AFCRL-65-854

VARIATION WITH ALTITUDE OF THE TRANSMITTANCE OF THE EARTH'S ATMOSPHERE WITH GRATING RESOLUTION

David G. Murcray, Frank H. Murcray

and

Walter J. Williams

Department of Physics
University of Denver
Denver, Colorado 80210

Contract AF 19(628)-5202

Project No. 8662

Task No. 866201

SCIENTIFIC REPORT NO. 1

November 1965

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 363

This research was supported by the Advanced Research Projects Agency and was monitored by Air Force Cambridge Research Laboratories under Contract No. AF 19(628)-5202

Prepared for
Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts

AFCRL-65-854

VARIATION WITH ALTITUDE OF THE TRANSMITTANCE OF THE EARTH'S ATMOSPHERE WITH GRATING RESOLUTION

David G. Murcray, Frank H. Murcray

and

Walter J. Williams

Department of Physics
University of Denver
Denver, Colorado 80210

Contract AF 19(628)-5202

Project No. 8662

Task No. 866201

SCIENTIFIC REPORT NO. 1

November 1965

Sponsored by

Advanced Research Projects Agency
ARPA Order No. 363

This research was supported by the Advanced Research Projects Agency and was monitored by Air Force Cambridge Research Laboratories under Contract No. AF 19(628)-5202

Prepared for
Air Force Cambridge Research Laboratories
Office of Aerospace Research
United States Air Force
Bedford, Massachusetts

TABLE OF CONTENTS

LIST OF FIGURES

ABSTRACT

The solar spectrum in the region from 3150 cm^{-1} to 3950 cm^{-1} was measured at various altitudes from 1.6 km to 31 km using a balloon borne grating spectrometer system. The spectral transmittance of the atmosphere above certain altitudes were deduced from these spectra. The observed spectral transmittance was compared with the theoretical transmittance predicted by Plass considering only CO_2 absorption. The comparisons agree well at 15 km. At 30 km. the absorption by H_2O approximately equals the absorption by CO_2 and the theoretical transmittance (estimated from CO_2 only) differs from the observed.

1. INTRODUCTION

In previous studies we have presented data concerning the spectral transmittance of the earth's atmosphere in several spectral regions as observed at various altitudes. These data have been obtained with a balloon borne system designed to study the variation of the infrared solar spectrum with altitude. A small Littrow type prism instrument has been used as the spectrometer for obtaining these data. With the development of large computers it has become feasible to theoretically predict the spectral transmittance one would observe under high resolution. In addition while the extreme detail one observes in high resolution data is not desirable in some studies there are other studies in which high resolution experimental data are necessary. In view of this the prism spectrometer used in the balloon borne system was replaced with a double pass 1/2 meter Czerny-Turner type grating instrument designed specifically for balloon use. This instrument was flown for the first time on March 26, 1964. The results of the flight are the subject of this report.

2. INSTRUMENTATION

2.1 Grating Spectrometer

The spectrometer is a 1/2 meter grating spectrometer of Czerny-Turner design equipped with a 75 line per mm Bausch and Lomb grating blazed for 12μ. The orders are separated by means of a small Littrow type prism predisperser. The position of the Littrow prism and hence the wavelength of the radiation which is allowed to reach the entrance slit of the grating spectrometer is controlled by means of a cam which is coupled to the grating drive system. Cams have been ground on a single blank which allow the grating spectrometer to be used in the 3rd, 4th, 5th, 6th and 25th order and it is possible to operate the instrument in any of these orders by rotating the cam to the proper position. The grating position is also controlled by a cam. This cam was ground so that as near as possible the recorded spectra are linear in wavelength. The position of the motor shaft used to drive the grating cam is monitored by means of a 13 bit shaft position encoder. This aids in reducing the data automatically.

The radiation illuminating the exit slit of the grating spectrometer is brought out the side of the instrument where it is focused by an auxiliary optical system onto the detector (a Schwarz rapid response thermocouple). This detector optical unit is built as a separate unit; thus it is possible to change the detector being used with the instrument without disturbing the spectrometer optical system.

The radiation is interrupted mechanically at 100 cps after its first pass through the spectrometer by means of a tuning fork chopper. The 100 cps signal generated by the detector is amplified by a low noise transistorized preamplifier designed specifically for use with the thermocouple.

2.2 Auxiliary Instrumentation

The solar radiation is reflected by a plane mirror into a telescope (diameter 10 in., focal length 5 ft.) which focuses the radiation on the spectrometer slit. The plane mirror or heliostat is oriented by means of a biaxial pointing control which is a modification of one described by Goddard, Juza, Maher and Speck.[1] The modifications are too extensive to discuss here; they will be detailed in a separate report.

The amplified detector output and auxiliary information necessary to ascertain the performance of the equipment during flight were recorded on board by means of an FM magnetic tape recorder and also transmitted to the ground by means of an FM/FM telemetry system. This flight was launched from Holloman Air Force Base and the ground station for telemetry was provided as a part of the range facilities.

Primary power for the various units was supplied by means of a 28 vdc silver-zinc battery. All mechanical operations were accomplished by means of 400 cycle single phase synchronous motors. The 400 cycle power was derived from the 28 vdc by means of a transistorized sine wave inverter. The power required by the electronics was supplied by means of mercury batteries.

The various components were mounted into a gondola system constructed from pieces of electrical conduit brazed together to form a unit of the desired configuration. The spectrometer and biaxial pointing control unit were mounted on an octagonal plate which was attached to the gondola by means of a spring suspension system. This system reduces accelerations which these units suffer when the equipment is returned to the ground by parachute.

3. FLIGHT DETAILS

The polyethylene balloon used to carry the instrumentation to high altitude was of taped design and when fully inflated was 172.6 feet in diameter with a volume of two million cubic feet. The instrumentation including the Air Force command package weighed 800 pounds. The balloon was launched from Holloman Air Force Base near Alamogordo, New Mexico at 0826 M. S. T., March 26, 1964. The balloon ascended with an average ascent rate of 200 m/min and reached a floating altitude of 31.6 km. The instrumentation was separated from the balloon at 1204 M. S. T. to facilitate recovery. The equipment was recovered in excellent condition.

4. RESULTS

All of the instrumentation operated properly and excellent spectra were obtained from the ground through floating altitude.

The spectral data are the continuous record of the output voltage from the detector. This record of output voltage versus time readily transforms to a record of output voltage versus wavelength since the scan mechanism is powered by a 400 cycle synchronous motor. The wavelength calibration of individual spectra were based on absorption features which are well known from laboratory studies.

Information on the relative output of the detector as a function of wavelength is sufficient for some purposes. It provides information on the relative absorption by the atmosphere above the balloon at various altitudes from 1.6 km to 31.6 km. More than such relative information about transmittance can be derived from these data. By studying the variations of the detector output with altitude it is possible to determine the detector voltage that one would observe if no absorption were present. Once this so-called vacuum envelope has been determined it is possible to convert all spectra to the form of percent transmission versus wavelength. In the past this data reduction has been performed using desk calculators. With the increased resolution achieved with the grating spectrometer it was obvious that such manual reduction would not be economical. In view of this an automatic method of data reduction was devised. As a first step the data were converted from analog to digital form. The vacuum envelope was also converted to digital form and the computations necessary to reduce the data to percent transmission were performed by means of an IBM 7094 computer. Selected spectra were plotted by means of a digital plotter. Seventeen of these spectra are presented in Figures 1 through 8. Each of the spectra presented are separated into four parts according to wave number intervals. The distribution of the spectral intervals among the nine figures is given in Table I. Observations of some parts of the spectra are lacking when the pointing control momentarily lost the sun, elsewhere they may be omitted for clarity.

Most of the strong atmospheric absorptions in this region are due to water vapor and carbon dioxide. The amount of water vapor present in the atmosphere decreases rapidly with altitude and except for the strongest lines most of the water vapor absorption has disappeared by the time the balloon reached an altitude of 13 km. These strong lines persist and at floating altitude a major portion of the residual absorption is due to water vapor.

5. COMPARISON WITH THEORETICAL PREDICTIONS

In a previous report[2] it was shown that the slant path transmittance predicted by Plass[3] for the CO_2 absorption in the 4.3μ region agreed fairly well with the transmittance observed at the higher altitudes. It was also shown that the theoretical transmittance given by Plass for the 6.3μ H_2O absorption did not agree with the observed transmittances. This lack of agreement appeared to be due to an overestimate of the amount of water vapor present at the higher altitudes. The absorptions in the wavelength region scanned during this flight are due to CO_2 and H_2O with the water vapor lines occurring throughout the region. As mentioned above many of the water vapor absorption lines have disappeared from the spectra obtained above 13 km. In view of this the spectrum obtained at 15.6 km altitude and a solar elevation angle of 46° was compared with that given by Plass for CO_2 absorption only for 15 km and a solar elevation angle of 45°. The spectrum obtained at 31.6 km and a solar elevation angle of 57.8° was compared with that given by Plass for 30 km and a solar elevation angle of 60°.

The result of these comparisons are given in Figure 9. In comparing the theoretical and experimental results allowance must be made for the fact that the experimental data are taken with a higher resolution that that given for the theoretical data. In addition the experimental curves contain the water vapor absorptions which are not considered in the theoretical data. Taking these factors into consideration the agreement between the theoretical and experimental results is fairly good in the case of the lower altitude spectrum. This agreement is no longer present at the higher altitude. This is not unexpected since at these altitudes the H_2O absorption is approximately equal to the CO_2 absorption. In addition the percentage error in the experimental data are much worse for small absorptions since any error in determining the vacuum envelope will result in a larger percentage error in this case than in the case for larger absorptions.

There are a number of strong H_2O absorption lines which occur outside of the region where CO_2 absorption is significant at the higher altitudes. Comparisons were made between the theoretical transmittance data of Plass for 15 km and the absorptions observed at 15 km. These comparisons indicate that the theoretical results predict considerably more absorption than was observed. It is felt that the discrepancy is due to an overestimate by Plass of the amount of water vapor present at the higher altitudes.

The water vapor absorption in the vicinity of 3854 cm^{-1} has been studied in detail. The variation of this absorption with altitude was used to determine the average water vapor mixing ratio in various layers in the stratosphere. The results of this analysis and a discussion of the results are given in a separate publication.[4]

TABLE I

PART A - Flight Data

Record	Time MST	Pressure Mb	Altitude (Km)	Sec θ*	P/Po Sec θ	Data Presented in Figures
19	0834	836	1.6	1.931	1.59	1, 4, 8
21	0840	782	2.1	1.865	1.44	2, 3, 5, 7
23	0846	733	2.7	1.804	1.30	1, 4, 6, 8
26	0855	647	3.7	1.728	1.10	2, 3, 5, 7
28	0901	547	5.0	1.684	.91	1, 4, 6, 8
32	0913	398	7.3	1.600	.63	2, 3, 5, 7
34	0919	309	9.1	1.563	.48	1, 6, 8
37	0928	206	11.7	1.511	.31	1, 5, 7
40	0937	172	12.8	1.465	.25	6
42	0943	154	13.5	1.438	.22	3, 5, 7
46	0955	110	15.6	1.388	.15	4, 6, 8, 9
48	1001	92	16.7	1.363	.12	5
51	1010	69	18.5	1.332	.091	6
56	1025	43	21.5	1.288	.054	4, 5, 7
63	1046½	21.2	26.1	1.239	.026	4, 6, 8
77	1125½	9.4	31.6	1.181	.011	2, 3, 5, 7, 9
78	1128½	9.4	31.6	1.178	.011	4, 6

*θ is Solar Zenith Angle

REFERENCES

1. Goddard, A., M. Juza, J. Maher, and F. Speck. (1956) "Balloon Borne System for Tracking the Sun." Review of Scientific Instruments 27, 381-385.

2. Murcray, D., F. Murcray and W. Williams. (1965) "Comparison of Experimental and Theoretical Slant Path Absorptions in the Region from 1400 to 2500 cm^{-1}." J. Opt. Soc. Am. 55, 1239-1246.

3. Plass, G. N. (1964) "Transmittance Tables for Slant Paths in the Stratosphere" SSD-IDR-62-117, Volume V, Final Report, Contract AF 04 (694)-96, ..eronutronic Division, Ford Motor Company.

4. Murcray, D., F. Murcray and W. Williams."Further Data Concerning the Distribution of Water Vapor in the Stratosphere." Accepted for publication in the Quarterly Journal of the Royal Meteorological Society.

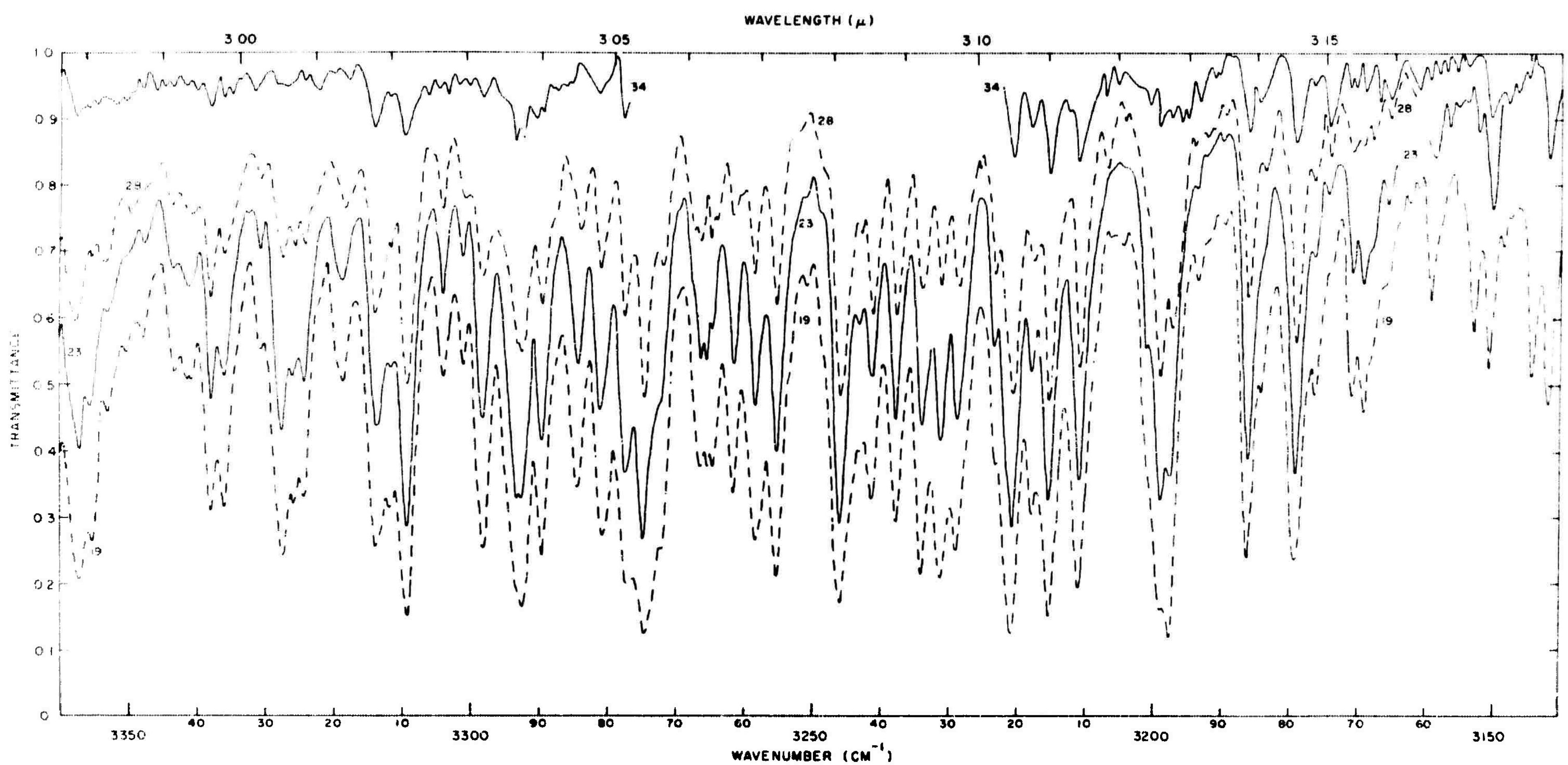

Figure 1. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3350 to 3150 cm^{-1}. (See Table I for identification of record numbers)

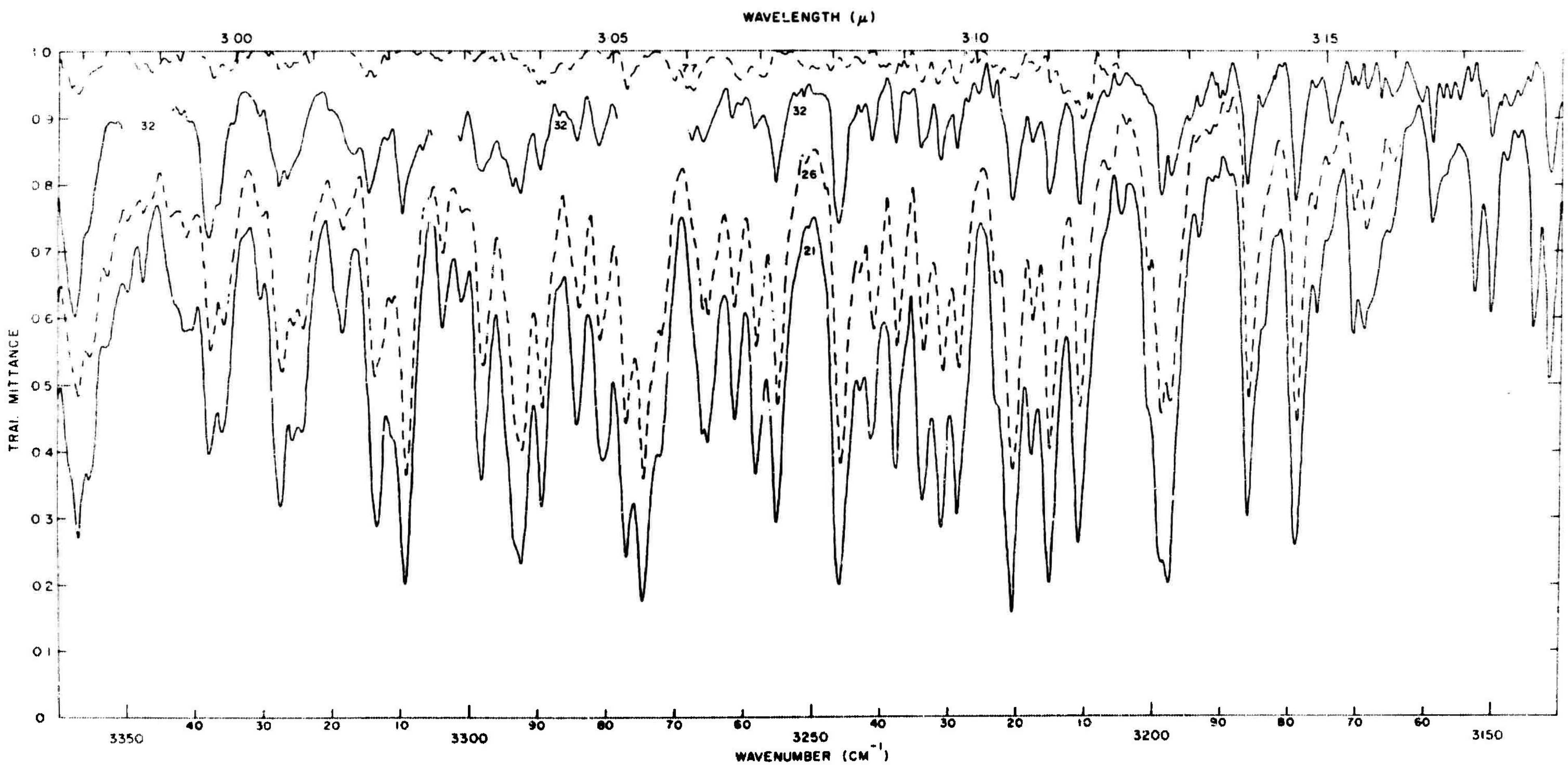

Figure 2. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3350 to 3150 cm^{-1}. (See Table I for identification of record numbers)

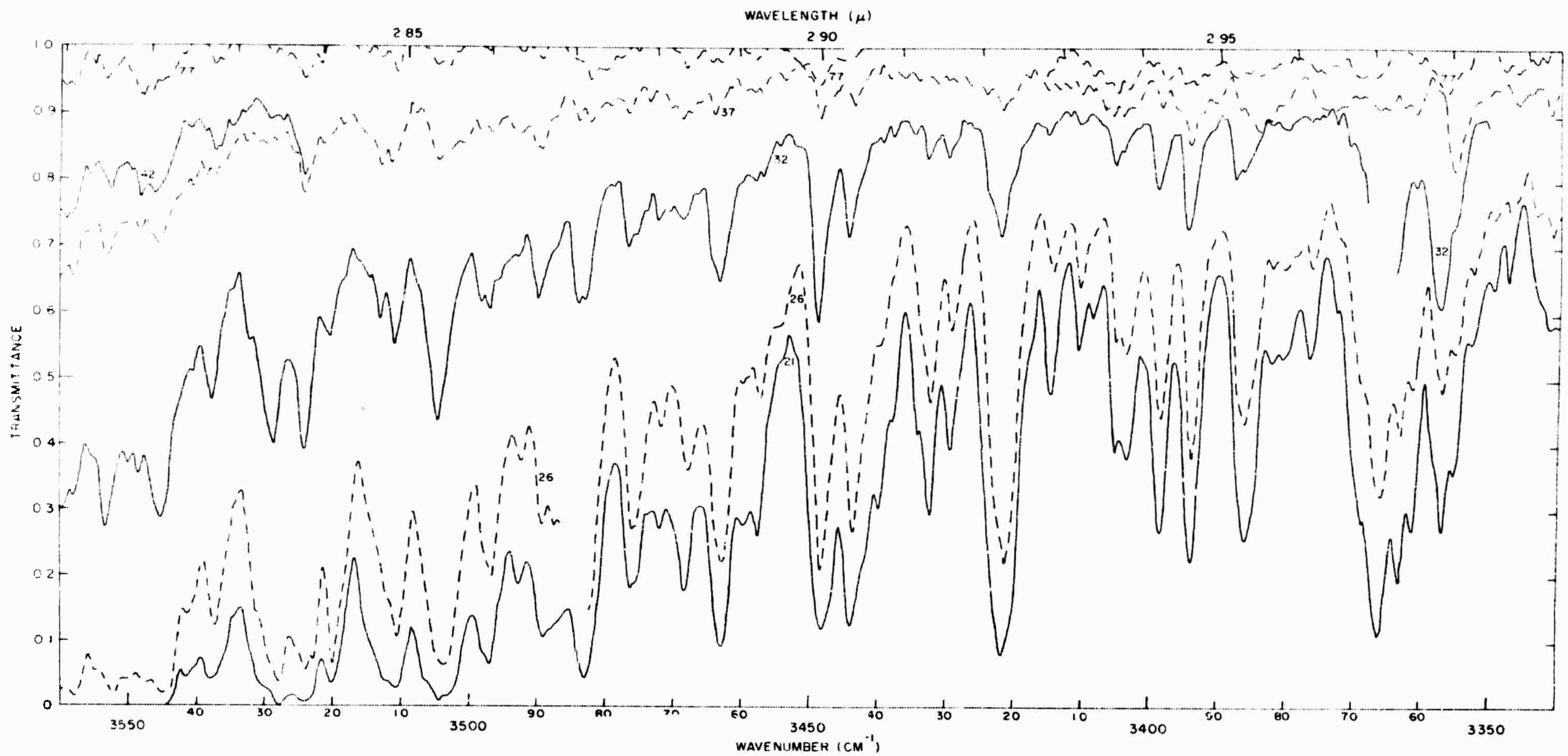

Figure 3. Variations with Altitude of the Spectral Transmittance of the Atmosphe 'rom 3550 to 3350 cm^{-1}. (See Table I for identification of record numbers)

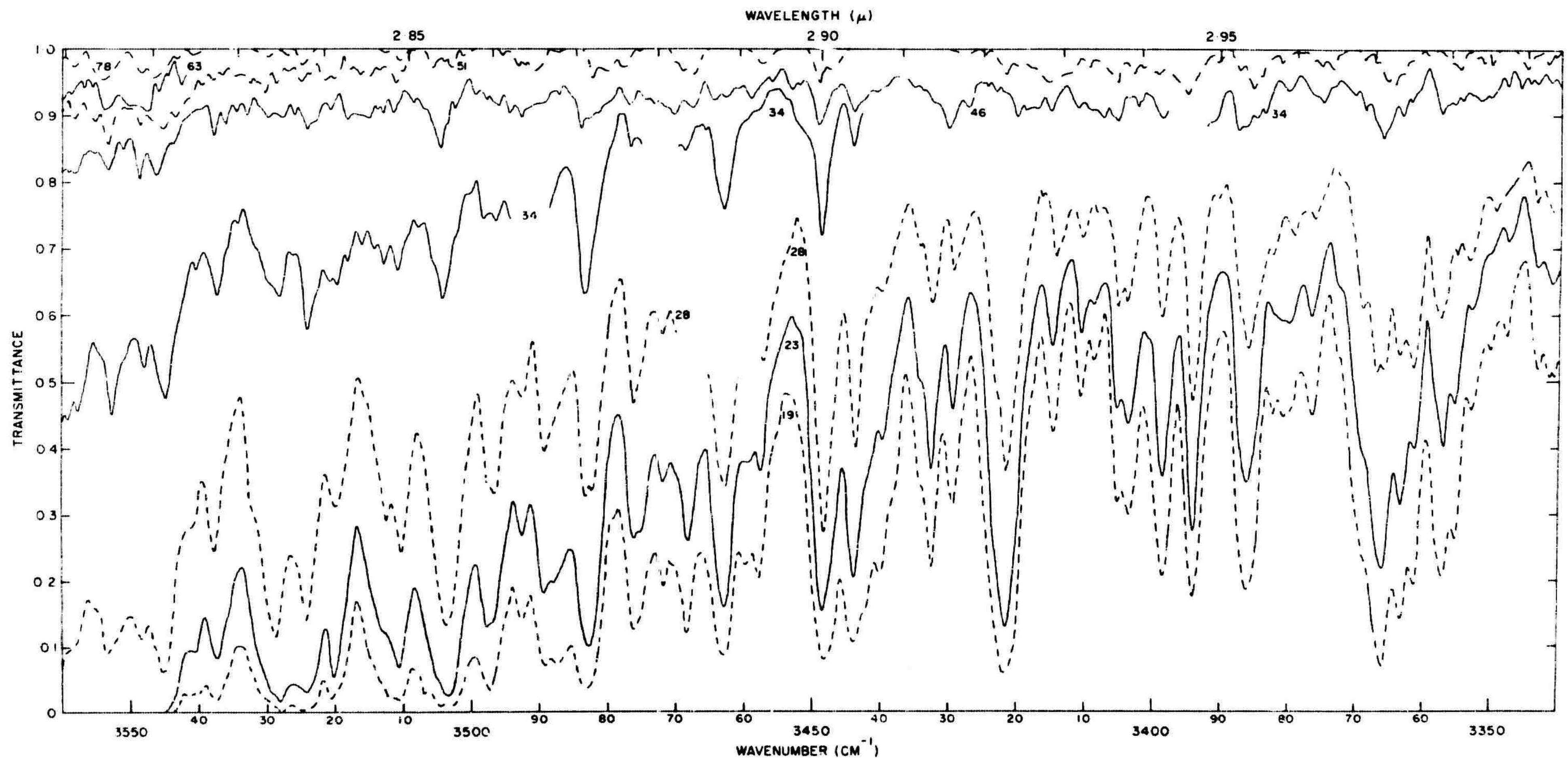

Figure 4. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3550 to 3350 cm^{-1}. (See Table I for identification of record numbers)

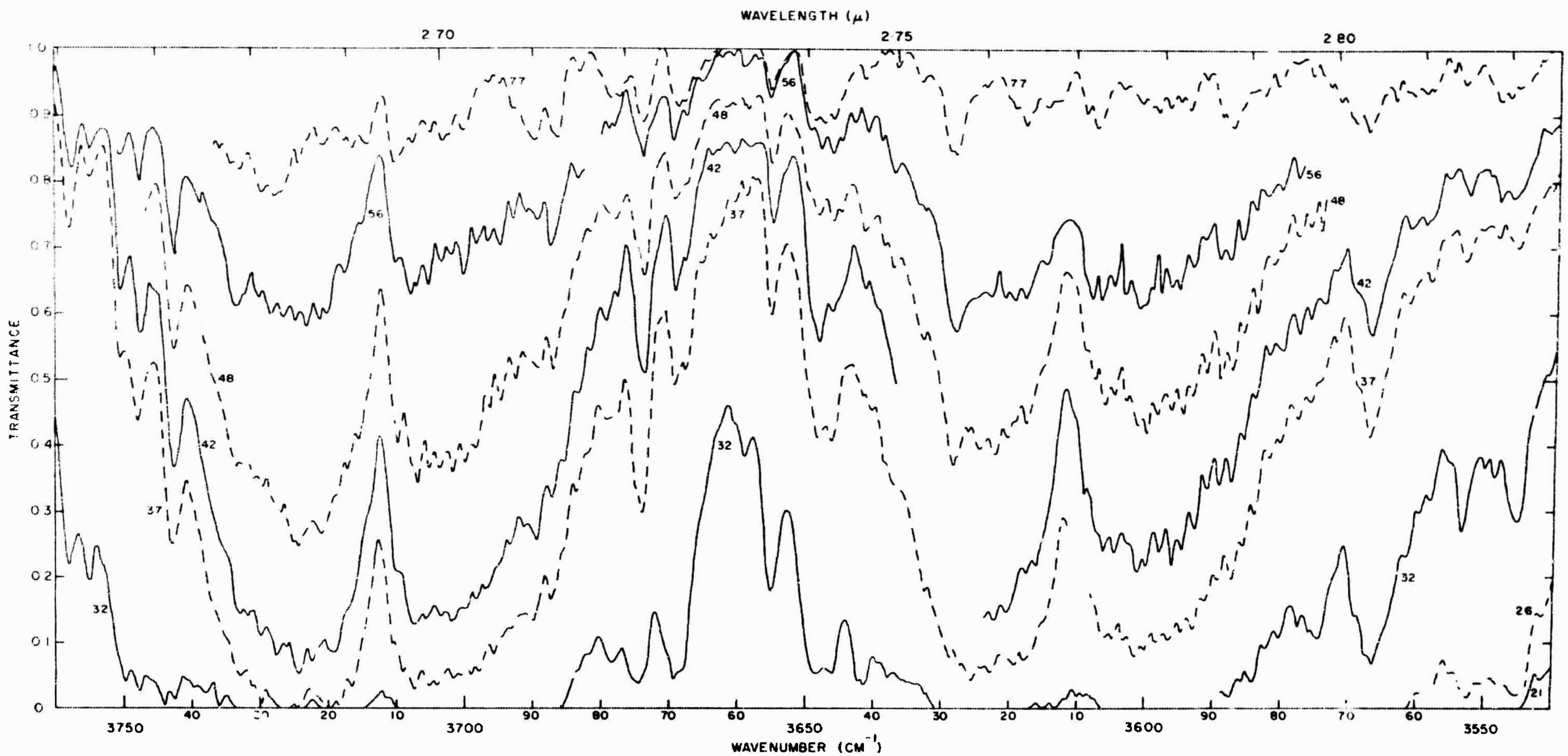

Figure 5. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3750 to 3550 cm^{-1}. (See Table I for identification of record numbers)

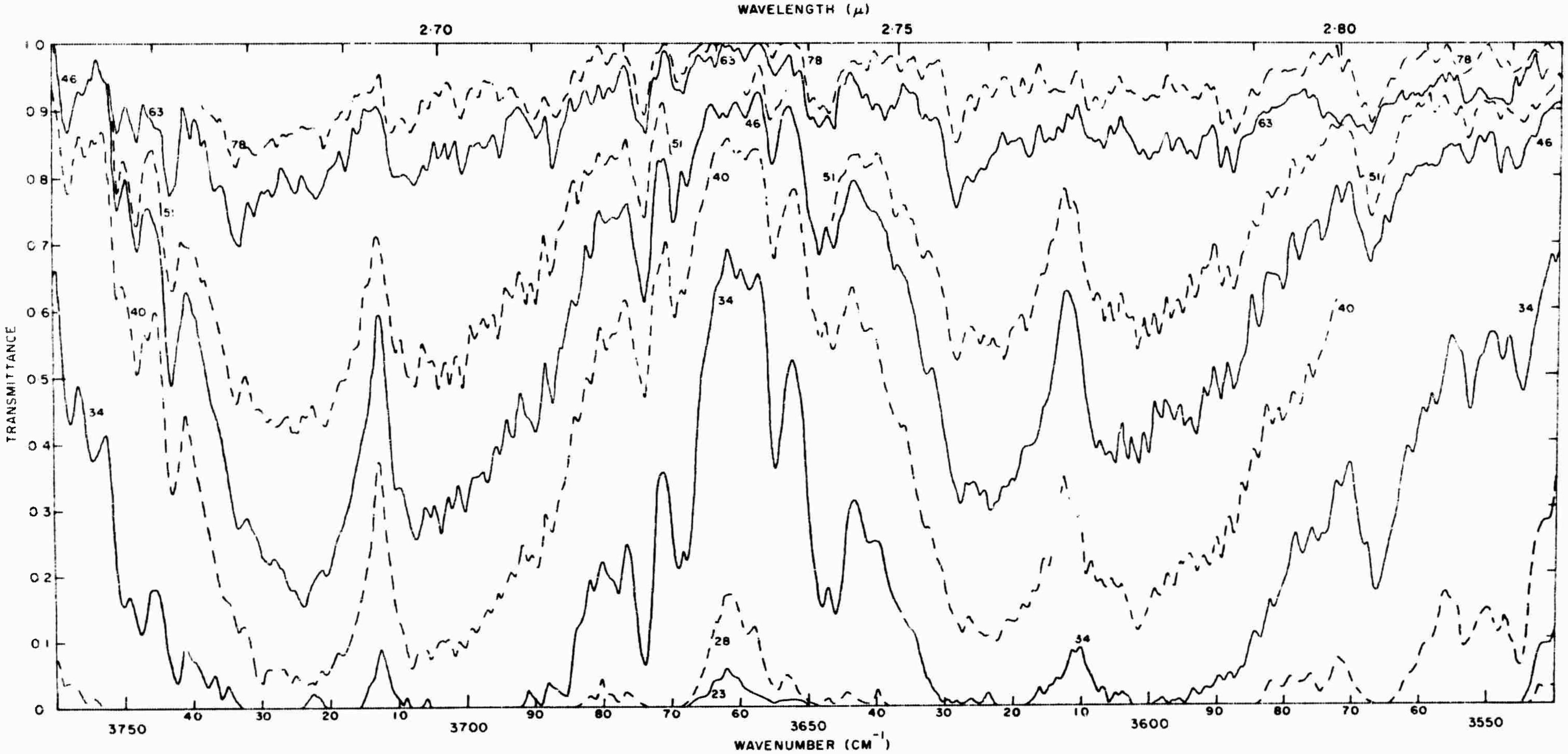

Figure 6. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3750 to 3550 cm^{-1}. (See Table I for identification of record numbers)

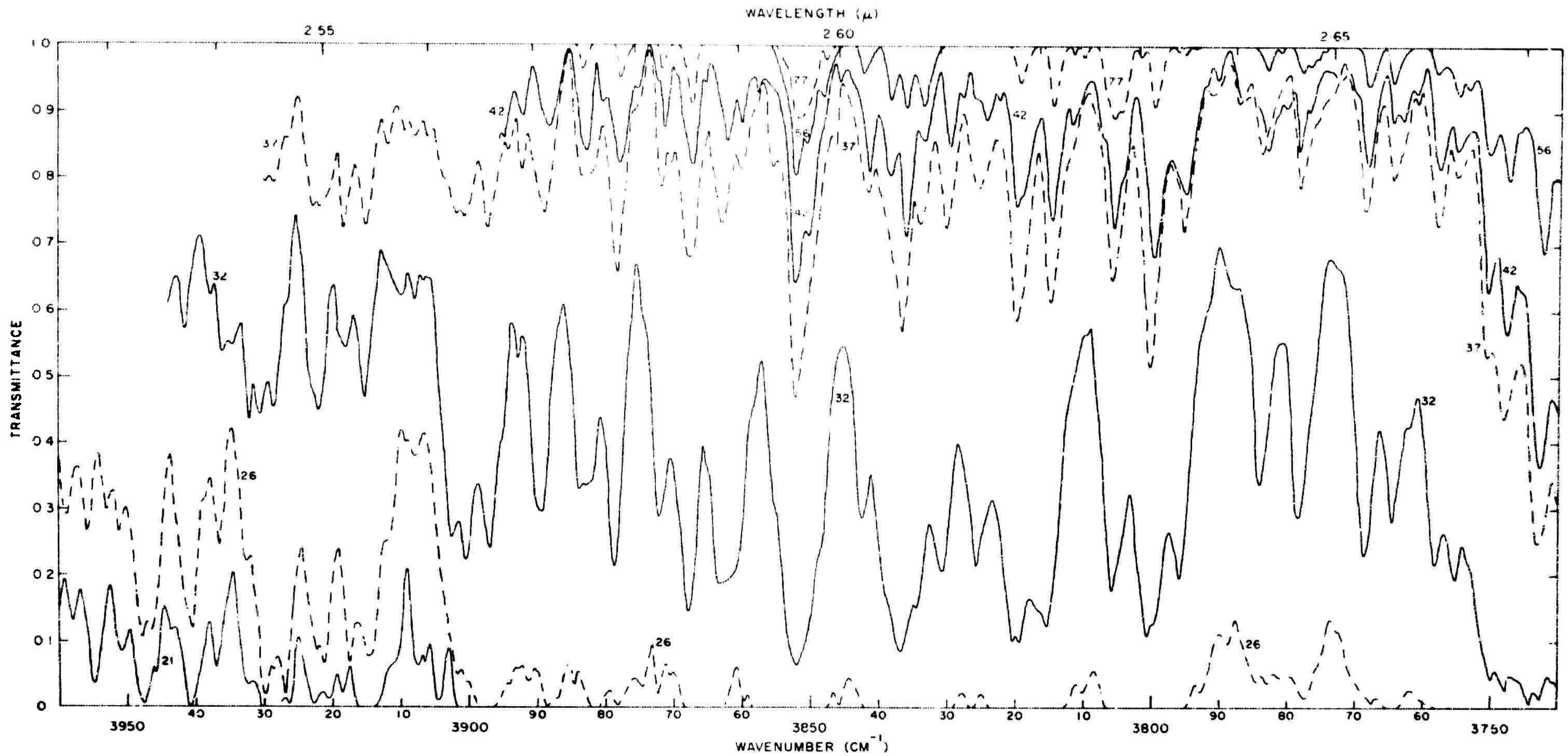

Figure 7. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3950 to 3750 cm^{-1}. (See Table I for identification of record numbers)

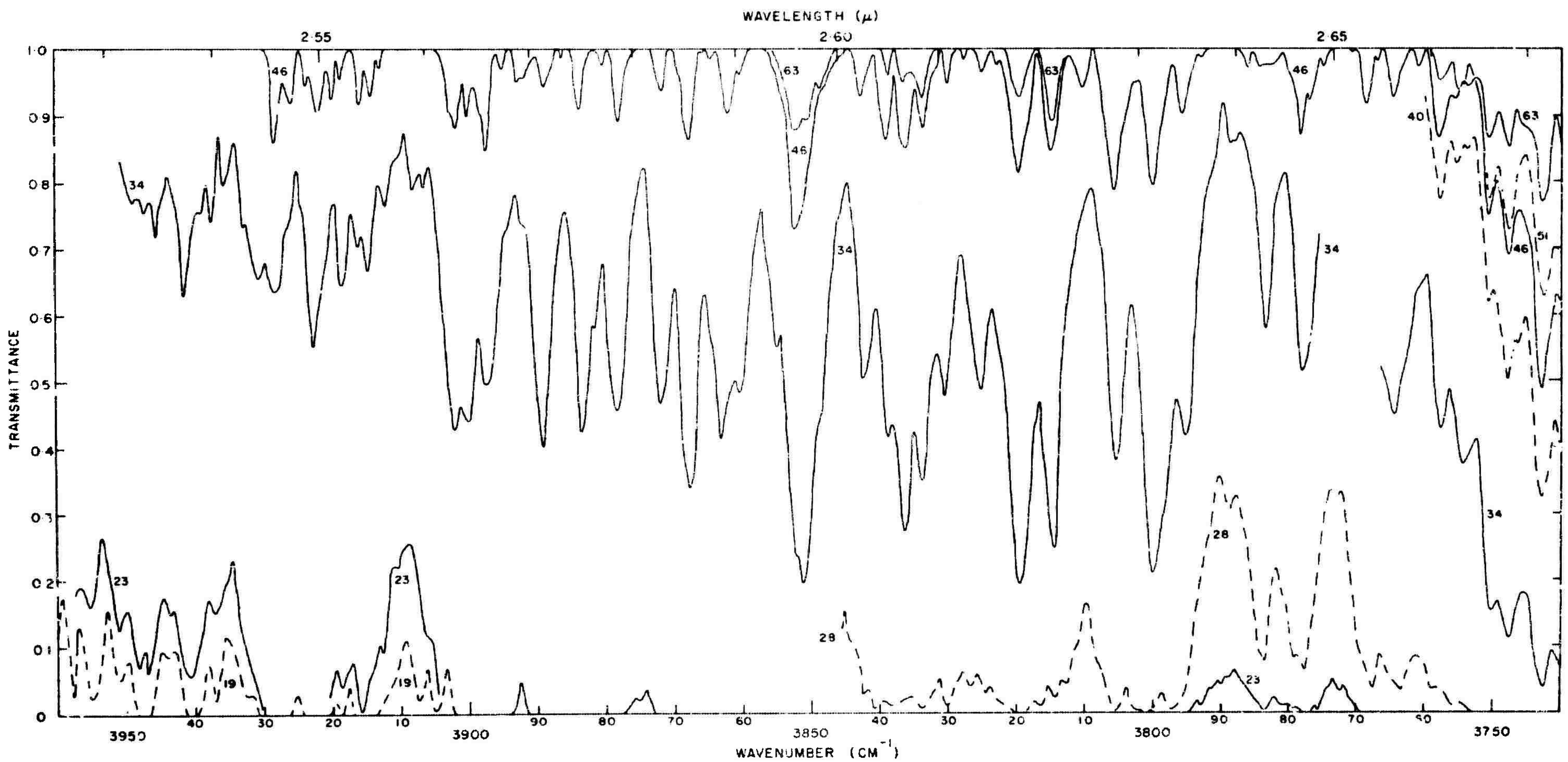

Figure 8. Variations with Altitude of the Spectral Transmittance of the Atmosphere from 3950 to 3750 cm^{-1}. (See Table I for identification of record numbers)

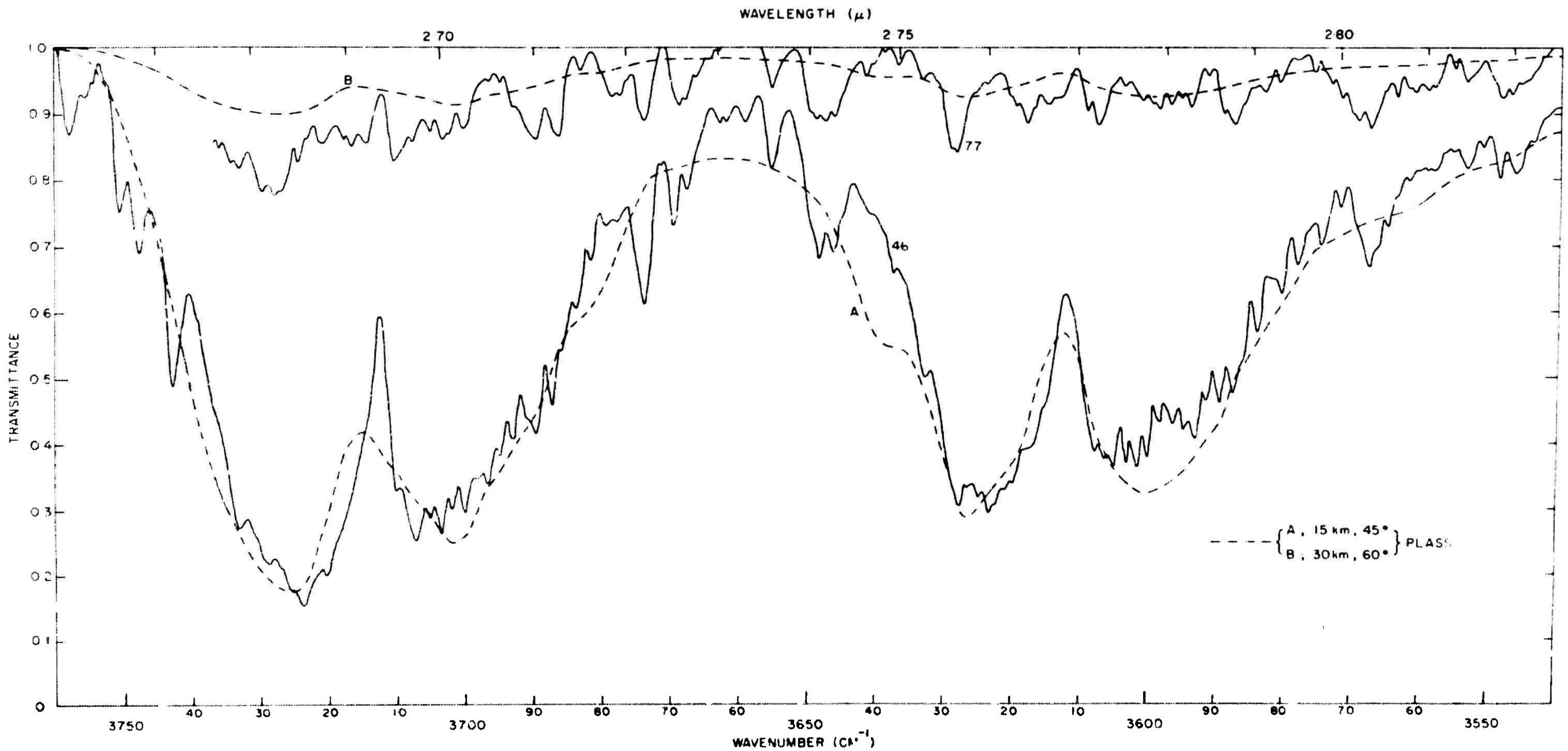

Figure 9. Comparison Between Experimental and Theoretically Predicted Atmospheric Transmittance Data at Altitudes of 15 and 30 km.

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) Department of Physics University of Denver Denver, Colorado 80210	2a. REPORT SECURITY CLASSIFICATION 2b. GROUP

3. REPORT TITLE
VARIATION WITH ALTITUDE OF THE TRANSMITTANCE OF THE EARTH'S ATMOSPHERE WITH GRATING RESOLUTION

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

5. AUTHOR(S) (Last name, first name, initial)
Murcray, David G., Murcray, Frank H., and Williams, Walter J.

6. REPORT DATE	7a. TOTAL NO. OF PAGES	7b. NO. OF REFS
November 1965	18	3

8a. CONTRACT OR GRANT NO. AF19(628)-5202 ARPA Order No. 363 b. PROJECT NO. 8662-01 c. 62503015 d. none	9a. ORIGINATOR'S REPORT NUMBER(S) 9b. OTHER REPORT NO(S) (Any other numbers that may be assigned this report) AFCRL-65-854

10. AVAILABILITY/LIMITATION NOTICES

11. SUPPLEMENTARY NOTES This research was supported by the Advanced Research Projects Agency	12. SPONSORING MILITARY ACTIVITY Hq. AFCRL, OAR (CRO) United States Air Force L. G. Hanscom Field, Bedford, Mass.

13. ABSTRACT

The solar spectrum in the region from 3150 cm^{-1} to 3950 cm^{-1} was measured at various altitudes from 1.6 km to 31 km using a balloon borne grating spectrometer system. The special transmittance of the atmosphere above certain altitudes were deduced from these spectra. The observed spectral transmittance was compared with the theoretical transmittance predicted by Plass considering only CO_2 absorption. The comparisons agree well at 15 km. At 30 km the absorption by H_2O approximately equals the absorption by CO_2 and the theoretical transmittance (estimated from CO_2 only) differs from the observed.

DD FORM 1 JAN 64 1473

Unclassified
Security Classification

Unclassified

Security Classification

14 KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Transmittance, Earth's Atmosphere						
Solar Spectrum Infrared						
Balloon Instrumentation						
Atmospheric Radiation						
Spectra Calculated						

INSTRUCTIONS

1. ORIGINATING ACTIVITY: Enter the name and address of the contractor, subcontractor, grantee, Department of Defense activity or other organization *(corporate author)* issuing the report.

2a. REPORT SECURITY CLASSIFICATION: Enter the overall security classification of the report. Indicate whether "Restricted Data" is included. Marking is to be in accordance with appropriate security regulations.

2b. GROUP: Automatic downgrading is specified in DoD Directive 5200.10 and Armed Forces Industrial Manual. Enter the group number. Also, when applicable, show that optional markings have been used for Group 3 and Group 4 as authorized.

3. REPORT TITLE: Enter the complete report title in all capital letters. Titles in all cases should be unclassified. If a meaningful title cannot be selected without classification, show title classification in all capitals in parenthesis immediately following the title.

4. DESCRIPTIVE NOTES: If appropriate, enter the type of report, e.g., interim, progress, summary, annual, or final. Give the inclusive dates when a specific reporting period is covered.

5. AUTHOR(S): Enter the name(s) of author(s) as shown on or in the report. Enter last name, first name, middle initial. If military, show rank and branch of service. The name of the principal author is an absolute minimum requirement.

6. REPORT DATE: Enter the date of the report as day, month, year; or month, year. If more than one date appears on the report, use date of publication.

7a. TOTAL NUMBER OF PAGES: The total page count should follow normal pagination procedures, i.e., enter the number of pages containing information.

7b. NUMBER OF REFERENCES: Enter the total number of references cited in the report.

8a. CONTRACT OR GRANT NUMBER: If appropriate, enter the applicable number of the contract or grant under which the report was written.

8b, 8c, & 8d. PROJECT NUMBER: Enter the appropriate military department identification, such as project number, subproject number, system numbers, task number, etc.

9a. ORIGINATOR'S REPORT NUMBER(S): Enter the official report number by which the document will be identified and controlled by the originating activity. This number must be unique to this report.

9b. OTHER REPORT NUMBER(S): If the report has been assigned any other report numbers *(either by the originator or by the sponsor)*, also enter this number(s).

10. AVAILABILITY/LIMITATION NOTICES: Enter any limitations on further dissemination of the report, other than those imposed by security classification, using standard statements such as:

(1) "Qualified requesters may obtain copies of this report from DDC."

(2) "Foreign announcement and dissemination of this report by DDC is not authorized."

(3) "U. S. Government agencies may obtain copies of this report directly from DDC. Other qualified DDC users shall request through
_______________________________________."

(4) "U. S. military agencies may obtain copies of this report directly from DDC. Other qualified users shall request through
_______________________________________."

(5) "All distribution of this report is controlled. Qualified DDC users shall request through
_______________________________________."

If the report has been furnished to the Office of Technical Services, Department of Commerce, for sale to the public, indicate this fact and enter the price, if known.

11. SUPPLEMENTARY NOTES: Use for additional explanatory notes.

12. SPONSORING MILITARY ACTIVITY: Enter the name of the departmental project office or laboratory sponsoring *(paying for)* the research and development. Include address.

13. ABSTRACT: Enter an abstract giving a brief and factual summary of the document indicative of the report, even though it may also appear elsewhere in the body of the technical report. If additional space is required, a continuation sheet shall be attached.

It is highly desirable that the abstract of classified reports be unclassified. Each paragraph of the abstract shall end with an indication of the military security classification of the information in the paragraph, represented as *(TS)*, *(S)*, *(C)*, or *(U)*.

There is no limitation on the length of the abstract. However, the suggested length is from 150 to 225 words.

14. KEY WORDS: Key words are technically meaningful terms or short phrases that characterize a report and may be used as index entries for cataloging the report. Key words must be selected so that no security classification is required. Identifiers, such as equipment model designation, trade name, military project code name, geographic location, may be used as key words but will be followed by an indication of technical context. The assignment of links, rules, and weights is optional.

Unclassified

Security Classification

ERRATA

Report No.	Scientific No. 1, November 1965
Contract No.	AF 19(628)-5202
AFCRL No.	65-854
ARPA Order No.	363
TITLE:	"Variation with Altitude of the Transmittance of the Earth's Atmosphere with Grating Resolution" by David G. Murcray, Frank H. Murcray and Walter J. Williams
CORRECTIONS TO DD FORM 1473:	7b. No. of Refs - should read 4 instead of 3
	10. Availability/Limitation Notices - the following should be inserted: Distribution of this Document is Unlimited.