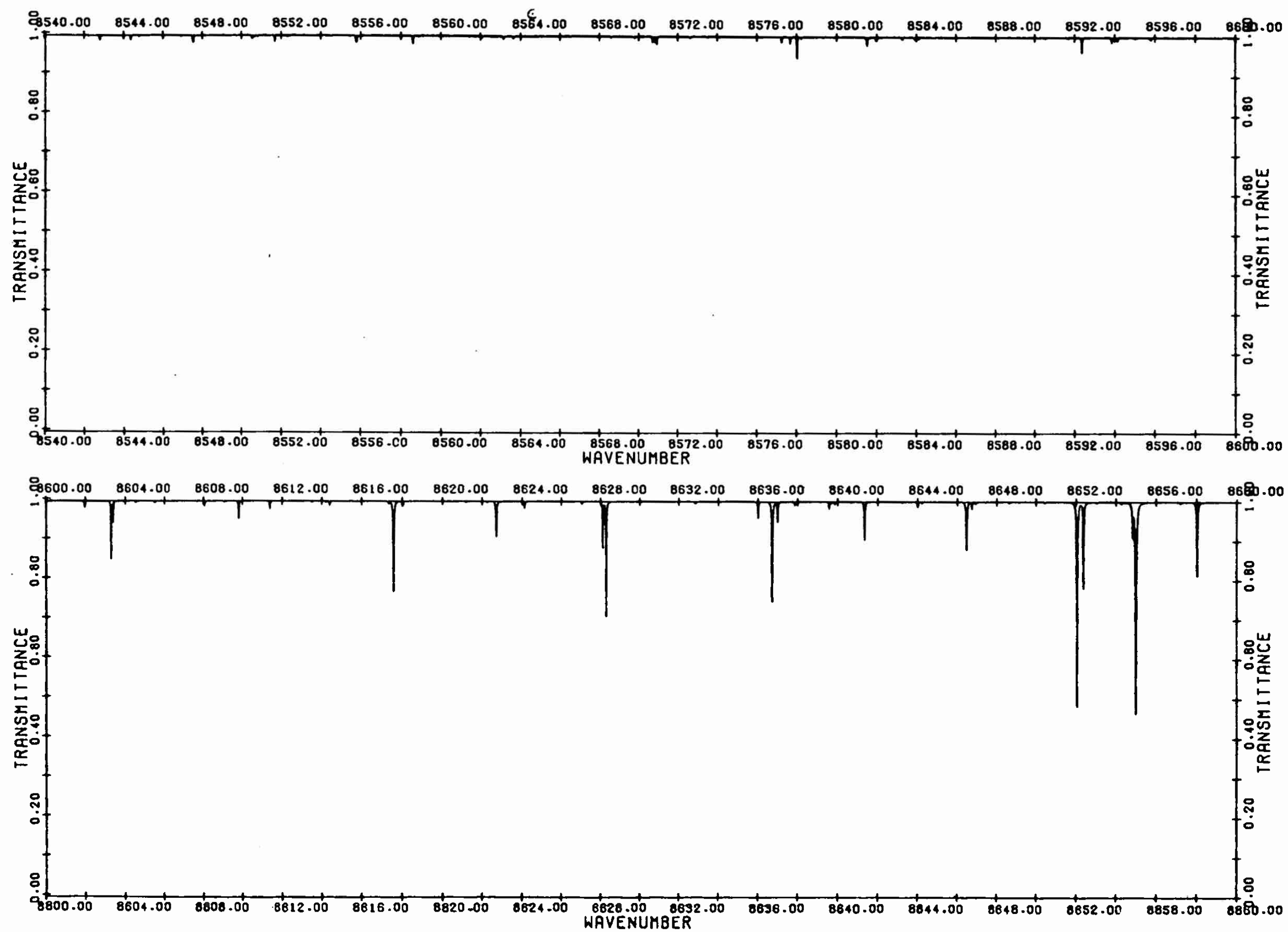


Figure 5br. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

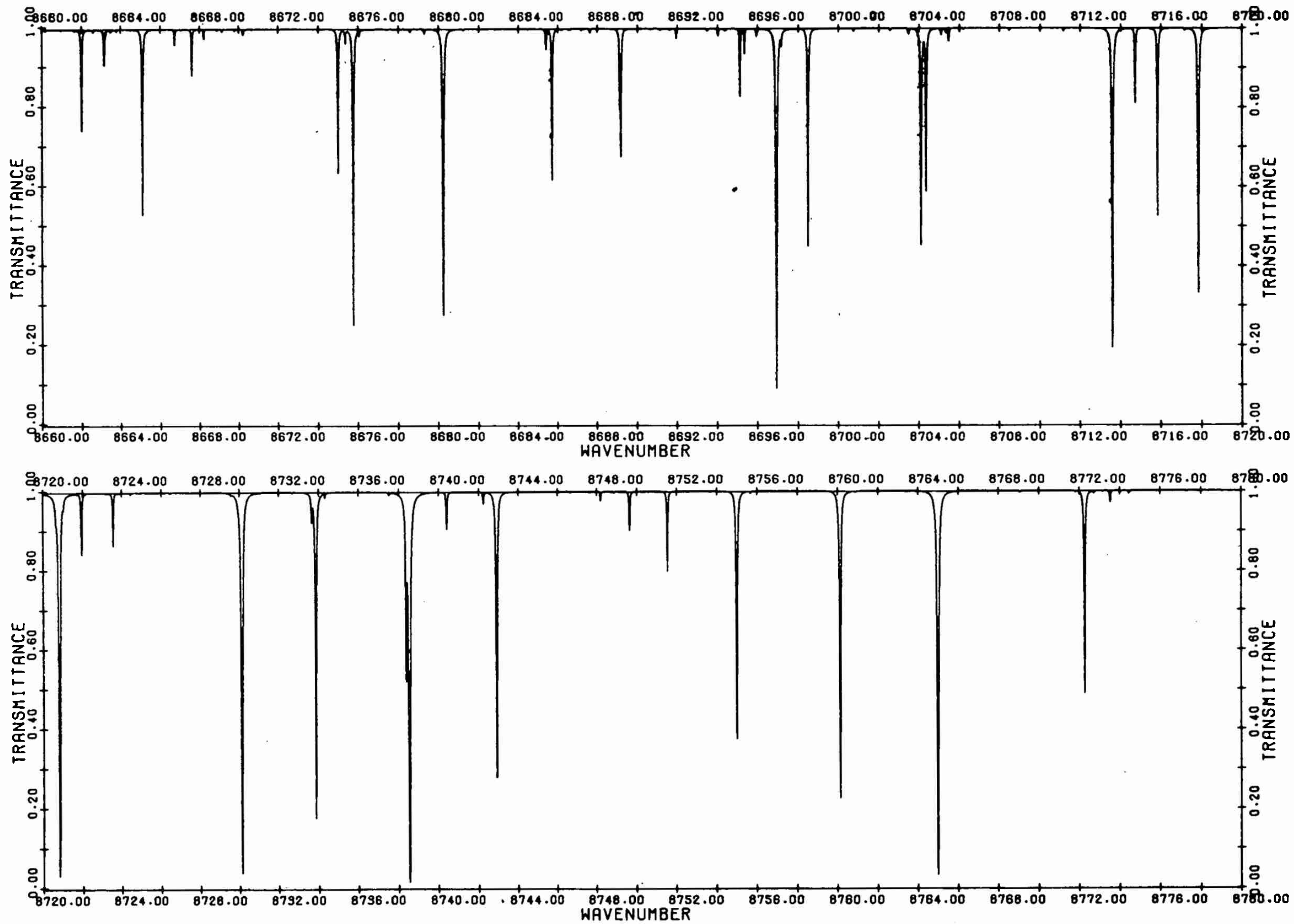


Figure 5bs. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

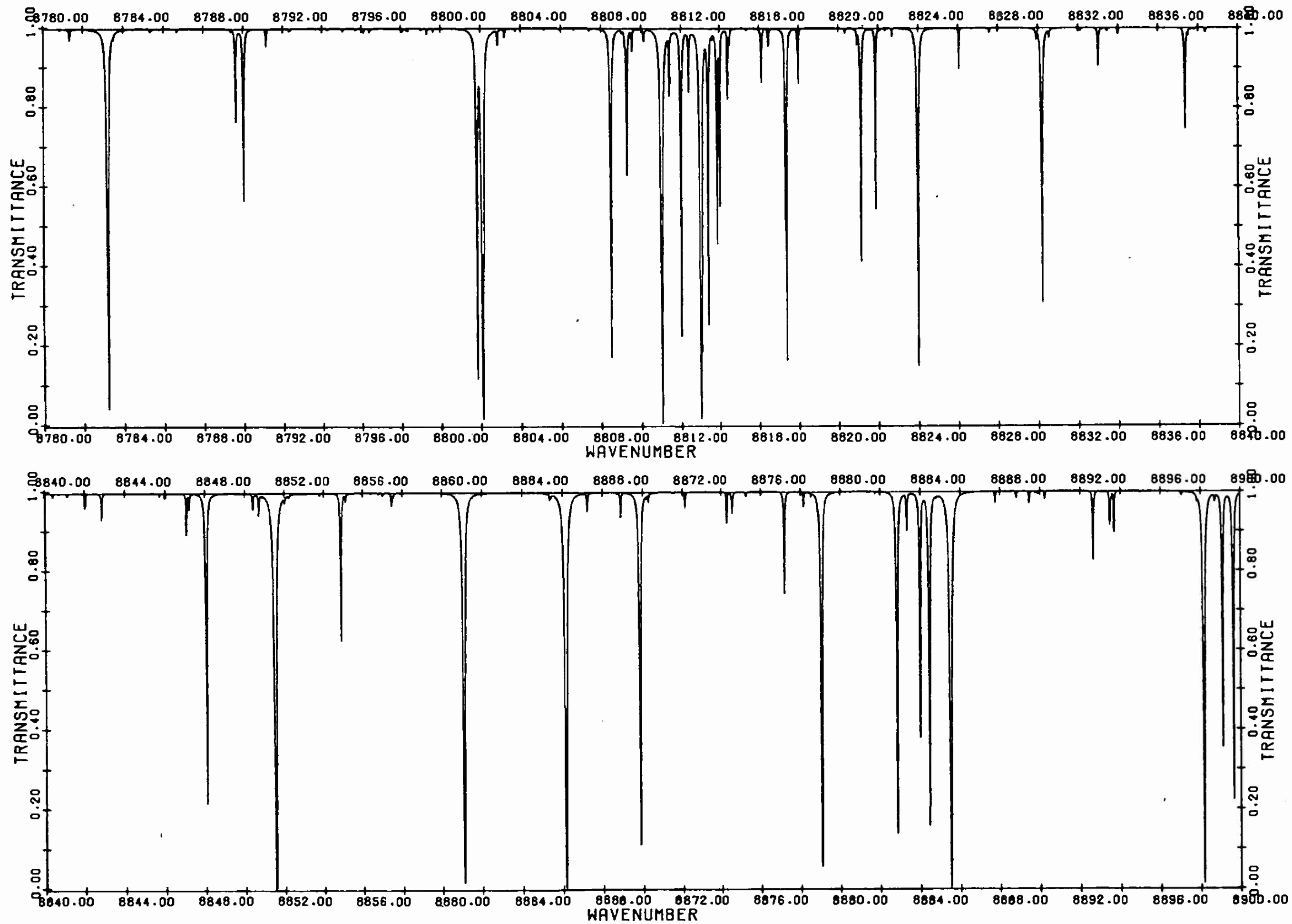


Figure 5bt. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

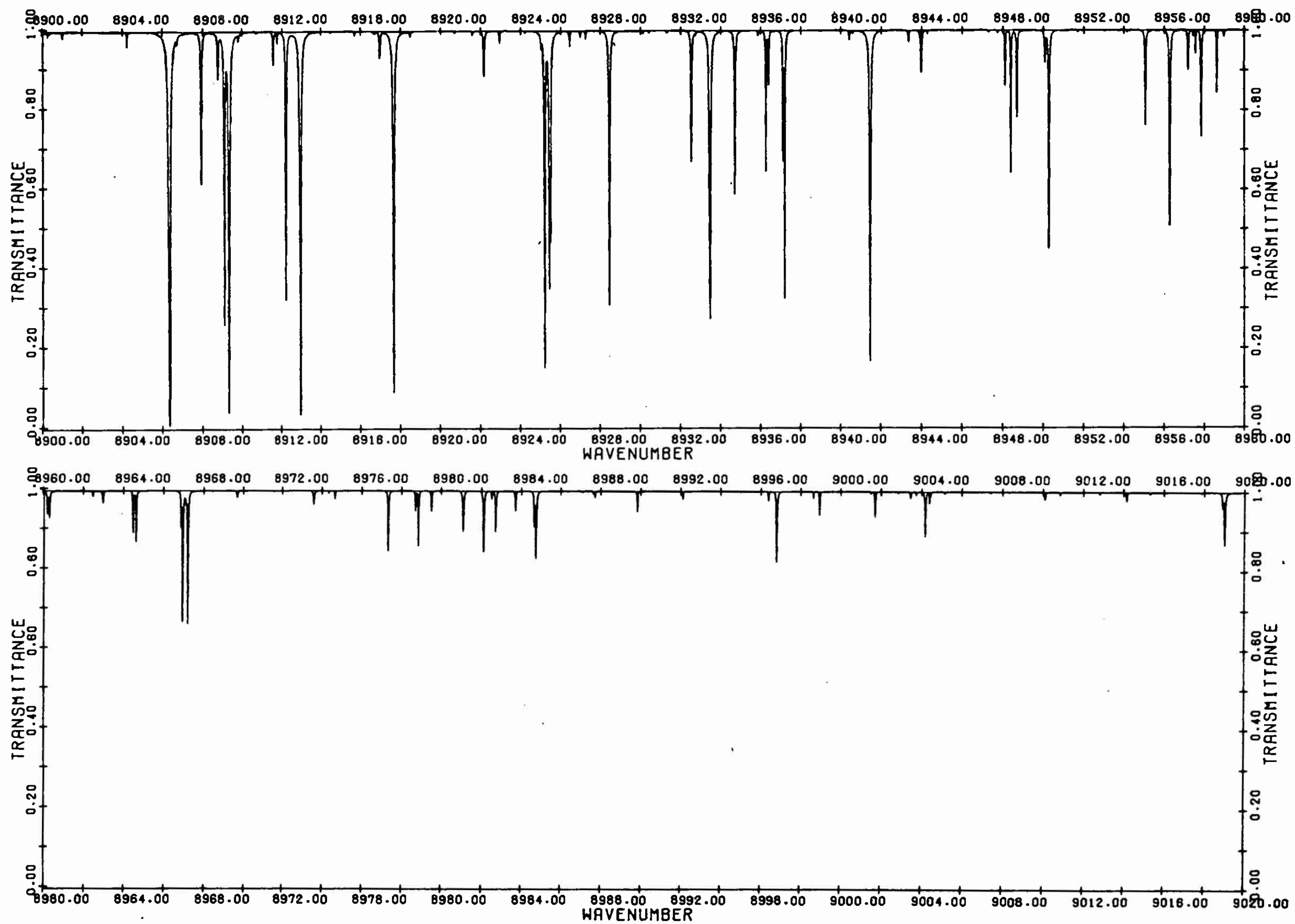


Figure 5bu. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

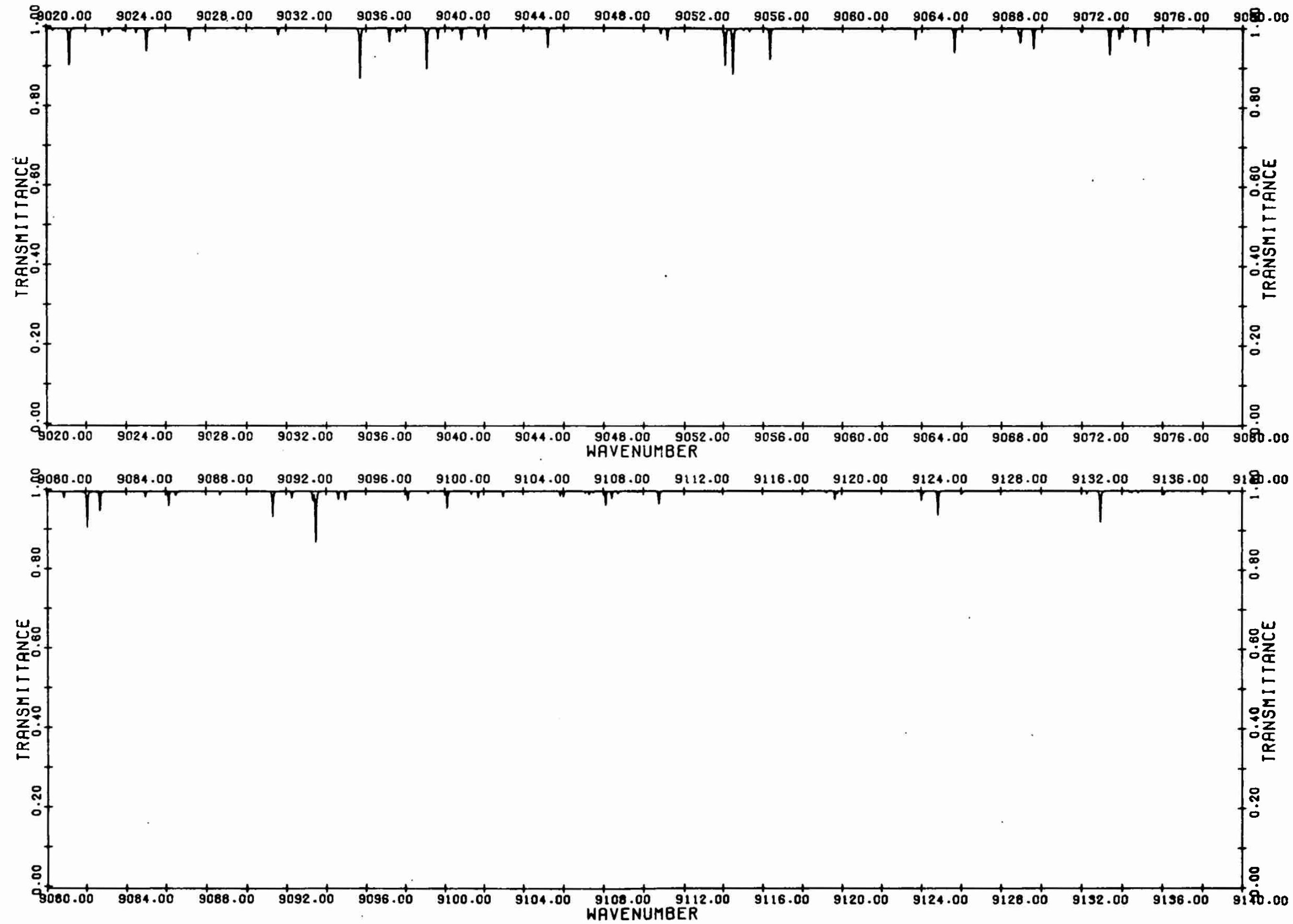


Figure 5bv. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

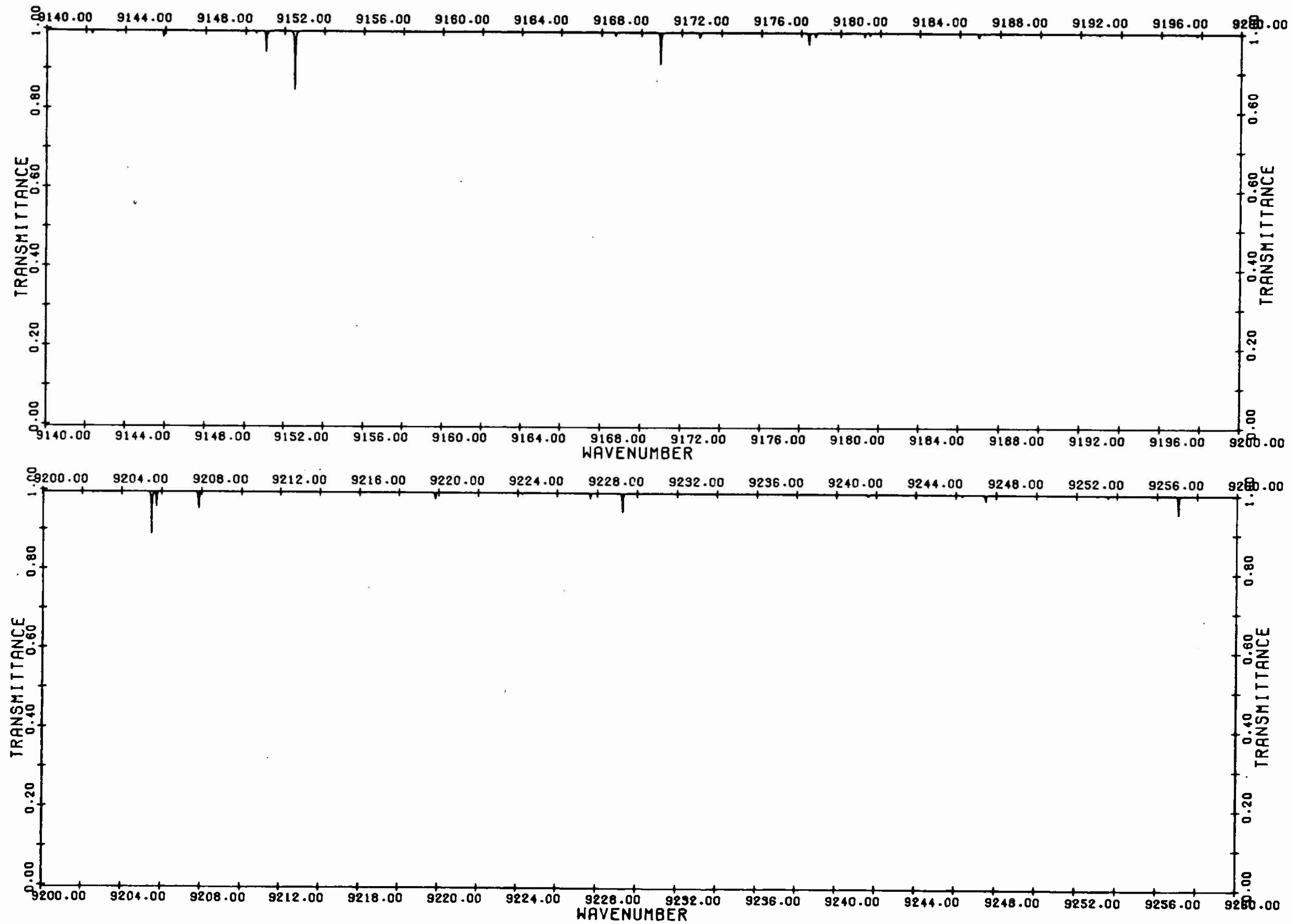


Figure 5bw. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

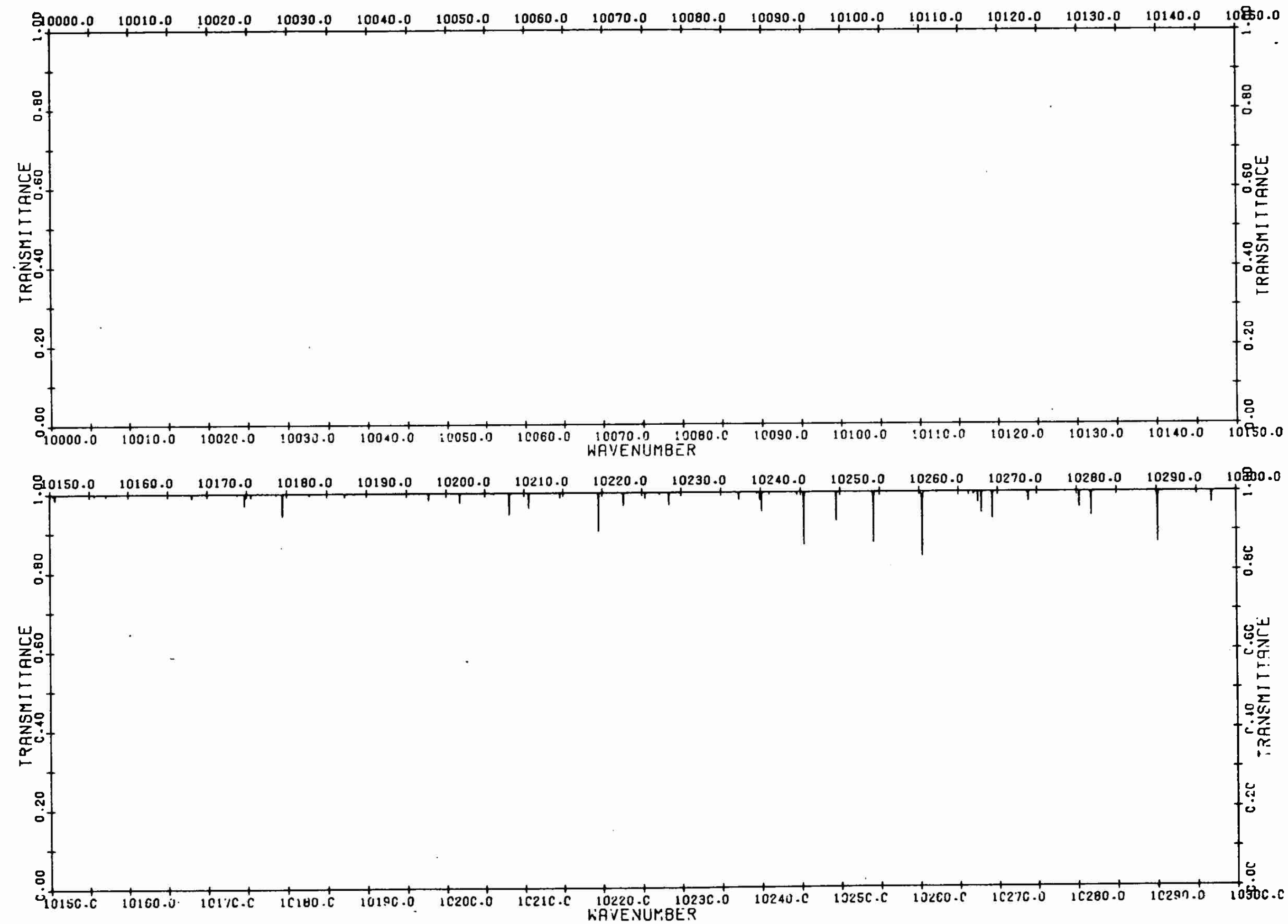


Figure 5ce. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

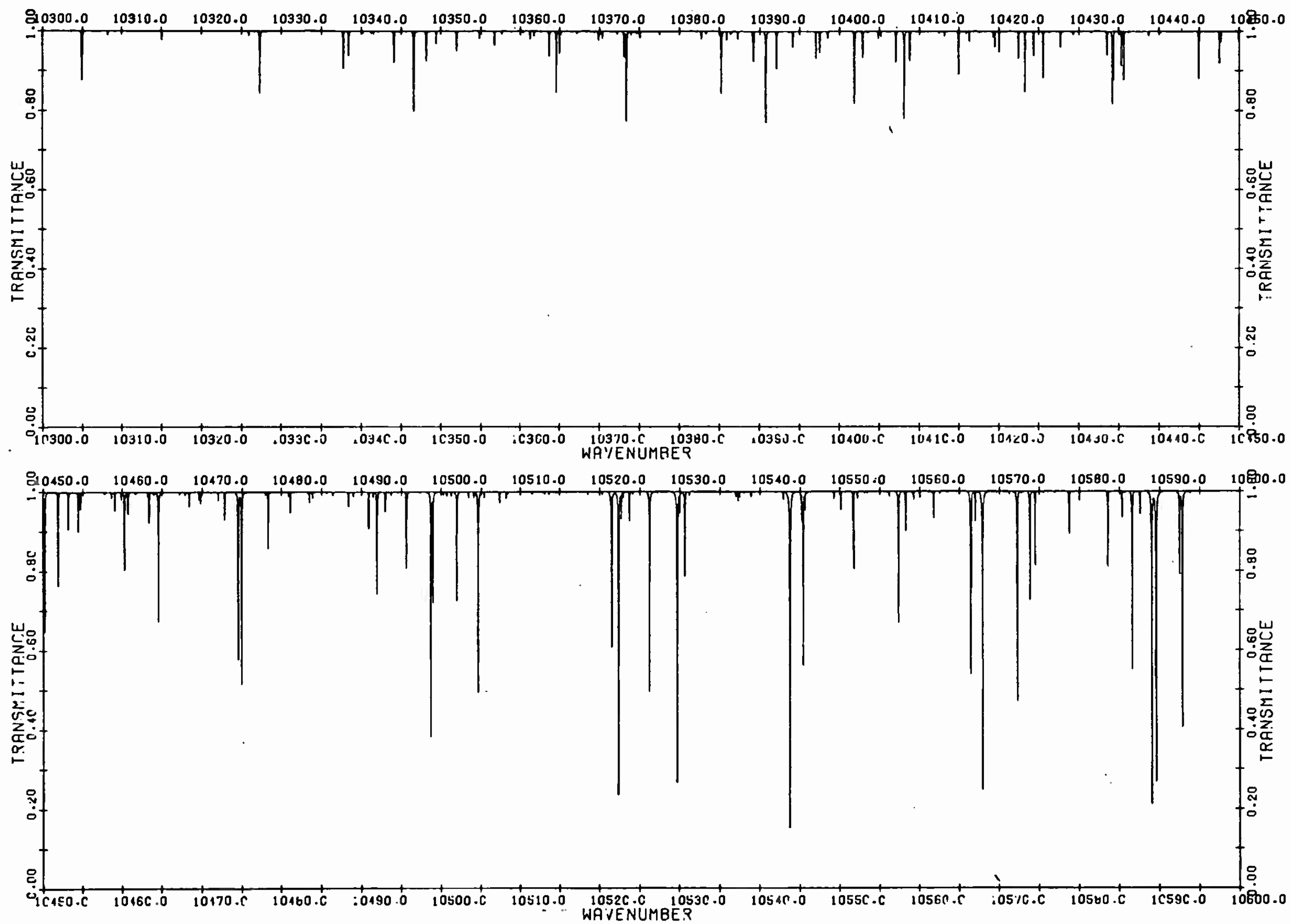


Figure 5cf. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

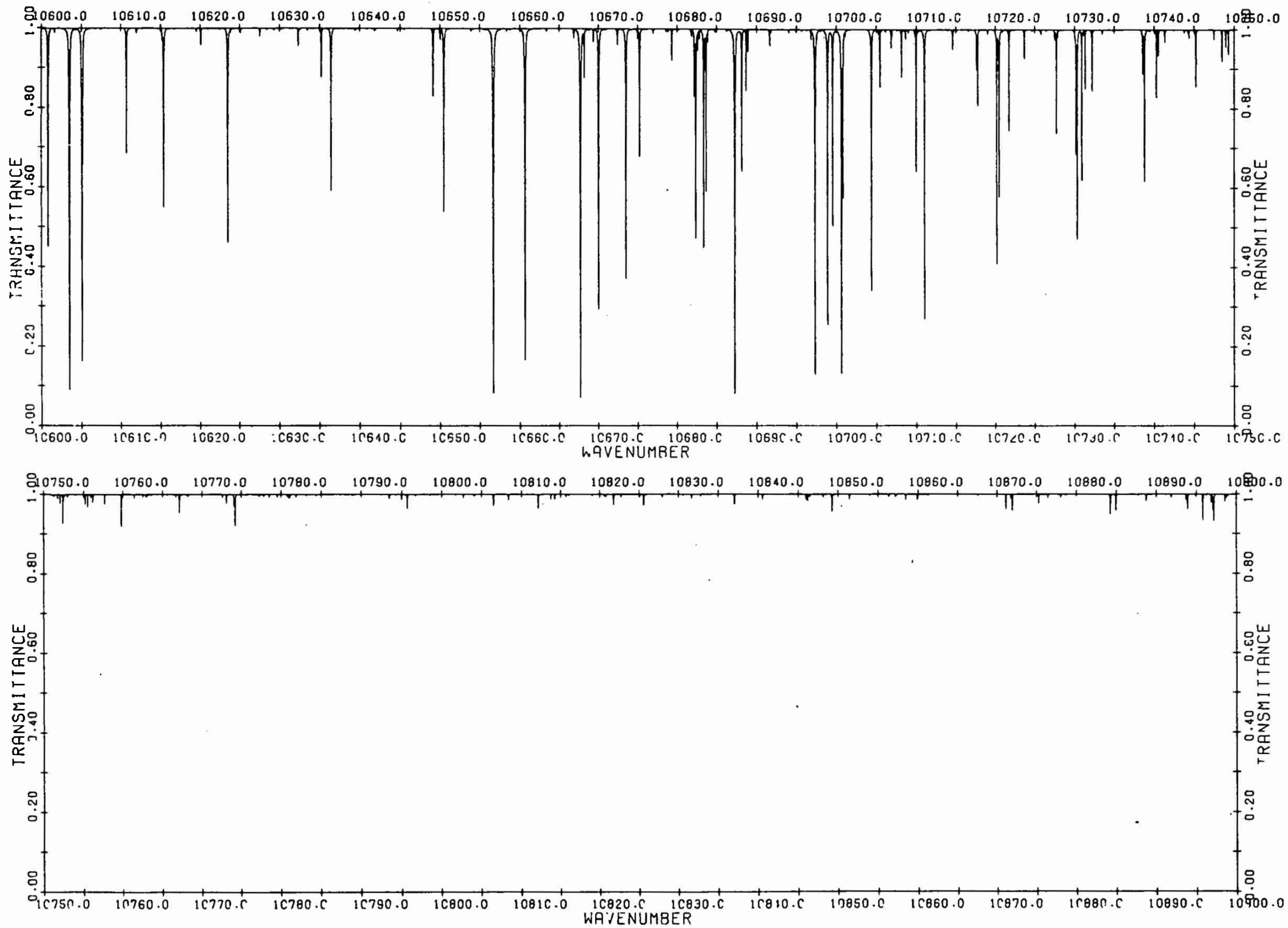


Figure 5cg. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

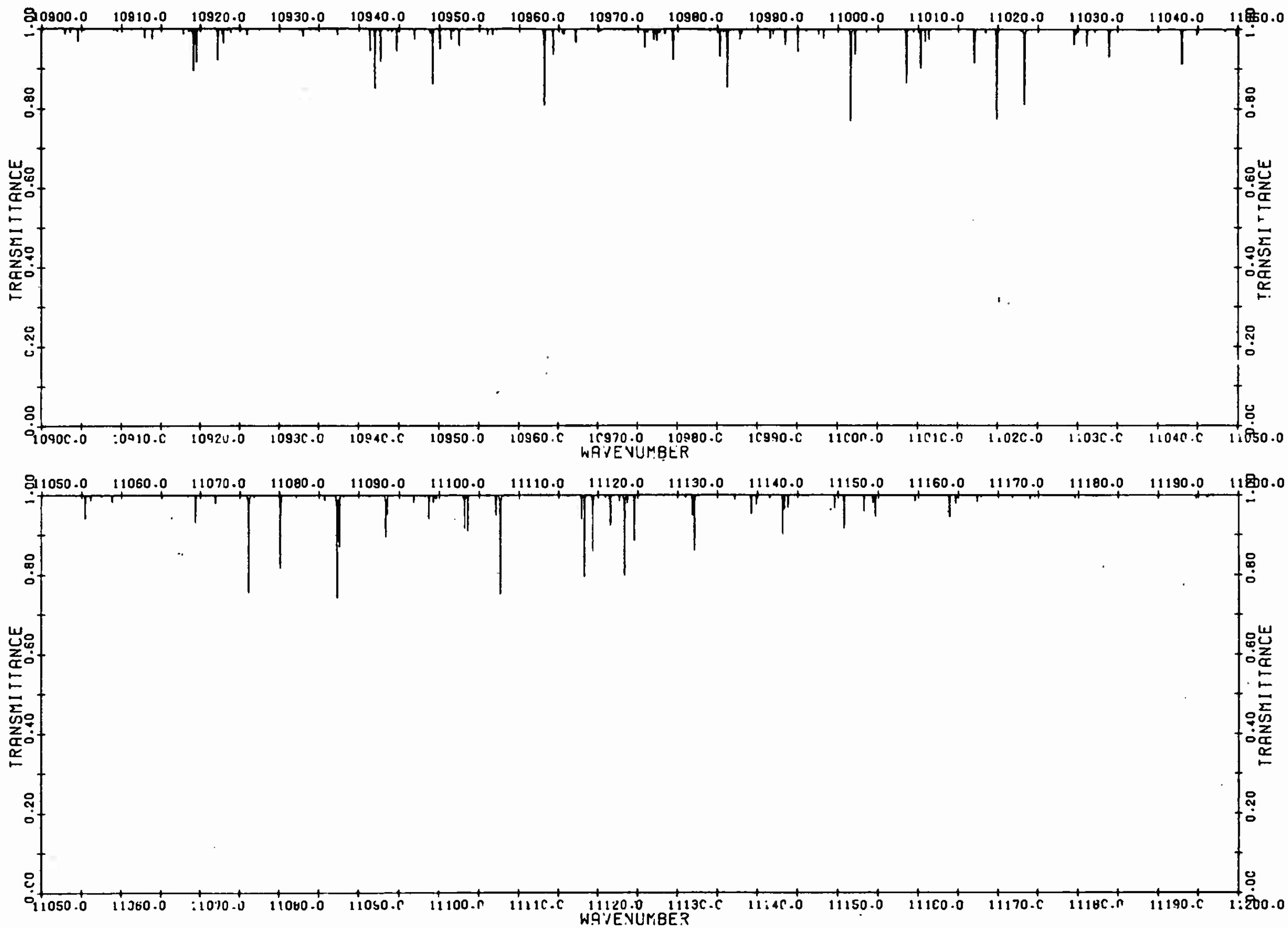


Figure 5ch. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

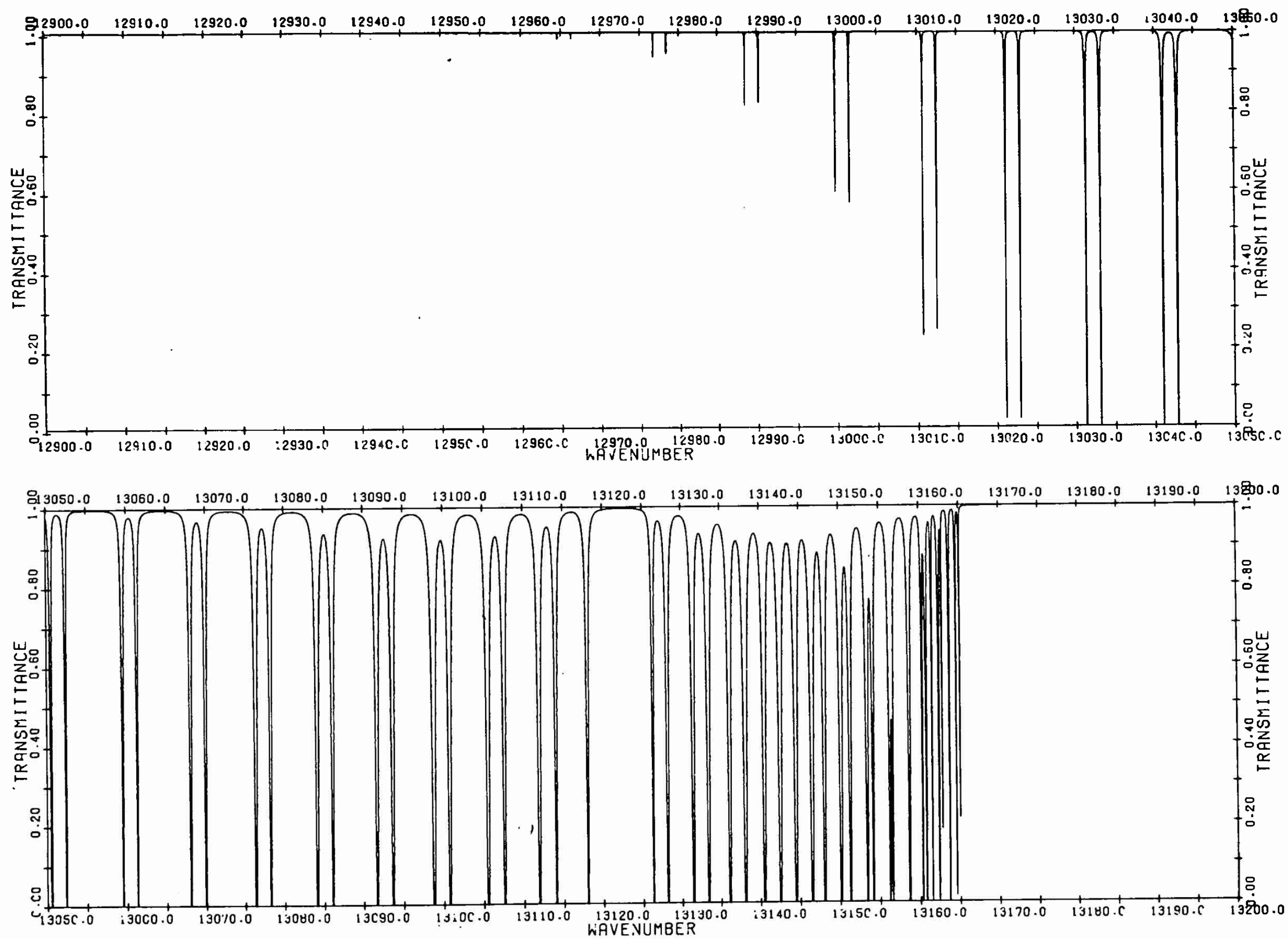


Figure 5cl. Atmospheric Transmittance due to Molecular Absorption Through a 10-km Horizontal Path at 12-km Altitude

References

1. McClatchey, R.A. (1970) Atmospheric Attenuation of CO Laser Radiation, AFCRL-71-0370, ERP 359.

2. McClatchey, R.A. and Selby, J.E.A. (1972a) Atmospheric Attenuation of HF and DF Laser Radiation, AFCRL-72-0312, ERP 400.

3. McClatchey, R.A. and Selby, J.E.A. (1972b) Atmospheric Transmittance, 7-30μm: Attenuation of CO_2 Laser Radiation, AFCRL-72-0611, ERP 419.

4. McClatchey, R.A., Benedict, W.S., Clough, S.A., Burch, D.E., Calfee, R.F., Fox, K., Rothman, L.S., and Garing, J.A. (1973) AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL-TR-73-0096.

5. Burch, D.E. (1970) Semiannual Technical Report, Investigation of the Absorption of Infrared Radiation by Atmospheric Gases U-4784, Jan. 1970.

6. Bignell, K.J. (1970) Quart. J. Roy. Meteorol. Soc. **96**:409.

7. Burch, D.E., Gryvnak, D.A., and Pembrook, J.D. (1971) Philco-Ford Corporation, Aeronutronic Division, Contract No. F19628-69-C-0263, U-4897, ASTIA AD882876.

8. Shapiro, M.M. and Gush, H.P. (1966) Canad, J. Phys. **44**:949.

9. McClatchey, R.A., Fenn, R.W., Selby, J.E.A., Volz, F.E., and Garing, J.W. (1972) Optical Properties of the Atmosphere (Third Edition), AFCRL-72-0497, August 1972.

10. Valley, S.L., Ed., (1965) Handbook of Geophysics and Space Environments, AFCRL.

11. Deirmendjian, D. (1963) Scattering and Polarization Properties of Polydispersed Suspensions with Partial Absorption, Proc. of the Interdisciplinary Conf. on Electromagnetic Scattering, Potsdam, N.Y., Milton Kerker, Ed., Pergamon Press.

12. Volz, F.E. (1972) Appl. Opt. **11**:755.

13. Elterman, L. (1968) UV, Visible, and IR Attenuation for Altitudes up to 50 km, 1968, AFCRL, Environmental Res. Paper No. 285, AFCRL-68-0153.

14. Elterman, L. (1970) Vertical-Attenuation Model with Eight Surface Meteorological Ranges 2 to 13 Kilometers, 1970, AFCRL, Environmental Research Paper No. 310, AFCRL-70-0200.

15. Young, C. (1965) J.Q.S.R.T. **5**:549-552.

16. Young, L.A. (1968) J. Quant. Spectrosc. Rad. Transfer **8**:693.

17. Mantz, A.W., Nichols, E.R., Alpert, B.D. and Reo, K.N. (1970) J. Mol. Spec. **35**:325.

18. Deutsch, T.F. (1968) Appl. Phys. Letters **10**:234.

19. Basov, N.G., Galochkin, V.T., Igoshin, V.I., Kulakov, L.V., Martin, E.P., Nikitin, A.I. and Oraevsky, A.N. (1971) Appl. Optics **10**:1814.

20. Spanbauer, R.N., Rao, K.N. and Jones, L.H. (1965) J. Mol. Spec. **16**:100.

☆ U. S. GOVERNMENT PRINTING OFFICE: 1974--704-296--65