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The Atmospheric 60-GHz Oxygen Spectrum: Modeling and Laboratory Measurements

Hans J. Liebe
George A. Hufford
Robert O. DeBolt

U.S. DEPARTMENT OF COMMERCE
Robert A. Mosbacher, Secretary

Janice Obuchowski, Assistant Secretary
for Communications and Information

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PREFACE

Certain commercial equipment products are identified in this report to adequately describe the design and operation of the program reported here. In no case does such identification imply recommendation or endorsement by the National Telecommunications and Information Administration, nor does it imply that the material or equipment identified is necessarily the best available for the purpose.

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THE ATMOSPHERIC 60-GHz OXYGEN SPECTRUM:
Modeling and Laboratory Measurements

Hans J. Liebe, George A. Hufford, and Robert O. DeBolt*

Molecular oxygen dominates the attenuation and delay rates of dry air throughout the V-band (50-75 GHz). Both rates display as a function of altitude an intricate pattern which, for the most part, has never been confirmed by experiment. The collective spectral behavior of 38 pressure-broadened $\mathbf{O}_2$ lines is described by a complex prediction model (MPM89). For atmospheric conditions of pressure equivalent to altitudes between sea level and 30 km (100 to 1 kPa), this behavior was studied under controlled laboratory conditions. The spectrometer consisted of a one-port Fabry-Perot resonator, which was excited by an automatic network analyzer. All operations were controlled by a microcomputer, including reference level calibrations at multiple (up to 15, separated by 0.73 GHz) resonances and control of the pressure steps. Introducing gas into the spectrometer cell changed the detected resonance response, from which was deduced a complex refractivity by means of a twin, nonlinear least squares method. The analysis of dry air measurements concentrated on the loss part, expressed as attenuation rate α in dB/km. The detection sensitivity was ± 0.01 dB/km for an effective path length of 0.24 km and a 5 percent coupling ratio of a resonance response. Coupling to a particular resonance and the duration (1-5 hrs) of a measurement sequence influenced the spectrometer performance. Over 4,000 attenuation values are reported. The results were measured between 53.9 and 66.3 GHz in 0.1 GHz frequency increments at eleven pressure steps (1-100 kPa) for three temperatures (7,30,52°C). The measurement uncertainties were estimated to be typically ± 0.05 below 3 dB/km and ± 2 percent for higher values (≤ 18 dB/km). A first comparison of experimental results with MPM89 predictions revealed, in addition to random data scatter, systematic differences that correlate with line broadening and overlap parameters.

Key Words: atmospheric oxygen spectrum; dry air; frequency range: 54 to 66 GHz; frequency, pressure and temperature parameters; laboratory attenuation measurements; parametric studies

1. INTRODUCTION

For V-band radio frequencies (50 to 75 GHz), molecular oxygen turns the atmosphere below 90 km altitude into an absorptive and dispersive medium. Accurate modeling of the spectral response is important for predicting the propagation of radiation through the atmosphere. At heights above 12 km where pressures are less than 20 kilopascal (200 mb), there is a definite line spectrum with more than 25 discernable features spread over the 50 to 70 GHz range. At lower heights, the increasing pressure broadens the lines and causes them to blend together. The composite shape resembles a band centered at 60 GHz; however, the resulting intensity is not the simple sum of isolated line responses. Instead, there is an "overlap interference", which is taken into account in a theory developed by Rosenkranz (1988; 1991) by means of pressure-proportional coefficients attached to each line of the $\mathbf{O}_2$ microwave spectrum.

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* The authors are with the Institute for Telecommunication Sciences, National Telecommunications and Information Administration,. U.S. Department of Commerce, Boulder, CO 80303.

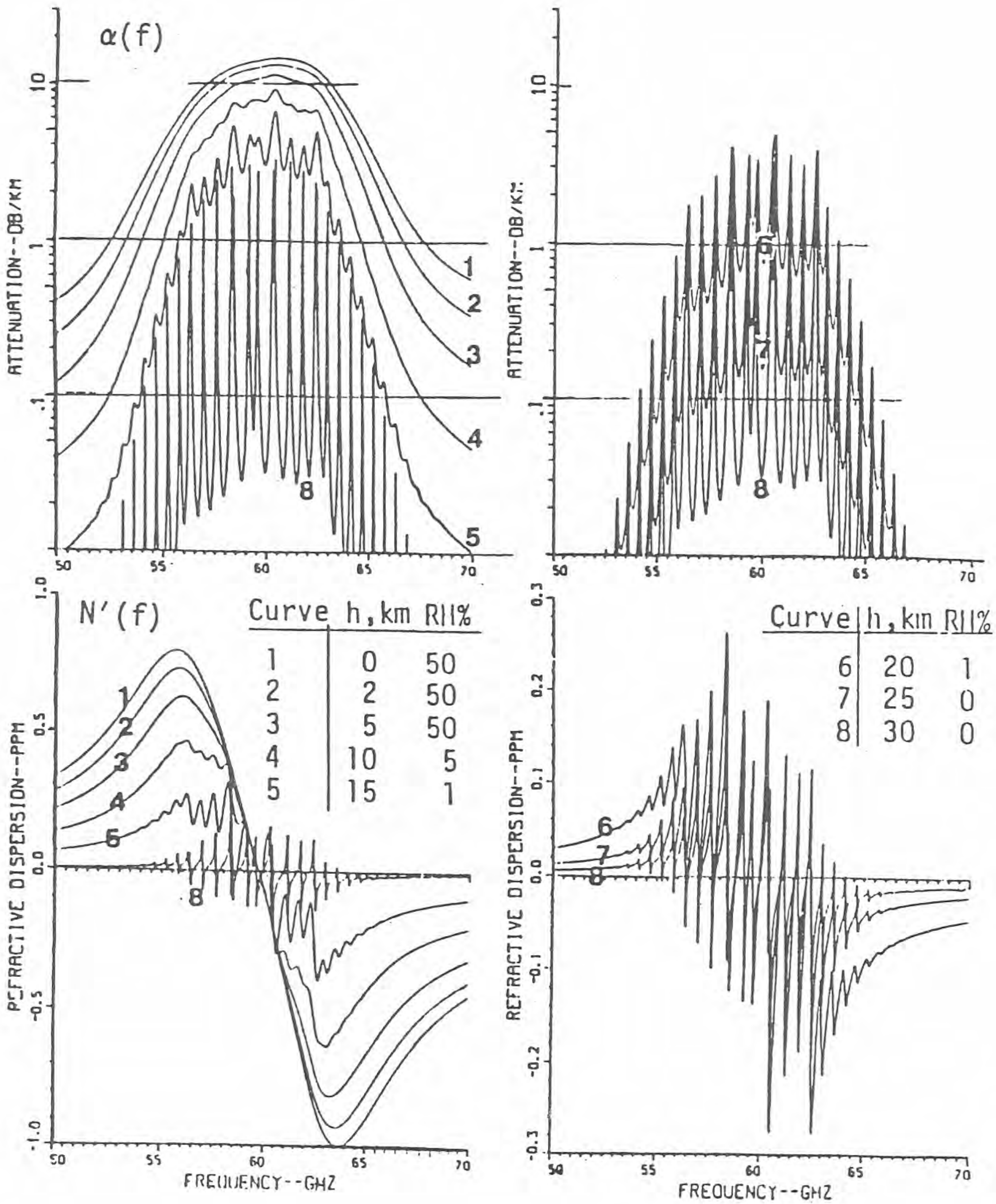

Figure 1. Attenuation rate α(f) and refractivity N'(f) of dry air (O2 spectrum) between 50 and 70 GHz, predicted by MPM89 for simulated conditions (U.S. Std. Atm.) at altitudes, H = 0 to 30 km.

Spectral properties of a gas may be expressed in terms of attenuation rate α in decibels per kilometer (dB/km) and refractivity N′ in parts per million (ppm). Frequency and height (pressure) dependence of these quantities for the atmospheric $\mathbf{O_2}$ spectrum between 50 and 70 GHz are depicted in Figure 1. The graphs encompass various stages from an unstructured band at sea level to isolated line behavior at 30-km height. Model predictions of these highly frequency-selective atmospheric transfer characteristics need to be corroborated by controlled laboratory studies, where frequency, pressure, and temperature provide the variables.

1.1 Overview

The main body of this report deals with the analytical and experimental aspects of the dry air module in the millimeter-wave propagation model MPM89 (Liebe, 1989). The multi-coefficient formulation of the atmospheric $\mathbf{O_2}$ spectrum has been called the Rosenkranz-Liebe model (e.g., Hill, 1987). Details of an experiment are given that provides high quality data for a comparison with model predictions. Precision measurements of the signal reflected from a one-port resonator were used. Interactive spectrometer operations, automatic recordings, and data reduction to attenuation rates α (and refractivities N′) were handled by a microcomputer. Optimization problems of the detection scheme, repeatability problems, and various experimental procedures are described in detail. Factors that influence precision and accuracy of the measurements are examined, examples are given, and the final results are summarily compared with model predictions. Possible corrections to the physical model MPM89 are discussed. In the Appendix, the measured attenuation rates α_x are tabulated and compared with MPM predictions. The extensive database contains information on the interaction process between colliding air molecules. Systematic deviations from model predictions challenge future theoretical efforts.

2. MPM89: A PREDICTION MODEL FOR THE ATMOSPHERIC 60 GHz O_2 SPECTRUM

2.1 Complex Refractivity

For a quantitative description of the $\mathbf{O_2}$ microwave spectrum the measure of complex refractivity,

$$N(f) = N_s + N'(f) - jN''(f) \quad \text{ppm,} \tag{1}$$

is adopted (Liebe, 1989). The nondispersive part N_s is real and positive; the frequency-dependent refractive dispersion and loss contributions are denoted by $N' - jN''$, which for $\mathbf{O_2}$ microwave transitions are represented by the sum of a line (resonant) and a relaxation (nonresonant) term, $N_L + N_D$; the unit ppm denotes 1×10^{-6}; and $j = \sqrt{-1}$. Converted into conventional radio engineering quantities, the imaginary part defines power attenuation α and the real part phase delay β, expressed as

$$\alpha = 0.1820 \cdot f \cdot N''(f) \quad \text{dB/km} \qquad \text{and} \qquad \beta = 1.2008 \cdot f \cdot N'(f) \quad \text{deg/km,} \tag{2}$$

where the frequency f is GHz. The numerical factors derive from $(4\pi/c)10\,log\,e = 0.1820$; c = 299.792 458 km·GHz·ppm^{-1} is the speed of light in vacuum; and 360/c = 1.2008.

The refractivity **N** is proportional to the number of molecules per unit volume, which is computed from the known quantities of pressure P (kPa) and temperature T (K) assuming the ideal gas law. The nondispersive term of the three gases of interest here is then given by

$$N_s = 792.06 \cdot r_G(P/T) \quad \text{ppm}, \tag{3}$$

where the factor $r_G \equiv r_{N2} = 1.0000(3)$[1] is the experimental value obtained for nitrogen by Newell and Baird (1965). Measurements at 60 GHz assuming $r_{N2} = 1$ (Liebe et al., 1977) yielded :

$r_{Air} = 0.98003(32)$ for CO_2-free, dry air

and

$r_{O2} = 0.9033(22)$ for Oxygen.

2.2 Line Spectrum

Resonance contributions from 44 oxygen lines are calculated by means of a line-by-line summation,

$$N_L = \sum_k S_k\mathbf{F}_k \quad \text{ppm}, \tag{4}$$

where

$$S_k = a_1 P\cdot\theta^3 \exp[a_2(1 - \theta)] \quad \text{kHz}, \tag{5}$$

is a line strength; $\theta = 300/T$ is a relative inverse temperature variable; $\mathbf{F}_k$ is a complex shape function in GHZ^{-1}; k is an index for 38 $\mathbf{O}_2$ fine structure transitions (quantum number code, $K^{\pm}$ = 1 to 37) and 6 rotational lines below 1000 GHz; and a_1, a_2 are spectroscopic coefficients (see Table 1).

The shape function of an isolated, pressure-broadened line was formulated by Van Vleck-Weisskopf (e.g., Hill, 1987) and modified by Rosenkranz (1988) to include pressure-induced line interference as follows:

$$F(f) = \frac{f}{\nu_k}\left[\frac{1 + jI_k}{\nu_k - f + j\gamma_k} - \frac{1 - jI_k}{\nu_k + f - j\gamma_k}\right] \tag{6}$$

which may be rationalized to absorption (F″) and dispersion (F′) profiles

[1] Throughout this report, digits in parentheses at the end of a numerical value give its standard deviation in terms of the final listed digits.

$$F''(f) = A(X + Y) - I_k [(1 - B)X + (1 + B)Y],$$

and

$$F'(f) = (1 - B)X - (1 + B)Y + I_k \cdot A(X - Y),$$

with the abbreviations

$$A = \gamma_k/\nu_k, \qquad B = f/\nu_k,$$
$$X = f/[(\nu_k - f)^2 + \gamma_k^2], \qquad Y = f/[(\nu_k + f)^2 + \gamma_k^2].$$

Width and interference parameters of (6) are for $\mathbf{O}_2$ lines in air,

$$\gamma_k = a_3 P \cdot \theta^{\eta} \quad \text{GHz}, \tag{7}$$

where $\eta = (0.8 - a_4)$ and

$$I_k = (a_5 + a_6\,\theta) P \cdot \theta^{0.8}. \tag{8}$$

Table 1 lists center frequencies $\nu_k(K^{\pm})$ in GHz (Zink and Mizushima, 1987) for strengths $a_1 \geq 3 \times 10^{-7}$ kHz; and the spectroscopic coefficients a_2, a_5 and a_6 from Rosenkranz (1991) and a_1, a_3 and a_4 (for $f \leq 300$ GHz we have $a_4 = 0$) from Liebe (1989) for strength S_k , pressure-broadened width γ_k and pressure-induced interference I_k , all at $\theta = 1$.

At height levels above 30 km ($P \leq 1$ kPa), the geomagnetic field imposes Zeeman-splitting on the $\mathbf{O}_2$ lines and the refractivity **N** becomes a three-dimensional tensor. As a consequence, radiowave propagation in the vicinity ($\nu_k \pm 5$ MHz) of $\mathbf{O}_2$ line-centers is direction-dependent and polarization-sensitive (Hufford and Liebe, 1989).

2.3 Relaxation Spectrum

The nonresonant refractivity of dry air makes a small contribution at ground level pressures due to the relaxation (Debye) spectrum of oxygen (Liebe, 1985), which is computed with

$$\mathbf{N}_D = S_o \mathbf{F}_o \qquad \text{ppm}, \tag{9}$$

The strength is given by

$$S_o = 6.14 \times 10^{-4} P \cdot \theta^2 \qquad \text{ppm}, \tag{9a}$$

and the complex Debye shape is

Table 1

Line Frequencies And Coefficients For Microwave Transitions Of $\mathbf{O}_2$ In Air

ν_o	a_1	a_2	a_3	$a_4 = 0$	a_5	a_6
GHz	kHz/kPa		GHz/kPa		1/kPa	1/kPa
	$\times 10^{-6}$		$\times 10^{-3}$		$\times 10^{-3}$	$\times 10^{-3}$
50.474239	0.94	9.694	8.60		1.600	5.520
50.987747	2.46	8.694	8.70		1.400	5.520
51.503349	6.08	7.744	8.90		1.165	5.520
52.021412	14.14	6.844	9.20		0.883	5.520
52.542393	31.02	6.004	9.40		0.579	5.520
53.066906	64.10	5.224	9.70		0.252	5.520
53.595749	124.70	4.484	10.00		–0.066	5.520
54.130001	228.00	3.814	10.20		–0.314	5.520
54.671158	391.80	3.194	10.50		–0.706	5.520
55.221367	631.60	2.624	10.79		–1.151	5.514
55.783802	953.50	2.119	11.10		–0.920	5.025
56.264774	548.90	0.015	16.46		2.881	–0.069
56.363388	1344.00	1.660	11.44		–0.596	4.750
56.968204	1763.00	1.260	11.81		–0.556	4.104
57.612484	2141.00	0.915	12.21		–2.414	3.536
58.323875	2386.00	0.626	12.66		–2.635	2.686
58.446590	1457.00	0.084	14.49		6.848	–0.647
59.164207	2404.00	0.391	13.19		–6.032	1.858
59.590984	2112.00	0.212	13.60		8.266	–1.413
60.306061	2124.00	0.212	13.82		–7.170	0.916
60.434776	2461.00	0.391	12.97		5.664	–2.323
61.150558	2504.00	0.626	12.48		1.731	–3.039
61.800156	2298.00	0.915	12.07		1.738	–3.797
62.411217	1933.00	1.260	11.71		–0.048	–4.277
62.486259	1517.00	0.083	14.68		–4.290	0.238
62.997978	1503.00	1.665	11.39		0.134	–4.860
63.568520	1087.00	2.115	11.08		0.541	–5.079
64.127769	733.50	2.620	10.78		0.814	–5.525
64.678902	463.50	3.195	10.50		0.415	–5.520
65.224068	274.80	3.815	10.20		0.069	–5.520
65.764771	153.00	4.485	10.00		–0.143	–5.520
66.302094	80.09	5.225	9.70		–0.428	–5.520
66.836830	39.46	6.005	9.40		–0.726	–5.520
67.369598	18.32	6.845	9.20		–1.002	–5.520
67.900864	8.01	7.745	8.90		–1.255	–5.520
68.431007	3.30	8.695	8.70		–1.500	–5.520
68.960312	1.28	9.695	8.60		–1.700	–5.520
118.750343	945.00	0.009	16.30		–0.247	0.003

$$F_d = \frac{1}{1 + jZ} - 1 \qquad (10)$$

where imaginary (loss) and real (phase) parts are

$F_o''(f) = Z/(1 + Z_2)$ and $F_o'(f) = - Z^2/(1 + Z^2)$,

with the abbreviation $Z = f/\gamma_o$. The nonresonant width follows from

$$\gamma_o = 5.6\times10^{-3}P\cdot\theta^{1.05} \quad \text{GHz} \qquad (11)$$

The width parameter γ_o was deduced from an MPM -based evaluation of atmospheric emission measurements between 2.5 and 10 GHz (Danese and Partridge, 1989).

2.4 Earlier Experimental Studies Between 50 and 75 GHz

The characteristics α(f) and N′(f) of the 60-GHz $\mathbf{O}_2$ spectrum have been measured on a limited scale under controlled laboratory conditions. Pure oxygen and dry air spectra were studied for variations with frequency f, pressure P, and temperature T under "isolated" and "overlapped" line conditions:

Line studies with oxygen furnished data on self-broadened ($\mathbf{O}_2 + \mathbf{O}_2$) width and strength parameters (Liebe et al., 1977). Pressure scans (P = 0 to 3 kPa) of differential refractivity, $\Delta N = N'(P)_f - N'(P)_{f/2}$, were done for 21 of the stronger $\mathbf{O}_2$ lines. The profiles ΔN(P) peak at $P = P_r$ to a value ΔN_o when measured at frequencies, $f = \nu_k \pm 15$ MHz. Isolated line parameters of width ($\gamma_k = \Delta\nu/P_r$) and strength ($S_k = \Delta N_o\gamma_k$) were determined from extrapolations to $f = \nu_k$. For these experiments, the geomagnetic field present in the laboratory was eliminated to avoid any Zeeman effect. Examples of measured data for ΔN_o and P_r are shown in Figure 2. Complementary experimental results for foreign-gas-broadened widths ($\mathbf{O}_2 + N_2$, H_2O, ...) were reported in Table 2 of the reference (Liebe, 1985).

Band behavior of overlapped lines is depicted in Figure 3. The data on complex refractivity **N** were measured for dry air between 53.6 and 63.6 GHz at pressures of 53 and 80 kPa and a temperature of 27°C, and in revised form reported by Liebe and Layton (1987). Rosenkranz fitted our data to his overlap theory (1988) and later (1991), based on our 1987 revisions, published the set of interference coefficients I_k which is listed in Table 1. The attenuation rates shown in Figure 4 are from measurements with pure oxygen at pressures of about 2 atm and two temperatures, -13 and 23°C (Read et al., 1988). Some quoted error bounds exceed ten percent. Nevertheless, these results support the correction of overlap interference effects as implemented in MPM89. The $\mathbf{O}_2$ results were scaled by us to represent dry air.

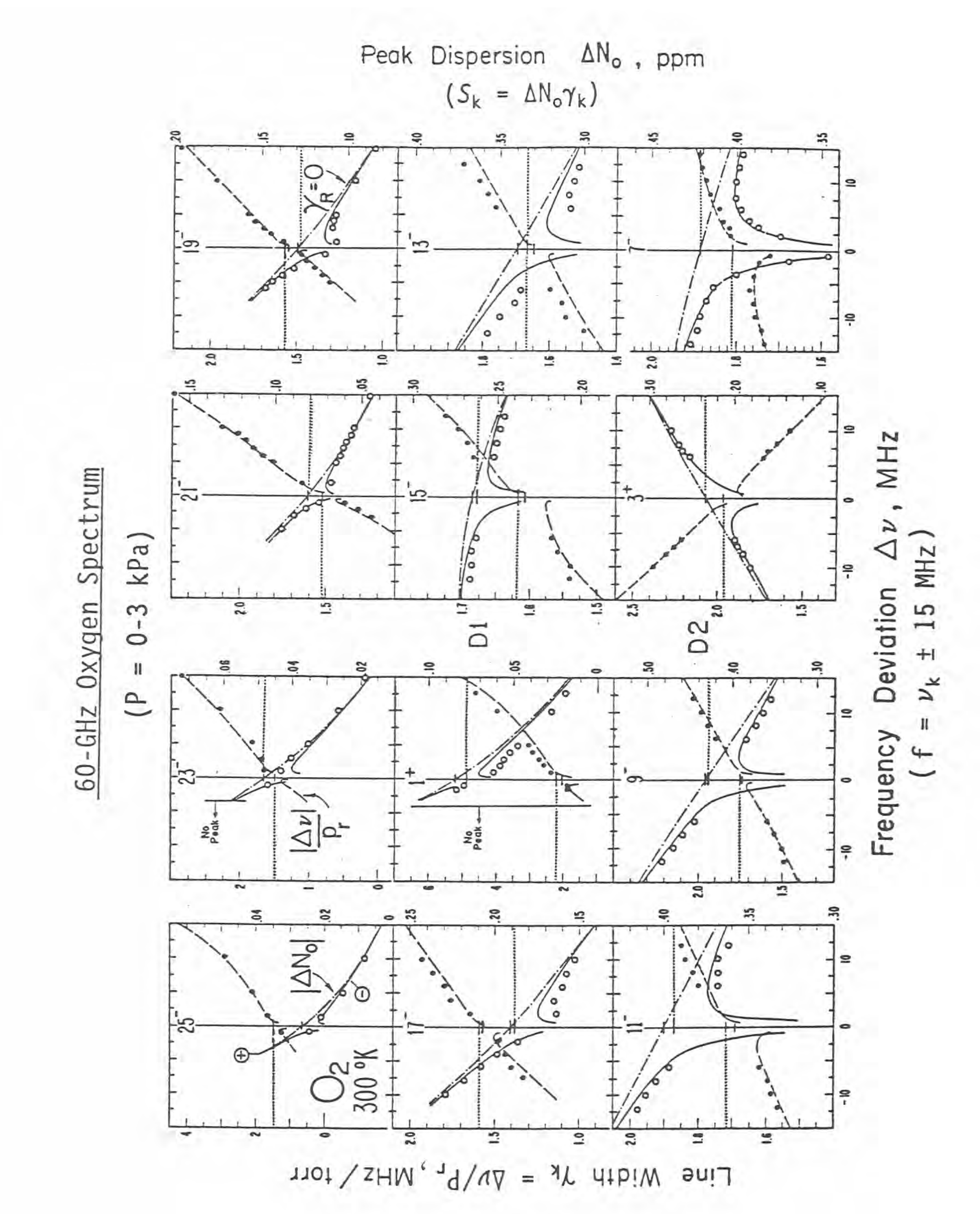

Figure 2. Experimental data on width and peak intensity for twelve pressure-broadened O_2 lines in the 60 GHz range. (for details see Liebe et al., 1977).

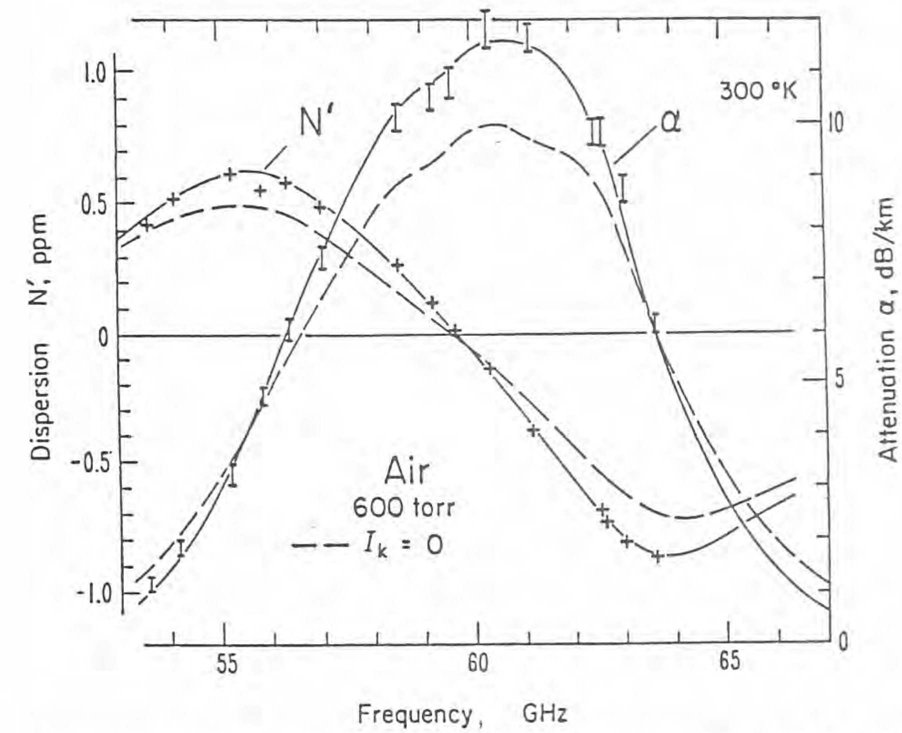

Figure 3. Measured attenuation α and refractivity N′ from 54 to 67 GHz for dry air at 80 kPa (I_k - line interference coefficients).

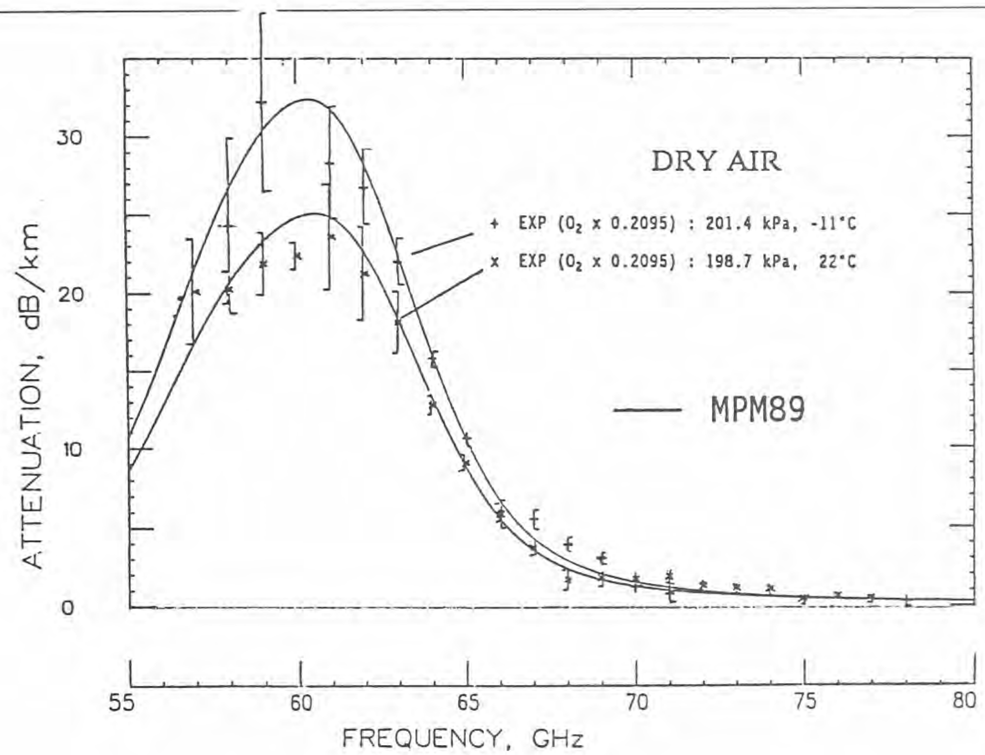

Figure 4. Attenuation data for dry air between 55 and 80 GHz, scaled from measurements of pure O_2 at 200 kPa pressure (Read et al., 1988).

Equations (1) to (11) represent the underlying theory of pressure-broadened, overlapping $\mathbf{O}_2$ lines that describes the spectrum of dry air centered at 60 GHz (Rosenkranz, 1988; 1990). The available range of quantitative data sets suitable to confirm a model for the atmospheric $\mathbf{O}_2$ microwave spectrum is more or less limited to what is shown in Figures 2 through 4. A serious effort to confirm pressure-broadening behavior under quasi-atmospheric conditions has been missing. Laboratory studies of the spectral intensity should focus on temperature and pressure dependences for single-line broadening and multi-line interference effects.

Relevant data are required to test the validity of various theoretical assumptions. Such "truth" data need to have negligible measurement error, must be free of systematic bias, and have to be numerous enough to sample all model dimensions. If we assume that center frequencies ν_k (Zink and Mizushima, 1987) and line strengths $S_k(a_1, a_2)$ (Liebe et al., 1977) are correct, then the values of at least 100 adjustable spectroscopic coefficients (a_3 to a_6, see Table 1) for 25 of the "stronger" lines centered between 54 and 66 GHz have to be determined from fits to measured data. Measurement techniques for such an ambitious undertaking will be discussed next. A comparison of predicted and measured results would check the accuracy of the MPM model and conceivably lead to revisions of the theory which, in turn, would provide an improved understanding of the molecular interaction effects that the theory seeks to describe.

3. THE RESONANCE SPECTROMETER

3.1 Resonator Characteristics

A semiconfocal, one-port Fabry-Perot resonator is the heart of the spectrometer. A flat and a spherical mirror (400 mm radius of curvature; both 100 mm in diameter, silver-plated brass with optically polished surfaces) are separated a distance d_R by three invar rods. The structure is housed in a stainless steel vacuum chamber that is temperature-controlled and can be pressurized (Liebe and Layton, 1987). A cross section of the spectrometer chamber with the resonator can be found in Fig. 2 of Liebe et al. (1984). Resonances were excited via a circular coupling iris centered in the flat mirror, followed by a quartz glass vacuum window, and V-band waveguide. Fundamental TEM_{00q} modes were utilized for which the center frequencies follow from

$$f_x = \frac{c}{n'}\left(\frac{4q-1}{8d_R}\right) \qquad GHz, \tag{12}$$

where c is the speed of light in vacuum, which has in units of mm·GHz the same value given at (2); q is the number of half-wavelength nodes between the mirrors; $n' = 1 + (N_s + N')10^{-6}$ is the real part of the refractive index of the gas inside the resonator, and $d_R = 205 \pm 12$ mm is the mirror spacing, varied with a precision ($\Delta d_R = \pm 0.3$ µm) micrometer. For example, the resonance center for the evacuated cell (P = 0) is at $f_0 = 62.500,000$ GHz when q = 85 and $d_R = 204.458,456$ mm. The experimental resonance frequency decreases to $f_x = f_0 \cdot [l - (N_s + N')10^{-6}]$ due to refractive tuning by the gas.

The key parameter of a sensitive spectrometer is its path length. The effective path length of an evacuated, high Q resonator is given by

$$L_E = 23.86/b_0 \qquad \text{km}, \tag{13}$$

where b_0 in kHz is the halfwidth of a high Q resonance centered at f_0, and $c/4\pi = 23.86$ for the units chosen. The vacuum value b_0 was found nearly a constant (≈ 105 kHz) for the TEM_{00q} modes between 54 and 66 GHz; thus the effective path length L_E is about 0.24 km. Losses due to coupling, conduction on the mirror surfaces, and diffraction ("spillover" at the spherical mirror) determine the value for b_0. Spurious fields inside the chamber, which might be excited by stray radiation, were suppressed with absorber material positioned off the resonance field. In rare cases, coincidence with a higher-order mode was suspected to be the cause of erroneous (b_x increased markedly over typical values) spectrometer readings.

3.2 Properties of the Resonance Signal

An automatic network analyzer (ANA, HP 85106A) was used, capable of making vector (magnitude and phase) measurements of a reflected signal with unprecedented speed, accuracy, and convenience. Between 10 and 15 GHz, the ANA's synthesized source generator (spectral purity and stability equal that of the internal 10 MHz quartz time base) provides a stimulus for the spectrometer resonator. A multiplier (× 5) transforms the RF signal to the 50 to 75 GHz band where the frequency resolution is typically 10 Hz. The RF signal changes frequency in discrete steps over a band Δf, centered at f_x and covering several halfwidths b. Reflected and incident signals from the resonator port are separately detected and their ratio is measured as complex reflection scattering coefficient,

$$s_{11}(\Delta f) = \mathbf{A}_c + \mathbf{A}_R(f). \tag{14}$$

The reflected signal amplitude and phase without a resonance is $\mathbf{A}_o = a' + ja''$, and $\mathbf{A}_R(f)$ is the frequency response of a high Q resonance. The ANA system allows calibration of the maximum reflection level to a normalized response, $a' = -1$ and $a'' = 0$.

The properties of an isolated resonance centered at f_x can be expressed by three interrelated (loaded = $\mathbf{Q}$, unloaded = Q^o, and coupling = Q_c) Q values,

$$1/\mathbf{Q} = 1/Q^o + 1/Q_c.$$

For weak coupling and high Q values ($Q_c > \mathbf{Q} > 10^5$), the reflected signal is then given by a Lorentzian (Schulten, 1966) in the form

$$\mathbf{A}_R(f) = (1 - \mathbf{Q}/Q_o)/[1 + j2\mathbf{Q}(f - f_x)/f_x]; \tag{15a}$$

which, when one sets $a_x = 1 - \mathbf{Q}/Q^o$ and $b_x = f_x/2\mathbf{Q}$, changes to

$$\mathbf{A}_R(f) = a_x/[1 + j(f - f_x)/b_x]. \tag{15b}$$

The frequency position of the reflection minimum (amplitude dip) a_x defines f_x, while $\pm b_x$ sets the frequency extensions from f_x to where the amplitude dip has dropped to $1/\sqrt{2}$ its original value (power halfwidth).

A statistical analysis of $s_{11}(\Delta f)$ data with the method of least squares provided the general approach to extracting five parameters (a', a'', f_x, and Q_o, $\mathbf{Q}$ or a_x, b_x) from (15a or b). Pairs of unloaded and loaded Q values and of parameters a_x and b_x are both strongly coupled (correlation coefficient $\rho > 0.9$; i.e., random signal variations that widen b_x simultaneously increase a_x). Hence, an alternate functional form,

$$\mathbf{A}_R(f) = 1/[g_x + j(f - f_x)/S_R], \tag{16}$$

was introduced for $\mathbf{A}_R$ in (14). Here we substituted $(1 - \mathbf{Q}/Q^o) = \mathbf{Q}/Q_c$, and defined $g_x = Q_c/\mathbf{Q} = 1/a_x$ as an amplitude factor, and $S_R = f_x/2Q_c = a_x b_x$ as resonance strength. The parameters g_x and S_R were found to be nearly independent (correlation coefficient $\rho < 0.35$), making (16) a better choice for the nonlinear least squares fit that extracts a', a'', S_R, g_x, and f_x.

3.3 Measurement Principle and Test Gases

The parameters in (15) and (16), which are subscripted by x, change with pressure, whereby $x \equiv 0$ implies $P = 0$, the reference state, and x the air-filled state for a constant pressure P. A difference measurement is conducted between the reference and a filled state. When air is introduced into the evacuated chamber, simultaneous changes in the resonance shape ($a_0 \rightarrow a_x$ and $b_0 \rightarrow b_x$), and shifts in the center frequency ($f_0 \rightarrow f_x$), are translated into attenuation rates α (Sect. 3.4) and refractivities N' (Sect. 3.5) (Newell and Baird, 1965; Poon, 1977; Read et al., 1988).

Gas pressure P was stepped between 0 and 101 kPa, controlled by a piezo-electric leak valve. The temperature T_c of the insulated spectrometer cell was kept stable to ± 0.01°C. Pressure was changed slowly (≤ ± 10 kPa/min) to ensure quasi-static gas conditions. The vacuum P = 0 (2×10^{-5} kPa) was established with a two-stage rotary vane pump (750 l/min) followed by a zeolith sorption trap.

The test gases were laboratory-grade dry air (composition and impurities stated by the supplier: 79.3 percent N_2, 20.7 ± 0.21 percent $\mathbf{O}_2$, 2.1 ppm H_2O, ≤ 1 ppm CO_2, ≤ 0.1 ppm total hydrocarbon content) and nitrogen serving as a lossless ($\alpha = 0$) substitute for air.

3.4 Attenuation Measurement

The attenuation rate α can be computed from detected changes in the reflected, linearly-detected resonance signal. The parameters that are deduced from (15) allow one to formulate (L_E in km, b_0 in kHz)

$$\alpha_a = (4.343/L_E)\,[(a_0/a_x) - 1] = 0.1820{\cdot}b_0\,[(a_0/a_x) - 1] \quad \text{dB/km}, \tag{17}$$

$$\alpha_b = (4.343/L_E)\,[(b_x/b_0) - 1] = 0.1820(b_x - b_0), \tag{18}$$

$$\alpha_{ab} = (\alpha_a + \alpha_b)/2. \tag{19}$$

A strong correlation between a_x and b_x suggest here to take (19) as an improved result. With the resonance parameters S_R and g_x of (16), attenuation is computed by (S_R in kHz)

$$\alpha_x = 0.1820{\cdot}S_R(g_x - g_0). \tag{20}$$

Equations (17)-(20) are valid when the assumption $\alpha{\cdot}d_R << 4.3\times10^6$ holds (Read et al., 1988). In our case, $\alpha{\cdot}d_R \leq 4\times10^3$ since $\alpha \leq 20$ dB/km and $d_R \approx 200$ mm.

A measurement precision of ± 0.02 dB/km was the set goal for detecting attenuation. Meeting this goal with an effective path length of 0.24 km, requires that relative ratio changes of a_0/a_x and b_x/b_0 in (17) and (18) are detected to the order of 1×10^{-3}; or in terms of frequency differences, that about 100 Hz are resolved for the term $S_R(g_x - g_0)$ in (20).

3.5 Refractivity Measurement

The real part of the complex refractivity N(f) of a gas is measured simply by (Newell and Baird, 1965)

$$N_x = (f_0 - f_x)10^6/f_0 \qquad \text{ppm}, \tag{21}$$

A measurement precision of 0.005 ppm is obtained at 60 GHz when the difference $f_0 - f_x$ is resolved to better than 300 Hz. The experimental value is the sum of three contributions,

$$N_x = N_s + N'(f) + N_c, \tag{22}$$

where N_s is nondispersive, N′(f) is the dispersive refraction of the $\mathbf{O}_2$ microwave spectrum in air, and N_c is an instrumental correction term accounting for the drift of f_0. Dispersive contributions N_f are small (≤ 1 ppm, see Fig. 1) and nondispersive refractivity (3) reduces (independent of pressure and temperature) to a constant

$$R_s = 792.06{\cdot}r_G = (N_x - N_c - N')(T/P) \quad \text{ppm·K/kPa}. \tag{23}$$

3.6 Computer Software for Spectrometer Operation

In order to best apply the ANA, new measurement procedures had to be developed. All spectrometer operations were controlled by a microcomputer. A comprehensive software package with 4,600 program lines was developed. The program offers various menus for single and multiple resonance scanning. Various subroutines

a) allow one to execute differing measurement configurations

b) set the operational parameters of ANA

c) control the pressure steps ΔP

d) control the data acquisition via a General Purpose Interface Bus (GPIB) from the following instruments:
- ANA
- Capacitance manometer (P)
- Precision quartz thermometer (T_c)
- Four-channel, fast response (τ = 0.5 s), scanning thermometer (one thermistor sensor is embedded in the resonator structure, three are sensing the open space)

e) initiate the automatic ("response") calibration to normalize the reflected signal level (A_o, = - 1 + *j*0)

f) center the detected resonance signal at f_x and, as an option, adjust the stepped frequency span (Δf) with respect to the changing halfwidth b_x (see Sect. 4.1)

g) call the NLS (nonlinear least-squares) fitting routines, which reduce with the help of either (15) or (16) the s_{11} data sets to the desired resonance parameters.

4. EXPERIMENTAL PROCEDURE

4.1 Single Resonance Detection

A first step in the detection process was the normalization of the off-resonance signal level s_{11} to A_o = - 1 + *j*0 over the frequency span Δf. A "response" calibration (ANA feature) with a short provided the reference. The waveguide plane of the coupling iris acts as short when, under computer control, the resonance is defeated (**A** = 0) with a motor-driven metal vane that rotates into the resonance space.

Optimization of the detection of s_{11} data at a resonance f_x was an important objective. A feature of the ANA is the superheterodyne detection scheme with an intermediate frequency (IF) of 20 MHz. A synthesized generator (identical to the RF source) serves as local oscillator (LO) for the harmonic (× 14) mixers that detect reflected and incident signals. Both IF signals are amplified, down-converted to 100 kHz, then detected and processed. The output is a normalized signal ratio called reflection scattering (S) parameter s_{11}(f). The S-parameter is sampled in even increments over the span Δf at a number (pts) of fixed frequency points each being averaged a number (avg) of times. An example of an S-parameter set is listed in Table 2, and the equivalent in log magnitude (power dB) and phase angle (deg) is plotted in Figure 5. The influence of various combinations by the three variables "Δf", "pts", and "avg" upon s_{11} was studied in detail.

- The frequency span was set at $\Delta f = 5 \cdot b_x$, centered at f_x to cover the amplitude range of a resonance response to about $a_x/9$. Centering at f_x was done automatically. Initially, the span Δf followed the changes of the halfwidth, $b_x(\alpha) - b_0$ ($\leq$ 90 kHz). However, this required an additional calibration adding about 10 seconds to each run. A comparison of both methods yielded identical results, (17) to (21). To not slow down the many production runs, a constant value Δf = 500 kHz was kept.

- For stepped frequency points, the choice is 51, 101, 201, 401 or 801 pts. Frequency switching time is about 50 msec.

- Averaging (avg) is possible in powers of 2^y (y = 1 to 12) at a speed of 5,000 values per second.

The optimum combination "Δf-pts-avg" is constrained by three factors: achievable frequency resolution ($\leq$ 100 Hz for both resonance center f_x and width b_x), inherent noise level ($\delta s_{11}/s_{11} \leq 0.0003$), and desired acquisition time ($t_x \leq 5$ s). After extensive test series (see Sect. 4.3), the reflected signal was measured around f_x by stepping in 10 kHz increments (51 pts) over a scan range of 500 kHz (Δf), averaging each point 128 (avg) times, in a total acquisition time of 2 seconds (t_x). Subsequent processing of s_{11} data used formulas (17) to (21), whereby the relevant parameters were deduced by fitting data strings of s_{11} to the analytical function given by either (15) or (16). A fast, nonlinear least-squares (NLS) routine was developed by us that worked very well. The method was based on the iterative Levenberg-Marquardt algorithm (Marquardt, 1963), which has become the standard of NLS routines. Two different sets of output parameters could be generated.

1) The NLS.1 fit to (15) produced center frequency, f_x, loaded and unloaded Q values, **Q** and Q^o, the reference signal level, a′, a″, and the standard fitting error of each parameter.

2) The NLS.2 fit to (16) replaced the two Q-values of NSL-1 with S_R and g_x. In addition, real and imaginary parts of the individual residuals $\delta s_{11}(\Delta t)$ were provided; also their rms standard deviations, σ_s, and the three correlation coefficients, $\rho_1(f_0 \rightarrow g_0)$, $\rho_2(f_0 \rightarrow S_R)$, and $\rho_3(g_0 \rightarrow S_R)$.

Several multi-parameter NLS fitting schemes were tested and the three accepted ones are summarized in Table 3. The F3 scheme initially infers five parameters, which serve as input for the final fit to the two parameters that determine α and N′. That scheme proved most useful and was applied to the production runs.

4.2 Multiple Resonance Operation

The resonator supports a comb of resonances, which were computed with (12). The computer tunes to multiple $TEM_{0,0,q}$ resonances (e.g., q = 79 to 88), which appear in c/2L-intervals (e.g., 0.7330 GHz for d_R = 204.5 mm) with loaded Q-factors, $\mathbf{Q}_0 \approx 2.5$ to 3.5×10^5. Multiple resonances can be utilized for one P-T combination as long as the coupling yields a sufficient signal level. For a tolerable signal-to-noise ratio, the needed amplitude a_0 was $\geq 0.01a'$. On the other hand, for a symmetric resonance response and a high **Q** factor, adequate decoupling ($\leq 0.1a'$) had to be ensured.

Example of Real and Imaginary Parts of the ANA Signal s_{11}
(101pts/256avg; 62.48 GHz, 101 kPa air, 30°C)

f	*Re*	*Im*	f	*Re*	*Im*
62482835615.	-.99332	.01453	62483243615.	-.96036	.00076
62482843615.	-.99420	.01413	62483245266.	-.96074	.00000 f_x
62482851615	-.99332	.01477	62483251615.	-.96014	-.00092
62482859615.	-.99310	.01468	62483259615.	-.96054	-.00284
62482867615.	-.99277	.01489	62483267615.	-.96082	-.00473
62482875615.	-.99234	.01477	62483275615.	-.96143	-.00668
62482883615.	-.99200	.01508	62483283615.	-.96228	-.00818
62482891615.	-.99188	.01532	62483291615.	-.96304	-.00977
62482899615.	-.99146	.01575	62483299615.	-.96362	-.01132
62482907615.	-.99164	.01584	62483307615.	-.96500	-.01254
62482915615.	-.99081	.01611	62483315615.	-.96588	-.01370
62482923615.	-.99054	.01627	62483323615.	-.96735	-.01492
62482931615.	-.99036	.01620	62483331615.	-.96848	-.01590
62482939615.	-.99005	.01639	62483339615.	-.96997	-.01672
62482947615.	-.98975	.01691	62483347615.	-.97083	-.01730
62482955615.	-.98917	.01721	62483355615.	-.97235	-.01785
62482963615.	-.98871	.01749	62483363615.	-.97342	-.01804
62482971615.	-.98853	.01755	62483371615.	-.97452	-.01886
62482979615.	-.98792	.01773	62483379615.	-.97580	-.01901
62482987615.	-.98746	.01794	62483387615.	-.97675	-.01923
62482995615.	-.98746	.01819	62483395615.	-.97781	-.01917
62483003615.	-.98651	.01871	62483403615.	-.97885	-.01923
62483011615.	-.98615	.01880	62483411615.	-.97980	-.01944
62483019615.	-.98532	.01862	62483419615.	-.98077	-.01929
62483027615.	-.98471	.01889	62483427615.	-.98166	-.01929
62483035615.	-.98392	.01907	62483435615.	-.98257	-.01907
62483043615.	-.98312	.01926	62483443615.	-.98343	-.01917
62483051615.	-.98251	.01953	62483451615.	-.98419	-.01892
62483059615.	-.98175	.01938	62483459615.	-.98486	-.01877
62483067615	-.98071	.01959	62483467615.	-.98547	-.01865
62483075615.	-.97974	.01968	62483475615.	-.98599	-.01831
62483083615.	-.97913	.01987	62483483615.	-.98669	-.01813
62483091615.	-.97787	.01944	62483491615.	-.98737	-.01813
62483099615	-.97696	.01929	62483499615.	-.98776	-.01755
62483107615.	-.97629	.01907	62483507615.	-.98834	-.01718
62483115615	-.97482	.01892	62483515615.	-.98920	-.01703
62483123615.	-.97382	.01874	62483523615.	-.98935	-.01712
62483131615.	-.97256	.01837	62483531615.	-.98972	-.01660
62483139615.	-.97134	.01791	62483539615.	-.99011	-.01645
62483147615.	-.97031	.01730	62483547615.	-.99081	-.01596
62483155615.	-.96921	.01627	62483555615.	-.99121	-.01578
62483163615.	-.96814	.01544	62483563615.	-.99152	-.01572
62483171615.	-.96640	.01453	62483571615.	-.99161	-.01553
62483179615.	-.96548	.01315	62483579615.	-.99197	-.01517
62483187615.	-.96463	.01236	62483587615.	-.99207	-.01517
62483195615.	-.96338	.01105	62483595615.	-.99246	-.01471
62483203615.	-.96252	.00919	62483603615.	-.99289	-.01440
62483211615.	-.96179	.00787	62483611615.	-.99301	-.01398
62483219615.	-.96106	.00613	62483619615.	-.99341	-.01419
62483227615.	-.96072	.00400	62483627615.	-.99301	-.01416
62483235615.	-.95993	.00247	62483635615.	-.99368	-.01398

Table 3

NLS Fitting Schemes to s_{11} (Levenberg-Marquardt method)

Code	Eqn	Para.	Level Cal.	Resonance Properties			Repeats $\times s_{11}$	$\times$ P
F1	(15)	5	a′,a″	Q^{o}	Q	f_x	1	1
F2	(15)	5	a′,a″	Q^{o}	Q	f_x	10	1
F3	(16)	5+2	a′,a″	S_R	g_x^{i}	f_x^{i}	10	11
			-	-	g_x	f_x	10	1

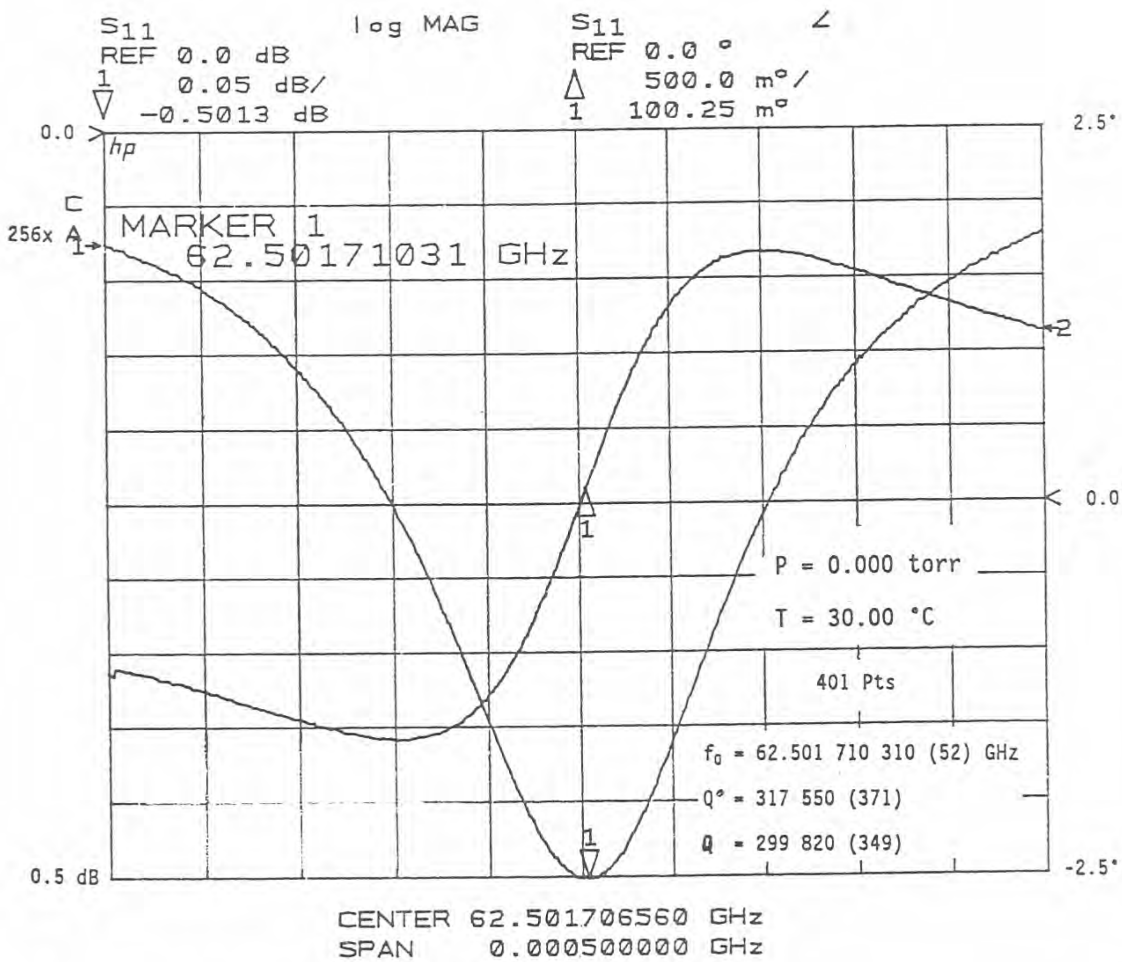

Figure 5. Typical reflected resonance signal s_{11}, as displayed by ANA in log magnitude (power dB) and phase angle (deg) (f_0, Q and Q^{o} from an F1 fit).

The diameter of the coupling iris in combination with an adjustable coupling circuit determines the usable frequency range. Two flat mirrors with different coupling irises (1.0 and 1.1 mm diameter) were available. The first produced adequate coupling down to 58 GHz, while the larger iris excited resonances as low as 49 GHz. A resonant (Q-value, **Q** ≈ 20) coupling circuit is made up by the surface, which retains the iris, followed by a cylindrical cavity (8 mm dia.) of adjustable length, l_c = 0.1 to 8 mm, and a quartz glass window (6.4 dia. × 0.64 mm) that provides the vacuum seal.

For the example exhibited in Figure 6, a maximum coupling of $a_0 \approx 0.08$ was adjusted at 61.5 GHz with $l_c \approx 3$ mm. Ten resonances were excited whereby the peak signal dropped over a span of ± 3.5 GHz to $a_0 \approx 0.01$. The amount of coupling to some extent affected the symmetry of a resonance. The quality of recorded s_{11} data improved when the measurements were organized in three groups of five resonances. This allowed a total of thirteen f_x (the 5th and 6th being the same, and also the 10th and 11th) to cover the range from 58 to 67 GHz. In this case, the coupling was adjusted (l_c) to yield amplitudes $a_0(f_0)$ between 0.08 and 0.02 with symmetric $s_{11}(\Delta f)$ data.

At the selected resonance frequencies f_x, each measurement sequence was repeated ten times before increasing the pressure. In addition to the initial and final record at P = 0 (reference state), ten pressure values were preprogrammed. The data acquisition was fully automated. A typical run with five sequential resonances took about one hour.

4.3 Sensitivity and Longterm Stability

The challenge of operating a spectrometer in the 60 GHz range lies in recovering small frequency differences (≤ 100 Hz) from the envelope response of two resonance states [see (20),(21)]. The ANA supplies a fixed power RF signal at specified frequencies, and the calibrated response is measured with little error for amplitude (dynamic gain) and phase (frequency) instabilities. The s_{11} parameters are detected with a precision equal to 3×10^{-5} (16-bit A/D converter, including sign) at a noise level, $ds_{11} \approx 3 \times 10^{-4}$, which is an analytical estimate that was obtained by comparing rms values of residuals from NLS fits (seeSect. 5.2).

Results of test runs under different detection conditions (varied values of pts and avg) are listed in Table 4. They were evaluated (F1) for resolutions in center frequency (δf_0) and in loaded Q-value ($\delta\mathbf{Q}_0$). The number of frequency steps (pts) determines the resolution of f_x. The error in fitting **Q** is reduced as either "pts" or "avg" increase, being more sensitive to "pts". Averaging only 128 times appeared reasonable since doubling the number reduces the errors by only a few percent. Note, that as "pts" is increased, the residuals of a fit grow smaller and the fluctuations of the longterm (500 ×) time series intensify, as indicated by their rms standard deviation, σ_Q. More "pts" require a longer time interval t_x for a scan. During this interval, the resonance changes its shape due to ANA phase drifts.

Another performance evaluation involved 24-hour repeat runs to check on the long term stability of $\alpha = 0$ for different combinations of pts/avg. Test data were taken repeatedly under vacuum conditions for various system configurations to determine stability and accuracy of the detection method. Reflection data were

Table 4

F1-Fitting Errors δf, δQ, and Standard Deviations, σ_Q, of Repeat (500×) Runs for a Single Resonance ($P = 0$, $f_x = 62.5$ GHz, $Q \approx 3\times10^5$, $a_x = 0.062$)

Number of Points	Averages	Duration t_x	Standard Error from NSL-fit δf_x	δQ	σ_Q
pts	avg	sec	Hz		
51	**128**	2	232	1900	735
	256	4	225(10)	1505(66)	655
	512	8	214		
	1024	12	218(20)	1466(130)	1150
101	**256**	8.5	149(11)	**1006**	**1050**
	512	17	133		
201	64	4		1000	946
	128	8.5	112		
	256	17	105(8)	710(57)	1340
	512	33	108		
401	128	17	96		
	256	33	75(7)	513(52)	3110
	512	70	72		

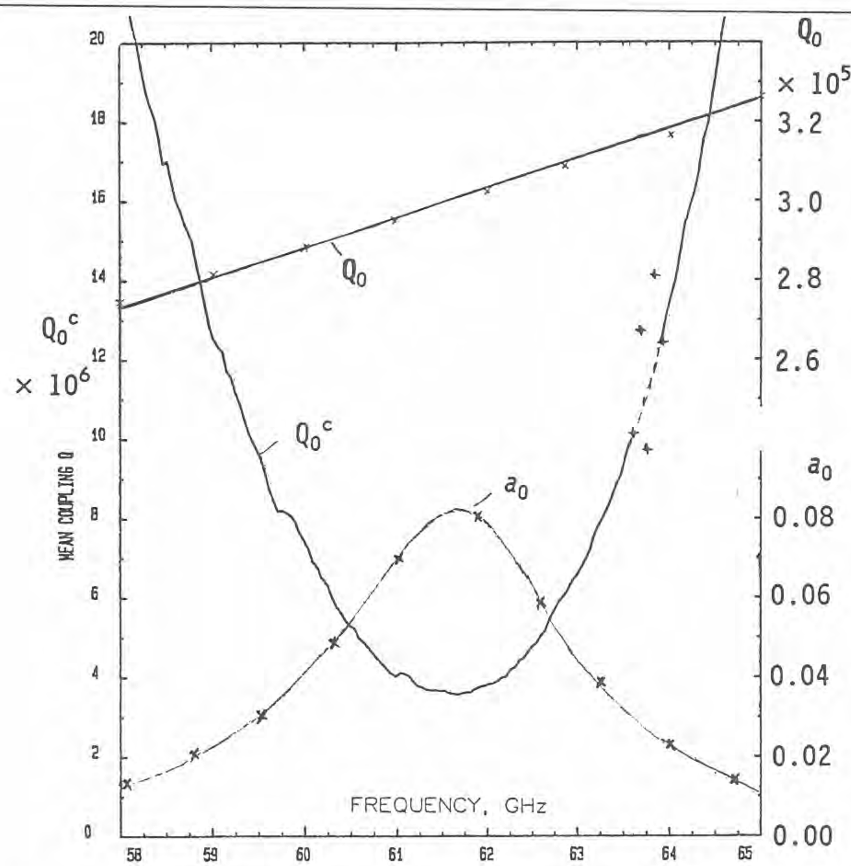

Figure 6. Measured Q values (Q - loaded, Q_c - coupling) and resonance amplitudes a_0 from 58 to 65 GHz for $d_R = 204.5$ and $l_c \approx 3$ mm at $P = 0$ and $T = 30°C$.

analyzed on-line by repeatedly applying F1 (500 ×) over 24-hour periods. Individual acquisition times and rms standard deviations from the mean, $\alpha = 0$, of the time series are listed in Table 5. The 51/128-case indicates that a fast scan produces s_{11} data of acceptable quality (see Fig. 4). Baseline variability for α_{ab} is about the same as for α_a; for longer time periods, the correlation between α_a and α_b improves the average.

Table 5

Longterm Detection Characteristics At 62.5 GHz
(see Fig. 7)

Pts	Avg	t_x	σ_a (17)	σ_b (18)	σ_{ab} (19)
		s		dB/km	
51	**128**	2.1	0.025	0.047	0.029
201	64	4.2	0.026	0.060	0.028
101	256	8.4	0.036	0.066	0.026

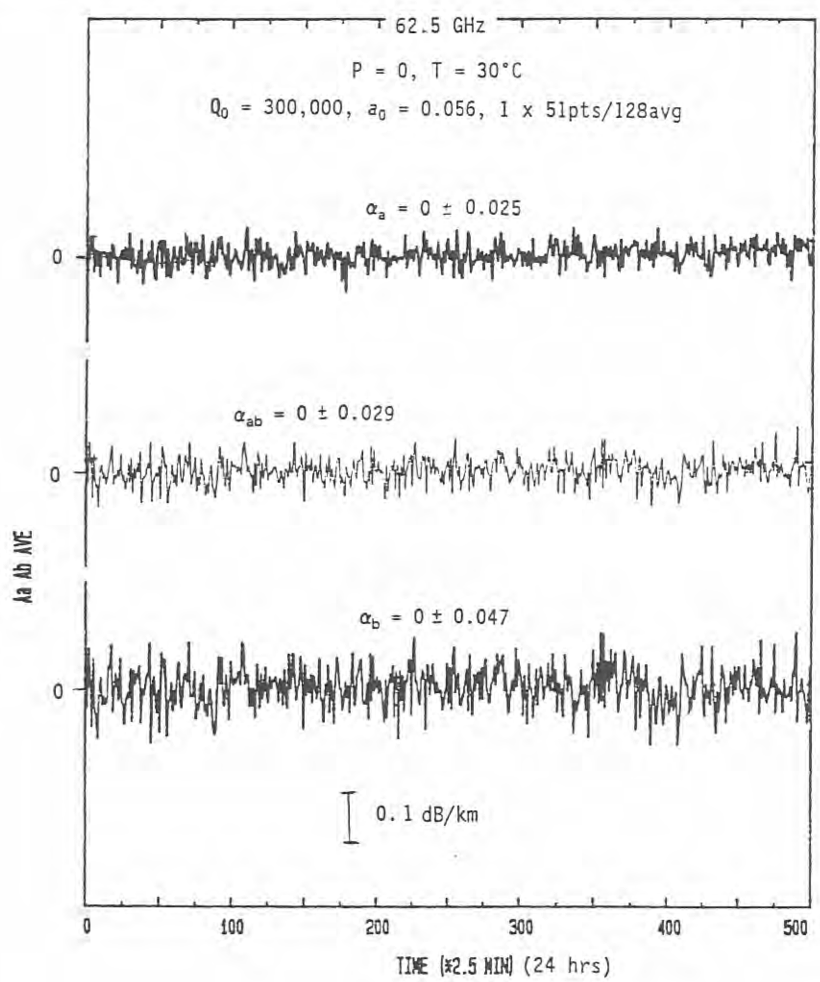

Figure 7. Longterm (24 hrs) behavior at 62.5 GHz for a repeat run (500x).

5. SPECTROMETER PERFORMANCE

5.1 Systematic and Random Error Sources

The performance of a spectrometer is judged by the absolute accuracy of the measured attenuation and refractivity. A key question is how reliably can one deduce from recorded s_{11} data the parameters that enter into (17) to (21). Two different circumstances govern absorption and refraction detection:

Attenuation α relies on distortion-free, repeatable detection of resonance responses, which specify either Q values, **Q** and Q° (15), or a resonance strength S_R and an amplitude factor, g_x (16). Interfering fluctuations are limited, to first order, to the scan period of 2 s. Both parameter sets, derived with different NLS methods (see Table 3) yielded comparable results, although for the production runs the F3 scheme was used exclusively.

Refractivity N′ depends on the stability characteristics of the resonator center frequency f_x as a function of temperature drift and pressure loading over measurement periods lasting from minutes to hours. The ANA guarantees high frequency stability.

Precise temperature control and solid resonator construction are mandatory to ensure a drift-free and pressure insensitive value for f_x. Typically, the ANA-based detection scheme allowed about 100 Hz frequency resolution, which leads to taxing requirements for the mechanical integrity of the resonator structure. Most of the non-repeatable measurement errors originate from physical changes in the resonator structure during the progression of an experiment. For example, the length d_R has to remain stable to within ±0.33 nm (!) over the time period of a measurement sequence (1 to 5 hrs). During this period the temperature is fluctuating; in addition, the pressure is changing, which loads the structure, introduces temperature gradients, and bends the vacuum window. The latter might tune the resonator and affect the coupling, which changes Q_c or S_R.

Cell temperature T_c was monitored with ±1°C accuracy and ±0.001°C resolution. The measured coefficient of thermal tuning at 60 GHz was

$$(\delta f_x/f_x/\delta T = 0.68 \quad \text{ppm/°C}. \tag{24}$$

The positive sign follows from the coefficient of thermal expansion for the two brass mirrors (18 ppm/°C) plus steel micrometer (11.7 ppm/°C), which shortens d_R with temperature. This decrease is not fully overcome by expansion of the invar spacers (- 0.8 ppm/°C). Resonator structure and surrounding cell walls possess a large thermal time constant (≥ 15 min), which ensures thermal stability. The cell was kept at a constant temperature by a proportional controller using a precision platinum probe (circulator bath, assisted below 35°C by a cooled thermal exchanger). Ambient temperature fluctuated typically by ±3°C, which translated into a temperature stability for the cell of $\Delta T/\Delta t \approx \pm 0.01$°C/min ≈ ±0.1°C/day, thus causing some slow drift of f_x. According to (21) and (24), changes of a few millidegrees lead to noticeable (≥ 100 Hz) drifts. The correction term N_c of (22) is a measure of the drift between start and finish of a run.

Gas pressure P was measured by a differential capacitance manometer with 0.2 percent error, and its absolute calibration was periodically compared with a precision (±0.2 percent) quartz Bourdon-type manometer. The resonator structure is mechanically rugged and is not affected by pressure differentials; however, there is some compressibility in the micrometer thread and a small bending of the quartz window. Pressure stability of the resonator was tested at ten frequencies between 58 and 66 GHz by performing 12-step pressure scans, P = 0 to 110 kPa, introducing loss-free nitrogen. Systematic pressure-induced, erroneous attenuation readings were not observed within the limits, $\alpha \leq \pm 0.1$ dB/km. From refractivity results for dry air and the known constant r_G (3), the pressure loading influence upon f_x was estimated to be

$$(\delta f_x/f_x)/\delta P \approx -6.5\times10^{-5} \quad \text{ppm/kPa}, \tag{25}$$

which translates for P = 0 to 101 kPa at 60 GHz into a change of - 490 Hz.

Mechanical tuning could be reproduced to within $\delta f_x \approx \pm 75$ kHz due to the resolution (δd_R) of the micrometer reading. When the resonator is mechanically tuned by changing d_R and then returned to its former position, the resonance parameters f_x, g_x, and S_R are not exactly replicated due to very small tilts in the mirror alignment. In addition, vibrations can affect the physical structure of the resonator, thus modulating the resonance response. In summary, foremost mechanical distortions of the resonator structure, related to temperature and pressure changes during a measurement period, lead to both systematic and random errors.

5.2 Signal Simulation

The spectrometer output s_{11} contains the reflected signal from the resonator and the noise spectra from both RF and LO sources. The two synthesized, identical generators of the ANA system have exceptionally clean spectra even after 5× (RF) and 14× (LO) multiplications. The complex reflection scattering coefficient, s_{11}, is determined by five parameters, a', a''; f_x, **Q** and Q° (15) or a', a''; f_x, g_x and S_R (16). These parameter sets were determined by NLS fits.

The residuals of a particular fit were examined for deterministic trends. In Figure 8, their real and imaginary parts from five-parameter fits to s_{11} parameters (scale ±0.001, in units of $|s_{11}|$ = 0 to 1) are plotted over a frequency span $\Delta f = 5b_x$ for three cases:

(a) Simulation with pure white noise (pseudo-random, Gaussian distributed variations with a standard deviation, $\sigma_s = 0.0003$) added to a normalized ($a' = -1$, $a'' = 0$, $S_R = 5$ kHz, $g_x = 20$, $f_x = 0$) resonance. Note, how these residuals appear to be white noise

(b) Example at 58.1 GHz ($\alpha = 1.30$ dB/km), which resembles case (a), and which can be interpreted to represent the amplitude/<u>phase</u> noise level of the ANA ($\sigma_s = 0.00028$)

c) Example at 61.8 GHz ($\alpha = 6.48$ dB/km), which exhibits a distinct deterministic component yielding $\sigma_s = 0.00087$; here, a five-parameter fit of the detected, somewhat asymmetric s_{11} response is not sufficient to emulate the signal. Attenuation measurements were not affected by σ_s (≤ 0.001); asymmetry effects seem to cancel (difference in equation 20).

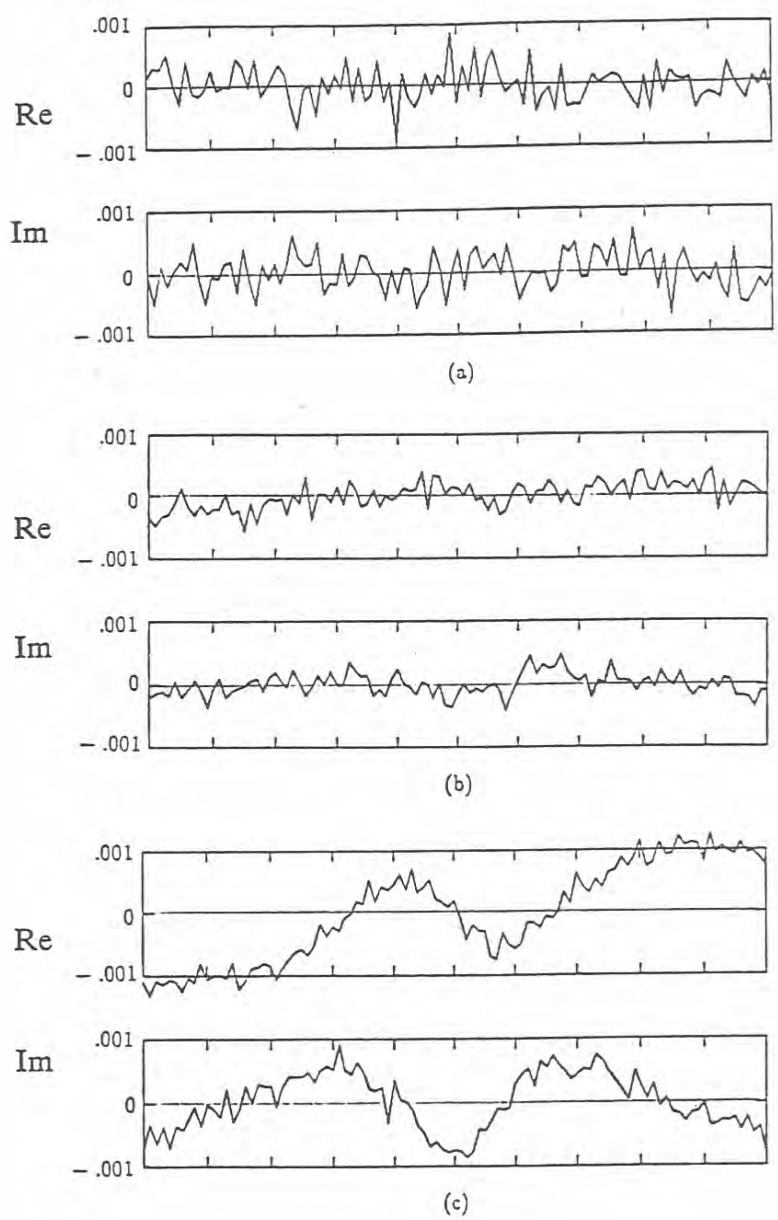

Figure 8. Three examples of real and imaginary parts of the point-by-point (101pts) residuals $\delta s_{11}(\Delta f)$:
(a) Simulated s_{11}, assuming random fluctuations
(b) Experimental s_{11} (58.1 GHz, 12.1 kPa air, 30°C), good response symmetry around f_x
(c) Experimental s_{11} (61.8 GHz, 47.2 kPa air, 30°C), poor response symmetry around f_x
(b,c are F2-fits).

5.3 Measurement Procedure

Up to this point, individual performances of various spectrometer elements have been evaluated. A typical measurement sequence for dry air measurements involves eight steps:

S1 - spectrometer cell is evacuated and thermally stable

S2 - resonator is mechanically tuned to an initial frequency f_0^i, value of q is determined from knowing d_R

S3 - coupling is tuned (l_c), multiple (up to 15×) consecutive (e.g., q = 71 to 85) resonances are excited

S4 - main program is started, ANA operating conditions (pts, avg) are selected, a data file name is created, the first center frequency is tuned in, and automatically (cursor is set to the peak: value under computer control) centered over the span $\Delta f = f_0 \pm 250$ kHz

S5 - resonance response is defeated by turning a motor-driven metal vane (rotary vacuum feedthrough) into the field region. ANA performs a "response" calibration for a short, which sets over the span Δf the signal level to $s_{11} = 1 + j0$. When the calibration is completed, the vane turns aside, and $s_{11}(\Delta f)$ data (51 pts, 128 avg) are recorded ten times to obtain a statistical average (see Table 6). The process is repeated for each f_0^i

S6 - air is introduced into the spectrometer cell, a piezo-activated valve opens and the gas pressure slowly rises until a computer-set pressure value P is reached

S7 - measurement sequence is completed after having stepped through fixed P values selected to increase from 0 to 101 kPa

S8 - cell is slowly evacuated by the operator, the resonator is mechanically retuned, and the next sequence is started.

5.4 Measurement Examples

The first example is for f = 55.7 GHz (q = 75) and T = 29.4°C. Ten s_{11} sets were individually fitted to (16) and statistically evaluated (F3). Table 7 exhibits the measurement protocol, of which one result is shown here in detail:

ANA Signal	$a' = -0.999\,517(50)$	and	$a'' = 0.000\,17(11)$.
Resonance Strength	$S_R = 1.2667(52)$ kHz.		

Center frequencies and amplitude factors

$P_0 = 0.0$ kPa	:	$f_0 = 55\,672\,046.18(39)$ kHz,	$g_0 = 83.91(06)$
$P = 101.3$ kPa	:	$f_x = 55\,657\,524.40(43)$,	$g_x = 106.75(16)$
$P_0 = 0.0$ kPa	:	$f_0 = 55\,672\,034.43(17)$,	$g_0 = 84.07(13)$.

Attenuation rates, computed with (20):

vacuum reference, $P_0^f - P_0^i$ (RE)	$\alpha_0 = 0.04(03)$,	
dry air	$\alpha_x = 5.27(05)$;	
MPM89 prediction	$\alpha_M = 5.41$ dB/km.	dB/km.

Refractivity, computed with (21):

total		$N_x = 260.845(12)$,
resonator drift		$N_c = 0.211(09)$;
MPM89 predictions	(nondispersive)	$N_s = 259.965$,
	(dispersive)	$N' = 0.669$ ppm.
Assuming $N_x' = N'$, yields with (23)		$r_x = 0.98050(6)$.

The measured refractivity factor r_x agrees with the accepted value, r_{Air} (3).

The second example is for f = 60.7 GHz (q = 82), T = 6.7°C:

ANA Signal $a' = -0.999\,703(24)$ and $a'' = -0.00138(18)$.

Resonance Strength $S_R = 6.6259(81)$ kHz.

Center frequencies and amplitude factors

$P_0 = 0.0$ kPa	:	$f_0 = 60\,685\,426.881(84)$ kHz,	$g_0 = 15.093(04)$,
$P = 101.4$ kPa	:	$f_x = 60\,668\,016.5(11)$,	$g_x = 28.608(18)$,
$P_0 = 0.0$ kPa	:	$f_0 = 60\,685\,465.376(96)$,	$g_0 = 15.079(03)$,

Attenuation rate, computed with (20):

vacuum reference (RE)	$\alpha_0 = -0.02(01) = 0.00(03)$,
dry air	$\alpha_x = 16.31(03)$;
MPM89 prediction	$\alpha_M = 16.63$ dB/km.

Refractivity, computed with (21):

total		$N_x = 286.896(19)$,
resonator drift		$N_C = -0.634(02)$;
MPM89 predictions	(nondispersive)	$N_s = 282.225$,
	(dispersive)	$N' = -0.401$ ppm.
Assuming $N_{f,x} = N_f$, yields with (23)		$r_x = 1.0009(8)$.

The refraction factor r_x is about 2 percent larger than r_{Air}. Additional instrumental tuning was caused by the mechanical coupler to the tuning micrometer, which transmitted pressure bending of the vacuum chamber to the resonator structure. This problem was eventually corrected; however, the earlier refractivity results above 60 GHz proved unreliable (see Sect. 6.2).

When the refractive dispersion N′ is known from model predictions (e.g., at $f_x \approx 60$ GHz: $N' \approx 0$), one obtains from (3),(23) a refractivity constant $R_s = 792.06 \cdot r_{Air} = 776.24$ ppm·K/kPa for dry air. This constant provides a check on the correct measurement of the gas density ($\propto$ P/T). A few selected results (e.g., $f_x = 60.0$ GHz, P = 101 kPa) for the difference N_x - N′(MPM89) revealed a systematic trend Δ which is indicative of small, temperature-dependent errors in either the pressure or the temperature measurement:

T (°C)	R_s (ppm·K/kPa)	Δ (%)
6.7	780.0	0.55
29.7	776.3	0.00
52.4	772.6	-0.48.

Table 6

Example of Statistical Averaging at 62.5 GHz (51pts/128avg):

- Results (f_0, g_0, S_R, and a′,a″) of an F3-fit to (16)
- Correlation Coefficients $\rho_1(f_0 \rightarrow g_0)$, $\rho_2(f_0 \rightarrow S_R)$, and $\rho_3(g_0 \rightarrow S_R)$
- Standard Deviation of the Residuals, σ_s

	f_0 (Hz)	g_0	S_R (Hz)	a′	a″	σ_s		
62.5 GHz, .0 torr, 29.8 C								
	62500443913.	15.876	6579.8	-.999735	-.000429	.00059		
	178.	.029	29.3	.000116	.000060	.004	-.011	-.388
	62500444409.	15.874	6577.6	-.999724	-.000557	.00058		
	175.	.029	27.7	.000113	.000059	.004	-.010	-.388
	62500444662.	15.886	6589.4	-.999743	-.000703	.00063		
	191.	.032	30.4	.000124	.000065	.004	-.009	-.389
	62500444882.	15.850	6615.6	-.999812	-.000902	.00060		
	182.	.030	29.1	.000118	.000062	.004	-.009	-.390
	62500444568.	15.865	6592.2	-.999765	-.000996	.00055		
	167.	.028	26.6	.000109	.000057	.004	-.010	-.389
	62500444760.	15.879	6581.5	-.999687	-.001116	.00052		
	158.	.026	25.1	.000103	.000053	.004	-.009	-.388
	62500445107.	15.882	6561.8	-.999638	-.001238	.00058		
	176.	.029	27.8	.000114	.000059	.003	-.009	-.386
	62500444311.	15.904	6556.6	-.999574	-.001311	00061		
	186.	.031	29.5	.000120	.000063	.004	-.010	-.387
	62500444355.	15.882	6591.7	-.999710	-.001578	.00055		
	168.	.028	26.7	.000109	.000057	.004	-.010	-.389
	62500444578.	15.865	6568.4	-.999670	-.001763	.00053		
	160.	.026	25.3	.000104	.000054	.004	-.009	-.386
Mean:	62500444554.	15.876	6581.5	-.999706	-.001059			
	316.	.014	16.2	.000064	.000408			
						ρ_1	ρ_2	ρ_3

Table 7

Example of an Output Protocol at 55.7 GHz (51pts/128avg):

- F3-fit Parameters (a′,a″; and S_R, f_x, g_x)
- Results for α_x (20) and N_x (21)
- Standard Deviation of the Residuals for Five- and Two-Parameter Fits, σ_s^a and σ_s^b

DRY AIR P = 0 to 760 to 0 torr 55.7 GHz, 29.4 C

S, Hz	a′	a″
1266.7	-.999517	.000165
5.2	.000050	.000111

P torr	f_x Hz	g_x	α_x dB/km	N_x ppm	σ_s^a	σ_s^b
.0	55672046179.	83.911	.00	.000	.00028	.00075
	491.	.063	.00	.000		
9.1	55671880862.	83.502	.00	2.969	.00030	.00036
	222.	.107	.03	.010		
14.2	55671798401.	82.873	.00	4.451	.00027	.00085
	395.	.082	.02	.011		
22.4	55671637695.	83.217	.00	7.337	.00031	.00040
	50.	.088	.02	.009		
35.6	55671379879.	84.415	.12	11.968	.00029	.00052
	493.	.083	.02	.012		
57.0	55670968313.	84.547	.15	19.361	.00031	.00039
	245.	.087	.02	.010		
90.8	55670322132.	86.191	.53	30.968	.00029	.00061
	186.	.156	.04	.009		
145.9	55669267863.	86.086	.50	49.905	.00032	.00053
	235.	.151	.04	.010		
231.0	55667638428.	89.597	1.31	79.173	.00030	.00040
	344.	.109	.03	.011		
353.9	55665293637.	92.916	2.08	121.291	.00029	.00039
	293.	.174	.04	.010		
525.6	55662010579.	99.172	3.52	180.263	.00029	.00035
	385.	.132	.04	.011		
759.7	55657524400.	106.754	5.27	260.845	.00030	.00058
	433.	.167	.05	.012		
.0	55672043427.	84.068	.04	.149 = N_c	.00000	.00037
	165.	.134	.03	.009		

6. ATTENUATION RESULTS AND ERROR DISCUSSION

6.1 Data Format

Over 4,300 attenuation values $\alpha_x(f,P,T)$ have been measured. This large data base is presented in the Appendix, where it is organized in 12 sections (**A**. to **L**., RE) each for a fixed pressure value. Three temperature groups (7°, 30°, 52°C) exist, arranged from 53.9 to 66.3 GHz in 100 MHz increments (132f x 11P x 3T = 4,356). The condensed presentation reduces the two examples detailed in Sect. 5.4 to the following format:

SECTION **L**.	Summary	Individual Record	
	29.7(4)	55.65752	5.25(.05)
	759.8(2)	759.7	5.36[0.11]
	0.31	p. A-107	
	6.7(2)	60.66801	16.31(.03)
	759.9(2)	760.2	16.63[0.32]
	0.38	p. A-110	

Summary information for each group (n ≈ 130 frequencies) includes mean and standard deviation of all measured temperatures T_x [29.7(4)°C] and pressures P_x [759.8(2) torr]. Also given is the standard deviation σ_s (0.31 dB/km) of the mean of all (n) differences $\Delta\alpha$ (26) within a P,T-group. An individual record lists six values:

1) Measured frequency, f_x = 55.65752 GHz
2) Mean of the attenuation rate, α_x = 5.25 dB/km
3) Standard deviation, $\delta\alpha_x$ = .05 dB/km (F3 method)
4) Measured pressure, P_x = 759.7 torr
5) MPM89 prediction, α_M = 5.36 dB/km based on f_x, P_x, T_x
6) The difference (+0.11 dB/km) between predicted and measured values,

$$\pm \Delta\alpha = \alpha_M - \alpha_x \; . \qquad (26)$$

6.2 Measurement Errors

Experimental errors are usually separated into random and systematic components. Random errors result from the residual noise inherent to the measurement process, which distributes successive data in a normal (Gaussian) sense about some mean. In the absence of systematic errors, this mean approaches the true value as the number of independent measurements increases. Electronic noise of the ANA causes signal fluctuations with elapsed time (see Fig. 7) which can be reduced by averaging the results of repeat measurements. The available capacity for data storage and the related increase in time duration for a full measurement sequence both set a practical limit on the number of repeat runs to ten.

Systematic errors in a measurement, such as mechanical changes in the resonator structure, cannot be described by statistical means. They produce a bias in the result, which (a) may be correctable, (b) remain uncorrected but can be included in the uncertainty statement, or in the worst case (c) go undetected and unknowingly affect the measurement. The error budget needs to be quantified to the level of the detection sensitivity, $d\alpha \approx \pm 0.02$ dB/km, which means signal changes of 2×10^{-3} ($0.02 \cdot L_E$, = 0.0048 dB) and phase changes of 40 millidegrees have to be specified. By design, a laboratory experiment under well controlled conditions minimizes random and averts systematic errors. Measurement uncertainties of the experimental variables f, P, T, for example, contributed only negligible errors to the measured attenuation rate. The relationship (20) between recorded s_{11}-data and computed α_x-result is based on knowing the parameters S_R, g_0, and g_x. The three parameters were extracted by the method of least squares, which also provided their standard fitting errors (see Tables 6 and 7). Mean α_x and standard deviation $\delta\alpha_x$ were computed from the statistics of ten runs. Throughout the twelve data groups, the individual uncertainties $\delta\alpha_x$ exhibit, on the average, two distinct trends that reflect different measurement conditions:

First period,	f = 60 to 64 GHz,	$\delta\alpha_x \le \pm 0.05$ dB/km
Second period,	f = 54 to 60 GHz,	$\delta\alpha_x \le \pm 0.15$ dB/km.

The deterioration in measurement precision for the second production sequence was caused by our attempt to complete the experiments within a given time frame. In the first period, only five successive resonances under optimized (tuned) coupling conditions (8 to 3 percent) were detected, and the completion of a measurement series took a little more than an hour. In the second period, thirteen successive resonances were used, which extended the duration of a measurement series to over four hours. Since for these multi-frequency measurements the coupling factors got as low as 0.5 percent, the signal-to-noise ratio for s_{11} was not optimized.

On the other hand, the refractivity results of the first period proved unreliable. The mechanical coupler to the tuning micrometer transmitted stress motion into the resonator structure. The problem was corrected for the second period by disengaging the coupler. Reliable refractivity results ($\delta N_x \le 0.02$ ppm) are available for future analysis on a similar scope that is demonstrated in the Appendix for attenuation rates.

After completing the scheduled experiments, a raw data base was available for analysis that consisted of $139(f_x) \times 12(P) \times 3(T) \approx 5{,}000$ attenuation values for dry air. A few measurement sequences were found to be corrupted by various experimental problems, leaving about 4,400 $\alpha_x(f_x,P,T)$-values of useful data, which are tabulated in the Appendix and for a large portion plotted in Figure 9 to give an overview. Although the logα-scale (Fig. 9) is deceiving, we notice generally good agreement with MPM predictions -- discrepancies exhibit roughly a ± 10 percent spread. We believe the new experimental data base has the potential to support adjustments to spectroscopic parameters of MPM89 to raise the consensus to a better than ±2 percent level. The rationale behind minor revisions of absorption data α_x due to small (± 0.25 dB/km) baseline corrections and their collective evaluation with respect to agreement with predictions close this report.

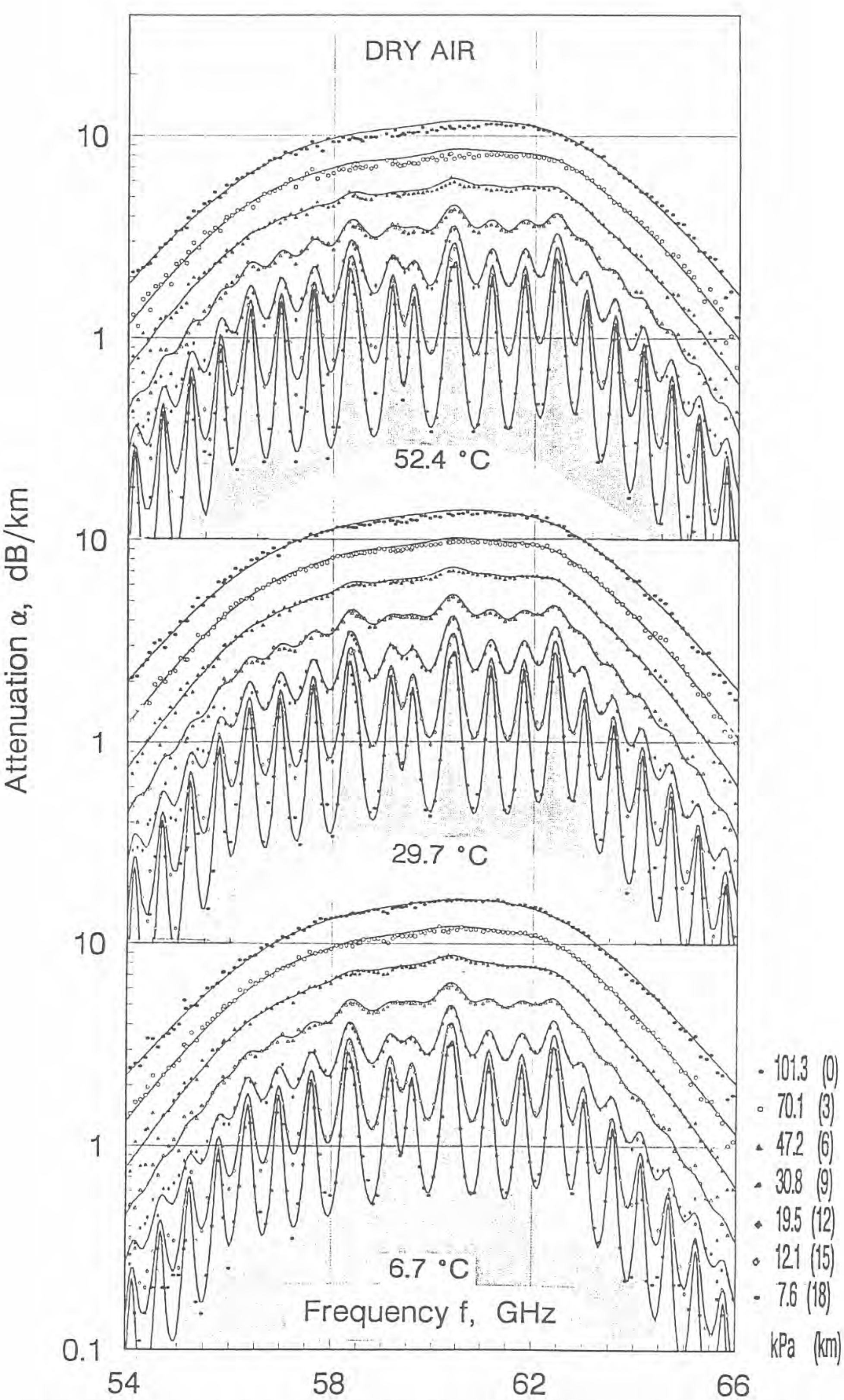

Figure 9. Overview of measured attenuation rates (symbols) and MPM89 predictions (solid lines) for dry air (f = 54-66 GHz, P = 7.6-101 kPa, T = 7,30,52°C; see Appendix **E.** - **L.**).

6.3 Baseline Behavior ($\alpha = 0$ at $P = 0$)

The evacuated ($P = 0$) spectrometer records $\alpha_x = 0.00 \pm 0.025$ dB/km over a 24-hr period if left unperturbed (see Fig. 7). However, each measurement series steps through a pressure sequence that begins with $P_i = 0$ and ends with $P_f = 0$. The baseline behavior $\alpha_x(P_f = 0)$ unmasks systematic errors that had occurred during the course of an experimental sequence (see RE - Appendix). The frequency distribution of the individual standard deviations $\delta\alpha_x$ for 139 α_x-values within a temperature group seemed nearly random with a zero mean. The standard deviation of that mean, σ_{Exp}, is listed in Table 8. Any pseudo-negative attenuation values were set equal to zero and the negative part added to the standard deviation, $\delta\alpha_x$. For example, $\alpha_x = -0.05(.04)$ was set to $\alpha = 0.00(.09)$ and $\alpha_M = 0.00[+0.05]$. About 95 percent of the individual values deviated from zero by no more than $\pm$ 0.25 dB/km; the remaining values were rejected as outliers.

Collective statistics of the data groups $\alpha_x(f_x, P)_T$ in the Appendix disclose certain sensitivities to various corrective measures. The first adjustment applied the inverse of one-half of the baseline signal to the original data, since at some point in the measurement sequence it actually had taken place. The standard deviation σ_{Exp} of the mean of $\Delta\alpha$ was reduced considerably to values σ_x; i.e., from about 0.1 to 0.05 dB/km (see Table 8). We report this "corrected" data set in the Appendix as final result of the experimental effort.

6.4 Data Manipulations

To investigate the systematic effects further, the hypothetical "true" attenuation $\alpha(f,P,T)$ was replaced by the predicted value $\alpha_M(f_x,P_x,T_x)$. Then various standard deviations σ of the mean of the collective data behavior, $\Sigma_n(\Delta\alpha)_n$, were computed to evaluate the effectiveness of data manipulations performed on the n groups of the data base. Correlated behavior of the difference $\Delta\alpha$ (26) between predicted and measured data, was used to selectively filter out random uncertainties of α_x and to extract information on systematic effects. Results of two different adjustments are listed in Table 9.

With the assistance of MPM89 one can identify systematic components in the collective experimental error (mean of $\delta\alpha_x$ related to incorrect model predictions (see Figs. A-1b to 11b). By making simple, though effective adjustments, it was possible to further reduce σ_x. The line positions (ν_k) of MPM89 were assumed to be correct; uncertainties are expected for strength, width, and overlap (S_k, γ_k, and I_k) parameters. When the strengths S_k and widths γ_k are correct, then one expects at low pressures ($P \leq 10$ kPa) over the limited frequency range of the isolated line shape ($\approx \nu_o \pm 10\gamma$) that the sum of the differences, $D = \Sigma n(\pm\Delta\alpha)_n \approx 0$. When the overlap coefficients I_k are correct, then one expects $D \approx 0$ at high pressures ($P \geq 50$ kPa) over the full band response ($\approx 60 \pm 30$ GHz). Since the results only cover 60 ± 8 GHz, one notices in the mean (Table 8) a bias increasing with pressure.

<u>Linewidth Dependence</u>: The standard deviation σ_n of $\Sigma_n(\Delta\alpha)_n$ for each of the three temperature sets is roughly a constant for P = 1 to 20 kPa that reduces (typically to $\sigma_c \approx 0.07$ dB/km), when (7) is modified to

$$(\gamma_{mod} = 1.05 \cdot \gamma_k \ . \qquad (27)$$

Table 8

Standard Deviations σ (dB/km) of the Mean of All Differences $\Delta\alpha$ (Prediction - Experiment) Within a Group of Attenuation Results $\alpha(f_x)_{P,T}$:

- Original Data and Baseline Adjustment -

H =		30	24	21	18	15	12	9	6	3	0	km
P =	0	1	3	5	8	12	20	31	47	70	101	kPa
σ_{Exp} for results $\alpha_{Exp}(f_x)_{P,T}$ [1]												Temp
	.08	.08	.08	.08	.09	.09	.11	.11	.16	.23	.29	7°C
	.11	.10	.11	.11	.11	.11	.13	.15	.19	.28	.42	30°C
	.11	.10	.09	.09	.09	.11	.13	.18	.20	.33	.46	52°C
σ_x for baseline-corrected results $\alpha_x(f_x)_{P,T}$ [2]												
σ_x	.04	.06	.06	.06	.08	.08	.08	.10	.15	.23	.31	7°C
mean	.00	.00	.00	.00	.01	.02	.03	.06	.07	.08	.08	
σ_x	.06	.07	.07	.07	.07	.08	.09	.09	.14	.19	.38	30°C
mean	.00	.00	.00	.00	.01	.02	.03	.06	.09	.13	.19	
σ_x	.05	.07	.06	.06	.07	.08	.08	.11	.15	.29	.43	52°C
mean	.00	.00	.00	.00	.01	.02	.03	.07	.10	.18	.27	

[1] Each group is made up by original results, $\alpha_{Exp}(139 \times f_x)_{P,T}$

[2] Each group is made up by edited results, $\alpha_x(132 \times f_x)_{P,T}$ (outliers eliminated and baseline correction applied).

Table 9

Standard Deviations σ (dB/km) of the Mean of All Differences $\Delta\alpha$ (Prediction - Experiment) Within a Group of Attenuation Results $\alpha(f_x)_{P,T}$

- Adjustments to the Prediction Model -

H =	30	24	21	18	15	12	9	6	3	0	km
P = 0	1	3	5	8	12	20	31	47	70	101	kPa
σ_a (linewidth adjustment)[a)]											
σ_x (see Table 8)											Temp
.04	.06	.06	.06	.07	.07	.07	.09	-	-	-	7°C
.04	.06	.06	.06	.08	.08	.08	.10				
.06	.07	.06	.06	.06	.07	.08	.08	-	-	-	30°C
.06	.07	.07	.07	.07	.08	.09	.09				
.05	.07	.06	.06	.06	.07	.08	.10	-	-	-	52°C
.05	.07	.06	.06	.07	.08	.08	.11				
σ_b (overlap adjustment)[b)]											
σ_x (see Table 8)											
.04	-	-	-	-	-	.07	.08	.14	**.26**	**.51**	7°C
.04						.08	.10	.15	.23	.31	
.06	-	-	-	-	-	.08	.08	.10	.17	.37[c)]	30°C
.06						.09	.09	.14	.19	.38[c)]	
.05	-	-	-	-	-	.07	.09	.11	.20	.30	52°C
.05						.08	.11	.15	.29	.43	

[a)] see Eqn (27)

[b)] see Eqn (28)

[c)] see Fig. 10 for - $\Delta\alpha$ data between 58 and 66 GHz

Overlap Dependence: Overlap effects become important as pressure P approaches one atmosphere. At P = 101 kPa = 1 atm, the standard deviation σ_x has increased to 0.31, 0.38, 0.43 dB/km at T_x = 7°, 30°, 52°C, respectively. These values change to 0.51 (worse), 0.37 (same), 0.30 (better), when (8) is modified to

$$I_{mod} = 0.80 \cdot I_k \, . \tag{28}$$

At 52°C, there is improvement, but not for the 7°C data. The temperature dependence of I_k needs to be reevaluated. Figure 10 shows an example (101 kPa, 30°C) of the individual differences $\Delta\alpha(f)$, plotted over a frequency range from 58 to 66 GHz for two sets of interference coefficients, $0.8 \cdot I_k$ and I_k. The distinction between random and systematic components is clearer and it remains a challenge to determine a better "I_k Set" that randomizes the difference distribution, $\Delta\alpha(f)$. Special fitting techniques need to be applied to infer revised spectrocopic parameter sets (2 × 38, Table 1) and associated temperature dependences for γ_k (7) and I_k (8) from the data base given in the Appendix.

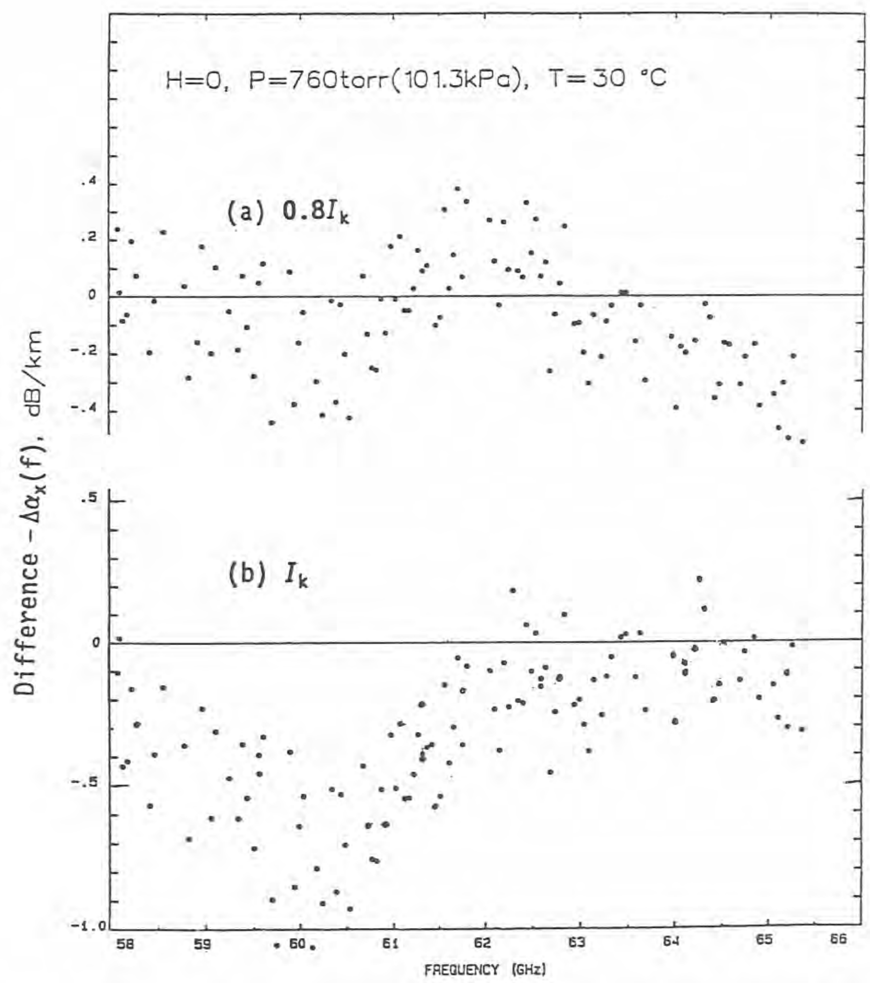

Figure 10. Differences between measured and predicted attenuation rates (α_x-α_M) from f = 58 to 66 GHz (101 kPa, 30°C) for two different model (MPM89) assumptions: (a) $0.8 \cdot I_k$ and (b) I_k (8).

7. CONCLUSIONS AND RECOMMENDATIONS

The 60-GHz oxygen spectrum dominates atmospheric radiative transfer roughly from 50 to 70 GHz. At altitudes below 30 km, an absorption band is formed by the overlap of more than thirty pressure-broadened lines. The spectral band shape is described by Equation (6). Interference (line coupling) effects take place when more than one spectral line contributes to an absorption value. In Rosenkranz's theory (1988), pressure-proportional interference parameters I_k alter the band shape in such a way that absorption is raised in the middle and lowered in the wings (see Fig. 3). Given pressure and temperature, absolute absorption by the $\mathbf{O}_2$ spectrum of dry air can be computed in terms of attenuation rates α (dB/km) by means of the MPM89 model that was detailed in Section 2. To check the model predictions, controlled laboratory experiments were prepared which simulate atmospheric pressure conditions below 30 km altitude in 3-km increments.

Two key components of the spectrometer setup were a Fabry-Perot resonator cell and an automatic network analyzer. Experimental principles, instrumental performance, examples of spectroscopic results, and the measurement uncertainties were discussed. The instrumental performance (sensitivity, stability, etc.) was much improved over past efforts (Newell and Baird, 1965; Poon, 1977; Liebe and Layton, 1987; Read et al., 1988) by taking advantage of recent advances in millimeter-wave instrumentation. A microcomputer was used to handle multiple tasks including spectrometer control, individual data acquisition totaling a number exceeding 10^9, and data reduction.

Measurements were performed at frequencies between 53.9 and 66.3 GHz in 100 MHz steps at three temperatures (7,30,52°C) for eleven selected pressures values (1.2-101 kPa). More than 4,000 attenuation rates α were deduced from the measurement series. Fluctuations of the detection level (≤ ± 0.05 dB/km) were a main cause for experimental uncertainty. The total relative errors were estimated to be typically smaller than ± 2 percent for attenuation rates between 2 and 20 dB/km. Selected results of α(f,P,T) were displayed in Figure 9, and the more complete set is presented numerically and graphically in the Appendix.

A first comparison of the detailed attenuation results with predictions revealed discrepancies which correlate with width and overlap parameters. Also, systematic over-predictions in the middle of the band seem to depend on temperature (e.g., at 60 GHz, 30-101 kPa, the relative error increases from about 2 % at 7°C to 8 % at 52°C). The extensive data set is suitable to support efforts aimed at improving the molecular data base for the atmospheric 60-GHz oxygen spectrum. The MPM89 model can serve as a selective filter to separate random measurement errors from incorrect model predictions. A reliable model is particularly valuable to atmospheric radiative transfer problems (Rosenkranz, 1991).

Additional, related work on the atmospheric 60-GHz $\mathbf{O}_2$ spectrum is recommended in three areas: (a) analyze the refractivity data which supplement many attenuation results and use the complete complex evidence to improve on the width and interference parameter sets; (b) continue measurement series at subfreezing temperatures (5 to -50°C) to simulate real atmospheric conditions; and (c) study the Zeeman effect of isolated $\mathbf{O}_2$ lines at low pressures (≤ 5 kPa) with high frequency resolution (0.01 to 10 MHz) under controlled simulations of the geomagnetic field.

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Appendix: DATA TABLES and GRAPHS

(Pressure-Broadened 60-GHz O_2 Spectrum in Dry Air)

CONTENTS OF APPENDIX

ID (Graph)	H	P		Page
	km	torr	(kPa)[+)]	**A-**
A. (Figs. A-1a,b)	30	9.0	(1.21)	5
B. (Figs. A-2a,b)	27	14.1	(1.90)	15
C. (Figs. A-3a,b)	24	22.3	(2.98)	25
D. (Figs. A-4a,b)	21	35.5	(4.75)	35
E. (Figs. A-5a,b)	18	56.9	(7.60)	45
F. (Figs. A-6a,b)	15	90.8	(12.1)	55
G. (Figs. A-7a,b)	12	146	(19.5)	65
H. (Figs. A-8a,b)	9	231	(30.8)	75
I. (Figs. A-9a,b)	6	354	(47.2)	85
K. (Figs. A-10a,b)	3	526	(70.1)	95
L. (Figs. A-11a,b)	0	760	(101.3)	105
RE (Figs. A-12a,b)		0		115

[+)]Pressure was measured in the unit torr (1 torr ≡ 0.133322 kPa)

LEGEND

ID		**A.** to **L.** (identifying code for pressures at eleven heights) **RE** (reference check at vacuum, $\alpha_x = 0$)
H		height levels of the U.S. Standard Atmosphere
f_x	GHz	measured frequency
α_x	dB/km	experimental attenuation rate
$\delta\alpha$	dB/km	standard deviation of the mean of ten α_x-runs
α_M	dB/km	MPM89 prediction
$\Delta\alpha$	dB/km	difference α_M - α_x
$\sigma_x(\Delta\alpha)$	dB/km	standard deviation of the mean of all (132 ×) differences $\Delta\alpha(f_x)$ within a T-group
P	torr	measured pressure P
T	°C	measured temperature T

A.

H = 30 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**9.10(07)**	**9.10(07)** 1.209	**9.00(19)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.057	0.068	0.069

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89596 9.2	0.00(.04) 0.00(0.01)	53.89590 9.1	0.00(.05) 0.00(0.02)	53.89583 8.9	0.00(.10) 0.00(0.07)
53.99468 9.1	0.10(.02) 0.00(-0.10)	53.99460 9.1	0.00(.04) 0.00(0.02)	53.99452 9.0	0.05(.02) 0.00(-0.05)
54.09333 9.2	0.07(.02) 0.02(-0.05)	54.09327 9.2	0.00(.02) 0.02(0.02)	54.09311 9.1	0.06(.03) 0.02(-0.04)
54.19205 9.2	0.00(.08) 0.01(0.06)	54.19223 9.1	0.00(.08) 0.01(0.06)	54.19184 9.1	0.03(.03) 0.01(-0.02)
54.29071 9.1	0.10(.02) 0.00(-0.10)	54.29055 9.2	0.00(.11) 0.00(0.09)	54.29050 9.1	0.00(.06) 0.00(0.02)
54.38817 9.2	0.10(.02) 0.00(-0.10)	54.38811 9.1	0.00(.05) 0.00(0.03)	54.38916 9.1	0.01(.03) 0.00(-0.01)
54.42971 8.9	0.10(.02) 0.00(-0.10)	54.43051 9.0	0.00(.05) 0.00(0.03)	54.43138 9.0	0.06(.03) 0.00(-0.06)
54.53085 9.2	0.00(.02) 0.00(0.00)	54.53176 9.1	0.00(.11) 0.00(0.09)	54.53164 8.6	0.00(.11) 0.00(0.08)
54.63173 9.2	0.08(.02) 0.04(-0.04)	54.63167 9.1	0.00(.15) 0.03(0.14)	54.63160 9.0	0.00(.08) 0.03(0.07)
54.73180 9.1	0.02(.02) 0.02(0.00)	54.73173 9.1	0.00(.10) 0.02(0.09)	54.73165 9.7	0.01(.03) 0.02(0.01)
54.83181 9.2	0.06(.03) 0.00(-0.06)	54.83174 9.2	0.00(.16) 0.00(0.14)	54.83158 9.1	0.00(.10) 0.00(0.07)
54.93187 9.2	0.05(.03) 0.00(-0.05)	54.93206 9.1	0.00(.10) 0.00(0.07)	54.93165 9.1	0.03(.04) 0.00(-0.03)
55.03188 9.1	0.04(.03) 0.00(-0.04)	55.03172 9.2	0.17(.02) 0.00(-0.17)	55.03168 9.1	0.11(.04) 0.00(-0.11)
55.13067 9.2	0.13(.02) 0.01(-0.12)	55.13063 9.1	0.00(.19) 0.01(0.17)	55.13168 9.1	0.00(.13) 0.01(0.12)
55.16275 9.0	0.00(.09) 0.03(0.09)	55.16357 8.9	0.00(.05) 0.03(0.05)	55.16444 9.2	0.14(.03) 0.03(-0.11)
55.26526 9.2	0.00(.12) 0.05(0.14)	55.26619 9.0	0.00(.17) 0.05(0.18)	55.26606 8.6	0.15(.04) 0.04(-0.11)
55.36750 9.2	0.04(.03) 0.01(-0.03)	55.36745 9.1	0.00(.11) 0.01(0.07)	55.36737 8.8	0.02(.03) 0.01(-0.01)
55.46892 9.1	0.11(.03) 0.00(-0.11)	55.46885 9.1	0.06(.04) 0.00(-0.06)	55.46877 9.0	0.04(.04) 0.00(-0.04)
55.57027 9.2	0.00(.06) 0.01(0.04)	55.57022 9.2	0.00(.19) 0.01(0.18)	55.57006 9.1	0.00(.15) 0.00(0.13)

H = 30 km

6.7°C f_x [GHz] / P [torr]	6.7°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] / P [torr]	29.7°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] / P [torr]	52.4°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km
55.67170 9.2	0.05(.03) 0.02(-0.03)	55.67188 9.1	0.00(.14) 0.01(0.12)	55.67148 9.1	0.07(.03) 0.01(-0.06)
55.77306 9.1	0.46(.02) 0.55(0.09)	55.77289 9.2	0.58(.03) 0.52(-0.06)	55.77285 9.1	0.43(.03) 0.48(0.05)
55.87318 9.2	0.08(.03) 0.03(-0.05)	55.87306 9.1	0.00(.11) 0.02(0.08)	55.87420 9.1	0.01(.04) 0.02(0.01)
55.89580 9.0	0.08(.04) 0.02(-0.06)	55.89663 9.0	0.00(.05) 0.02(0.05)	55.89751 9.3	0.01(.03) 0.01(0.00)
55.99966 9.2	-0.02(.02) 0.01(0.03)	56.00060 9.1	0.00(.09) 0.01(0.05)	56.00048 9.1	0.13(.04) 0.01(-0.12)
56.10326 9.2	0.14(.03) 0.01(-0.13)	56.10321 9.1	0.00(.08) 0.01(0.05)	56.10315 8.8	0.02(.04) 0.01(-0.01)
56.20604 9.1	0.10(.03) 0.06(-0.04)	56.20597 9.1	0.11(.04) 0.04(-0.07)	56.20589 9.0	0.03(.03) 0.03(0.00)
56.30874 9.1	0.08(.02) 0.16(0.08)	56.30868 9.2	0.00(.08) 0.13(0.18)	56.30853 9.1	0.16(.04) 0.10(-0.06)
56.41152 9.2	0.07(.03) 0.12(0.05)	56.41171 9.1	0.00(.04) 0.10(0.11)	56.41130 9.1	0.03(.04) 0.09(0.06)
56.51423 9.1	0.00(.05) 0.02(0.04)	56.51406 9.2	0.17(.03) 0.02(-0.15)	56.51402 9.1	0.00(.06) 0.01(0.04)
56.62883 9.0	0.10(.03) 0.01(-0.09)	56.62968 8.9	0.00(.03) 0.01(0.01)	56.63058 9.3	0.00(.14) 0.01(0.13)
56.73407 9.2	0.00(.08) 0.01(0.05)	56.73502 9.0	0.00(.08) 0.01(0.05)	56.73489 8.7	0.03(.03) 0.01(-0.02)
56.83903 9.1	0.00(.09) 0.03(0.10)	56.83899 9.1	0.00(.09) 0.02(0.07)	56.83892 8.8	0.00(.15) 0.02(0.14)
56.94316 9.1	0.32(.04) 0.44(0.12)	56.94308 9.1	0.36(.04) 0.37(0.01)	56.94301 9.0	0.21(.04) 0.31(0.10)
57.04721 9.1	0.12(.03) 0.06(-0.06)	57.04716 9.2	0.04(.02) 0.05(0.01)	57.04700 9.1	0.16(.03) 0.04(-0.12)
57.15134 9.2	0.02(.04) 0.02(0.00)	57.15153 9.1	0.00(.18) 0.01(0.17)	57.15113 9.1	0.00(.04) 0.01(0.01)
57.25540 9.1	0.06(.04) 0.01(-0.05)	57.25524 9.2	0.07(.04) 0.01(-0.06)	57.25520 9.1	0.00(.09) 0.01(0.07)
57.36188 9.0	0.04(.03) 0.01(-0.03)	57.35815 9.1	0.12(.03) 0.01(-0.11)	57.36366 9.3	0.14(.03) 0.01(-0.13)
57.46848 9.2	0.00(.04) 0.03(0.03)	57.46946 9.0	0.00(.09) 0.02(0.07)	57.46933 8.7	0.10(.05) 0.02(-0.08)

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57482 9.2	0.32(.03) 0.30(-0.02)	57.57476 9.1	0.11(.04) 0.24(0.13)	57.57470 8.8	0.29(.05) 0.19(-0.10)
57.68031 9.1	0.17(.03) 0.11(-0.06)	57.68023 9.1	0.12(.03) 0.09(-0.03)	57.68015 9.0	0.18(.05) 0.07(-0.11)
57.78571 9.1	0.04(.04) 0.02(-0.02)	57.78565 9.2	0.00(.09) 0.02(0.07)	57.78550 9.1	0.06(.03) 0.01(-0.05)
57.89119 9.2	0.00(.04) 0.01(0.01)	57.89138 9.1	0.00(.09) 0.01(0.06)	57.89098 9.1	0.08(.03) 0.01(-0.07)
57.99659 9.1	0.00(.08) 0.01(0.06)	57.99644 9.2	0.00(.09) 0.01(0.08)	57.99640 9.1	0.07(.04) 0.01(-0.06)
58.10084 9.1	0.03(.02) 0.02(-0.01)	58.09582 9.0	0.11(.02) 0.01(-0.10)	58.10143 9.0	0.00(.04) 0.01(0.02)
58.18993 9.1	0.02(.02) 0.04(0.02)	58.20390 9.1	0.00(.08) 0.04(0.09)	58.19102 9.1	0.15(.02) 0.03(-0.12)
58.29557 9.1	0.56(.02) 0.57(0.01)	58.31055 9.1	0.95(.05) 1.12(0.17)	58.31048 8.7	0.90(.03) 0.94(0.04)
58.37877 9.1	0.11(.02) 0.27(0.16)	58.37926 9.2	0.18(.02) 0.21(0.03)	58.37912 9.0	0.01(.02) 0.16(0.15)
58.41743 9.1	0.43(.04) 0.42(-0.01)	58.41735 9.1	0.23(.03) 0.32(0.09)	58.41729 9.0	0.28(.04) 0.25(-0.03)
58.47176 9.1	0.53(.03) 0.48(-0.05)	58.47203 9.0	0.23(.02) 0.37(0.14)	58.47202 9.1	0.29(.02) 0.29(0.00)
58.52419 9.1	0.00(.03) 0.09(0.10)	58.52412 9.2	0.00(.04) 0.07(0.08)	58.52396 9.1	0.00(.13) 0.05(0.15)
58.56452 9.1	0.10(.01) 0.05(-0.05)	58.56459 9.0	0.12(.01) 0.03(-0.09)	58.56461 9.1	0.09(.02) 0.03(-0.06)
58.63101 9.2	0.12(.02) 0.02(-0.10)	58.63120 9.1	0.00(.08) 0.02(0.08)	58.63079 9.1	0.12(.03) 0.01(-0.11)
58.73775 9.1	0.00(.03) 0.02(0.02)	58.73759 9.2	0.02(.02) 0.01(-0.01)	58.73755 9.1	0.00(.04) 0.01(0.02)
58.84320 9.2	0.09(.02) 0.01(-0.08)	58.84317 9.1	0.07(.02) 0.01(-0.06)	58.82980 9.3	0.16(.02) 0.01(-0.15)
58.92416 9.0	0.00(.09) 0.02(0.10)	58.92577 9.0	0.04(.01) 0.01(-0.03)		
59.03115 9.1	0.00(.07) 0.04(0.09)	59.03108 9.0	0.07(.01) 0.03(-0.04)	59.04623 8.7	0.00(.08) 0.03(0.08)
59.11539 9.1	0.29(.01) 0.25(-0.04)	59.15445 9.1	1.36(.03) 1.39(0.03)	59.15438 9.0	1.24(.02) 1.17(-0.07)

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20956 9.1	0.31(.01) 0.28(-0.03)	59.20984 9.0	0.23(.01) 0.21(-0.02)	59.20984 9.1	0.18(.01) 0.17(-0.01)
59.26263 9.1	0.06(.02) 0.07(0.01)	59.26257 9.2	0.00(.07) 0.05(0.10)	59.26241 9.1	0.00(.08) 0.04(0.09)
59.30350 9.1	0.06(.01) 0.04(-0.02)	59.30358 9.0	0.02(.01) 0.03(0.01)	59.30360 9.1	0.04(.01) 0.02(-0.02)
59.37080 9.2	0.07(.02) 0.03(-0.04)	59.37100 9.1	0.04(.02) 0.02(-0.02)	59.37058 9.1	0.00(.08) 0.02(0.08)
59.39914 9.0	0.09(.01) 0.03(-0.06)	59.39894 9.0	0.06(.01) 0.02(-0.04)	59.39942 9.1	0.01(.01) 0.02(0.01)
59.47889 9.1	0.12(.01) 0.05(-0.07)	59.47873 9.2	0.00(.09) 0.04(0.12)	59.47868 9.1	0.00(.07) 0.03(0.08)
59.56704 9.1	0.63(.01) 0.67(0.04)	59.56759 9.1	0.54(.01) 0.54(0.00)	59.56767 9.0	0.49(.01) 0.43(-0.06)
59.58566 9.2	1.65(.02) 1.76(0.11)	59.58555 9.1	1.41(.03) 1.48(0.07)	59.58678 9.1	1.26(.03) 1.33(0.07)
59.65840 9.0	0.12(.01) 0.13(0.01)	59.67268 9.1	0.20(.02) 0.07(-0.13)	59.67255 8.6	0.03(.03) 0.06(0.03)
59.76673 9.1	0.03(.01) 0.03(0.00)	59.76665 9.0	0.04(.01) 0.02(-0.02)	59.76668 9.1	0.04(.01) 0.02(-0.02)
59.85202 9.1	0.07(.01) 0.02(-0.05)	59.85254 9.2	0.04(.01) 0.01(-0.03)	59.85241 9.0	0.01(.01) 0.01(0.00)
59.94735 9.1	0.01(.01) 0.02(0.01)	59.94765 9.0	0.03(.01) 0.01(-0.02)	59.94765 9.1	0.00(.02) 0.01(0.02)
60.04247 9.1	0.03(.01) 0.02(-0.01)	60.04255 9.0	0.01(.01) 0.01(0.00)	60.04259 9.1	0.04(.01) 0.01(-0.03)
60.13931 9.0	0.07(.01) 0.04(-0.03)	60.13912 9.0	0.02(.01) 0.03(0.01)	60.13961 9.1	0.01(.01) 0.02(0.01)
60.22005 9.1	0.07(.05) 0.10(0.03)			60.21984 9.1	0.18(.06) 0.06(-0.12)
60.30018 9.1	1.69(.01) 1.78(0.09)	60.30072 9.1	1.45(.01) 1.52(0.07)	60.30082 9.0	1.07(.01) 1.31(0.24)
60.32817 9.1	0.65(.04) 0.82(0.17)	60.32814 9.1	0.56(.04) 0.64(0.08)	60.32931 9.1	0.68(.06) 0.48(-0.20)
60.39265 9.0	0.36(.01) 0.39(0.03)	60.39429 9.1	0.33(.01) 0.32(-0.01)	60.39381 9.1	0.28(.01) 0.24(-0.04)
60.50232 9.1	0.12(.01) 0.16(0.04)	60.50224 9.0	0.14(.01) 0.12(-0.02)	60.50228 9.1	0.10(.00) 0.09(-0.01)

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58866 9.1	0.04(.00) 0.04(0.00)	60.58918 9.2	0.01(.00) 0.03(0.02)	60.58905 9.0	0.01(.00) 0.02(0.01)
60.68516 9.1	0.00(.02) 0.02(0.03)	60.68547 9.0	0.01(.01) 0.02(0.01)	60.68546 9.1	0.03(.00) 0.01(-0.02)
60.78145 9.1	0.03(.01) 0.02(-0.01)	60.78154 9.0	0.03(.01) 0.01(-0.02)	60.78157 9.1	0.01(.00) 0.01(0.00)
60.87949 9.0	0.00(.03) 0.02(0.04)	60.87929 9.0	0.03(.01) 0.01(-0.02)	60.87979 9.1	0.00(.02) 0.01(0.02)
61.03330 9.1	0.02(.00) 0.05(0.03)	61.03386 9.1	0.03(.01) 0.04(0.01)	61.03395 9.0	0.10(.00) 0.03(-0.07)
61.12692 9.2	0.83(.01) 0.78(-0.05)	61.12856 9.1	0.68(.01) 0.69(0.01)	61.12820 9.1	0.54(.01) 0.55(0.01)
61.23789 9.1	0.07(.00) 0.09(0.02)	61.23793 9.0	0.03(.01) 0.07(0.04)	61.23785 9.1	0.06(.01) 0.05(-0.01)
61.32529 9.1	0.05(.00) 0.03(-0.02)	61.32582 9.2	0.01(.00) 0.02(0.01)	61.32574 9.0	0.06(.01) 0.02(-0.04)
61.42296 9.1	0.05(.00) 0.02(-0.03)	61.42346 9.1	0.03(.01) 0.01(-0.02)	61.42324 9.1	0.04(.01) 0.01(-0.03)
61.52045 9.1	0.01(.01) 0.02(0.01)	61.52050 9.0	0.00(.02) 0.01(0.02)	61.52058 9.0	0.02(.01) 0.01(-0.01)
61.61966 9.0	0.04(.00) 0.02(-0.02)	61.61957 9.0	0.00(.01) 0.02(0.02)	61.61996 9.0	0.00(.02) 0.02(0.03)
61.76640 9.0	0.44(.01) 0.41(-0.03)	61.76729 9.1	0.34(.01) 0.35(0.01)	61.76709 7.8	0.44(.01) 0.28(-0.16)
61.86116 9.2	0.16(.01) 0.15(-0.01)	61.86282 9.1	0.10(.01) 0.11(0.01)	61.86248 9.1	0.11(.00) 0.09(-0.02)
61.97366 9.2	0.00(.04) 0.03(0.06)	61.97351 9.0	0.04(.00) 0.02(-0.02)	61.97344 9.1	0.04(.01) 0.02(-0.02)
62.06186 9.3	0.05(.01) 0.02(-0.03)	62.06246 9.1	0.01(.00) 0.01(0.00)	62.06239 9.0	0.01(.01) 0.01(0.00)
62.16086 9.1	0.03(.01) 0.02(-0.01)	62.16127 9.1	0.00(.01) 0.02(0.03)	62.16106 9.1	0.00(.01) 0.01(0.01)
62.25942 9.0	0.02(.01) 0.04(0.02)	62.25948 9.0	0.02(.01) 0.03(0.01)	62.25957 9.0	0.02(.01) 0.02(0.00)
62.36000 9.1	0.22(.01) 0.20(-0.02)	62.35975 9.0	0.15(.01) 0.16(0.01)	62.36015 9.0	0.14(.01) 0.13(-0.01)
62.49952 9.0	0.86(.00) 0.98(0.12)	62.50042 9.1	0.72(.00) 0.75(0.03)	62.50023 7.3	0.62(.01) 0.62(0.00)

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59540	0.04(.00)	62.59709	0.07(.00)	62.59675	0.00(.01)
9.2	0.06(0.02)	9.1	0.04(-0.03)	9.1	0.03(0.03)
62.70924	0.03(.00)	62.70910	0.00(.00)	62.70902	0.04(.01)
9.2	0.02(-0.01)	9.0	0.02(0.02)	9.1	0.01(-0.03)
62.79849	0.00(.01)	62.79911	0.03(.00)	62.79904	0.00(.01)
9.3	0.02(0.02)	9.1	0.01(-0.02)	9.0	0.01(0.01)
62.89867	0.04(.00)	62.89909	0.04(.01)	62.89888	0.00(.00)
9.1	0.04(0.00)	9.1	0.03(-0.01)	9.1	0.03(0.03)
62.99841	1.48(.00)	62.99847	1.37(.01)	62.99857	1.28(.01)
9.0	1.57(0.09)	9.0	1.51(0.14)	9.0	1.44(0.16)
63.10018	0.04(.01)	63.09992	0.06(.01)	63.10033	0.05(.00)
9.1	0.03(-0.01)	9.0	0.03(-0.03)	9.0	0.02(-0.03)
63.23264	0.05(.00)	63.23355	0.02(.00)	63.23335	0.02(.01)
9.0	0.01(-0.04)	9.1	0.01(-0.01)	7.0	0.01(-0.01)
63.32964	0.01(.00)	63.33136	0.04(.01)	63.33102	0.03(.01)
9.2	0.01(0.00)	9.1	0.01(-0.03)	9.1	0.01(-0.02)
63.44482	0.04(.00)	63.44468	0.00(.01)	63.44461	0.00(.02)
9.2	0.02(-0.02)	9.0	0.02(0.02)	9.1	0.01(0.02)
63.53512	0.22(.01)	63.53574	0.21(.01)	63.53568	0.15(.01)
9.3	0.18(-0.04)	9.1	0.16(-0.05)	9.0	0.14(-0.01)
63.63648	0.05(.00)	63.63691	0.07(.01)	63.63670	0.07(.01)
9.1	0.05(0.00)	9.1	0.04(-0.03)	9.1	0.04(-0.03)
63.73738	0.01(.01)	63.73746	0.02(.00)	63.73756	0.00(.01)
9.0	0.01(0.00)	9.1	0.01(-0.01)	9.0	0.01(0.01)
63.84036	0.01(.00)	63.84010	0.00(.02)	63.84052	0.00(.01)
9.1	0.01(0.00)	9.0	0.01(0.02)	9.0	0.00(0.00)
63.96575	0.00(.06)	63.96668	0.00(.05)	63.96648	0.06(.01)
9.0	0.01(0.06)	9.1	0.01(0.05)	6.8	0.01(-0.05)
64.06388	0.00(.02)	64.06562	0.03(.01)	64.06528	0.07(.01)
9.2	0.04(0.05)	9.1	0.04(0.01)	9.1	0.03(-0.04)
64.18040	0.03(.01)	64.18026	0.03(.01)	64.18005	0.00(.01)
9.2	0.05(0.02)	9.0	0.05(0.02)	9.0	0.04(0.04)
64.27176	0.00(.03)	64.27238	0.00(.02)	64.27225	0.04(.01)
9.3	0.01(0.03)	9.1	0.01(0.02)	9.1	0.01(-0.03)
64.37434	0.04(.01)	64.37465	0.04(.01)	64.37443	0.01(.01)
9.0	0.00(-0.04)	9.1	0.00(-0.04)	9.0	0.00(-0.01)
64.47607	0.07(.01)	64.47630	0.00(.01)	64.47652	0.00(.01)
9.1	0.00(-0.07)	9.0	0.00(0.00)	9.0	0.00(0.00)

H = 30 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.58054 9.0	0.00(.02) 0.01(0.02)	64.58025 9.0	0.01(.01) 0.01(0.00)	64.58070 9.0	0.01(.01) 0.01(0.00)
64.69888 9.0	0.20(.01) 0.15(-0.05)	64.69978 9.0	0.06(.01) 0.14(0.08)	64.69952 9.0	0.23(.01) 0.14(-0.09)
64.79758 9.0	0.03(.01) 0.01(-0.02)	64.79950 9.1	0.01(.00) 0.01(0.00)	64.79952 9.1	0.00(.02) 0.01(0.02)
64.91599 9.0	0.10(.01) 0.00(-0.10)	64.91582 9.1	0.00(.01) 0.00(0.01)	64.91563 9.0	0.00(.03) 0.00(0.02)
65.00835 9.0	0.00(.01) 0.00(0.00)	65.00890 9.0	0.01(.00) 0.00(-0.01)	65.00889 9.1	0.02(.01) 0.00(-0.02)
65.11214 9.0	0.03(.00) 0.01(-0.02)	65.11247 9.1	0.03(.00) 0.00(-0.03)	65.11225 9.0	0.00(.01) 0.00(0.00)
65.21504 9.1	0.20(.01) 0.19(-0.01)	65.21529 9.0	0.19(.00) 0.21(0.02)	65.21552 9.0	0.21(.01) 0.23(0.02)
65.32071 9.0	0.01(.01) 0.01(0.00)	65.32043 9.0	0.00(.01) 0.01(0.01)	65.32076 9.1	0.01(.01) 0.01(0.00)
65.43200 9.0	0.00(.03) 0.00(0.02)	65.43291 9.0	0.00(.08) 0.00(0.07)	65.43265 9.0	0.05(.01) 0.00(-0.05)
65.53181 9.1	0.00(.04) 0.00(0.03)	65.53378 9.1	0.00(.01) 0.00(0.00)	65.53378 9.1	0.06(.01) 0.00(-0.06)
65.65157 8.9	0.10(.01) 0.00(-0.10)	65.65140 9.1	0.01(.01) 0.00(-0.01)	65.65122 9.0	0.00(.04) 0.00(0.03)
65.74498 9.0	0.06(.01) 0.05(-0.01)	65.74554 9.0	0.07(.00) 0.05(-0.02)	65.74554 9.1	0.02(.01) 0.06(0.04)
65.84995 9.0	0.02(.01) 0.00(-0.02)	65.85029 9.1	0.00(.02) 0.00(0.01)	65.85007 9.0	0.01(.01) 0.00(-0.01
65.95403 9.1	0.01(.01) 0.00(-0.01)	65.95427 9.0	0.00(.01) 0.00(0.00)	65.95451 9.0	0.04(.01) 0.00(-0.04)
66.06089 9.0	0.00(.03) 0.00(0.02)	66.06062 9.0	0.00(.02) 0.00(0.01)	66.06095 9.1	0.00(.04) 0.00(0.03)
66.16512 9.0	0.00(.02) 0.00(0.01)	66.16604 9.0	0.00(.02) 0.00(0.02)	66.16578 9.0	0.01(.01) 0.00(-0.01)
66.26604 9.1	0.00(.01) 0.01(0.01)	66.26804 9.1	0.07(.01) 0.01(-0.06)	66.26805 9.1	0.00(.01) 0.01(0.01)

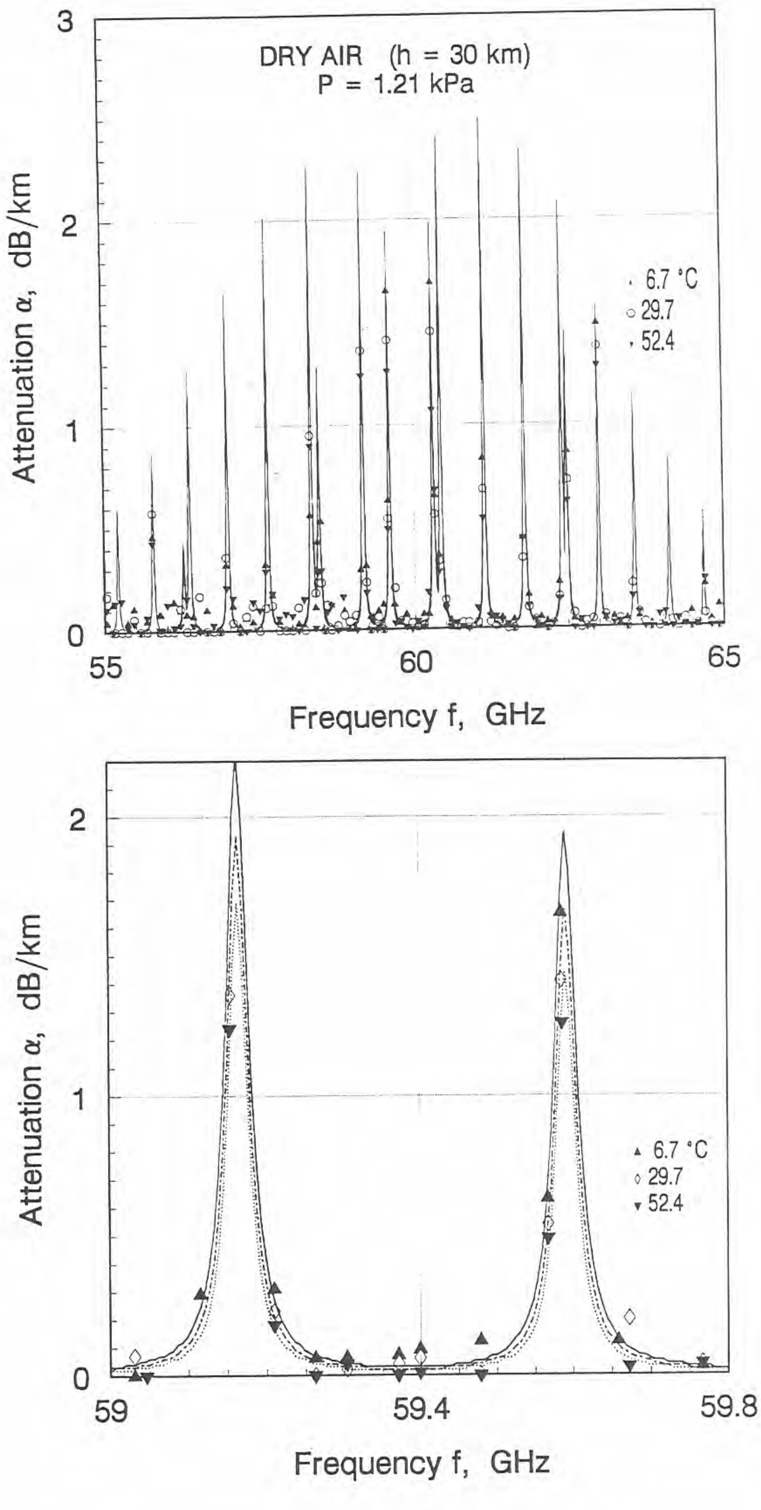

Figure A-1a. Predicted and measured attenuation rates of dry air, α_M and α_x, at P = 1.21 kPa (see A.) for frequencies between 55 and 65 GHz.

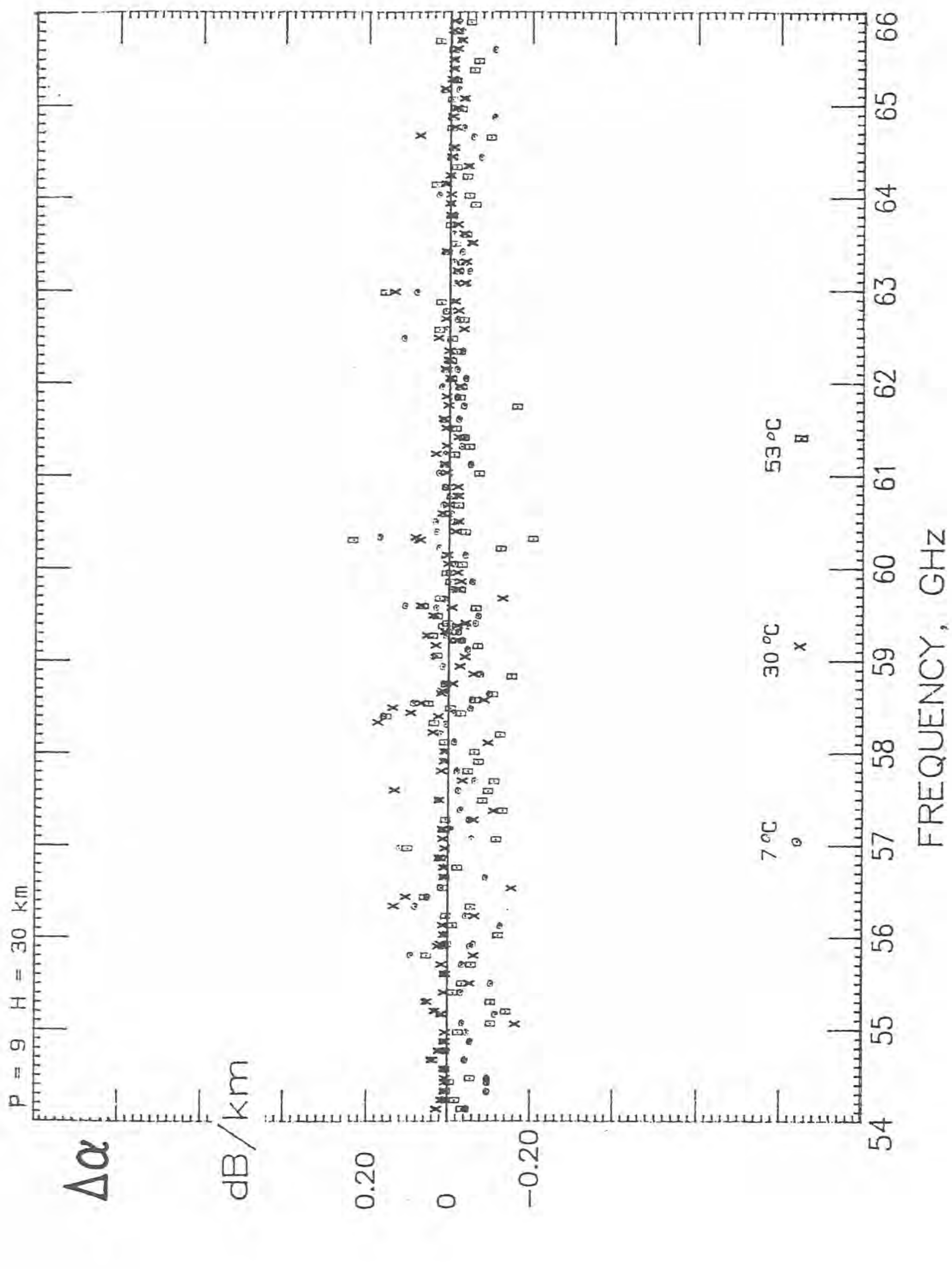

Figure A-1b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation rates of the data listed under **A**.

B.

H = 27 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**14.30(07)**	**14.20(05)** 1.898	**14.20(20)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.057	0.069	0.060

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89585 14.3	0.02(.03) 0.00(-0.02)	53.89581 14.2	0.09(.03) 0.00(-0.09)	53.89575 14.1	0.00(.12) 0.00(0.10)
53.99460 14.3	0.00(.02) 0.01(0.01)	53.99452 14.2	0.00(.12) 0.01(0.13)	53.99445 15.0	0.00(.03) 0.01(0.01)
54.09324 14.3	0.12(.02) 0.05(-0.07)	54.09319 14.2	0.00(.04) 0.05(0.07)	54.09304 14.2	0.00(.08) 0.05(0.10)
54.19197 14.2	0.01(.03) 0.02(0.01)	54.19215 14.2	0.05(.03) 0.02(-0.03)	54.19176 14.2	0.11(.03) 0.02(-0.09)
54.29061 14.3	0.00(.13) 0.01(0.12)	54.29046 14.2	0.00(.05) 0.01(0.04)	54.29042 14.2	0.03(.03) 0.01(-0.02)
54.38805 14.2	0.03(.02) 0.00(-0.03)	54.38803 14.2	0.02(.03) 0.00(-0.02)	54.38908 14.2	0.00(.08) 0.00(0.05)
54.42958 14.1	0.02(.02) 0.00(-0.02)	54.43042 14.1	0.00(.07) 0.00(0.04)	54.43130 14.0	0.05(.04) 0.00(-0.05)
54.53073 14.3	0.10(.02) 0.01(-0.09)	54.53167 14.1	0.00(.06) 0.01(0.04)	54.53155 14.2	0.00(.09) 0.01(0.08)
54.63162 14.3	0.12(.02) 0.08(-0.04)	54.63158 14.2	0.08(.03) 0.07(-0.01)	54.63152 14.1	0.03(.03) 0.07(0.04)
54.73171 14.3	0.10(.03) 0.04(-0.06)	54.73164 14.1	0.00(.08) 0.04(0.09)	54.73157 14.2	0.00(.03) 0.04(0.04)
54.83170 14.3	0.12(.03) 0.01(-0.11)	54.83166 14.2	0.00(.05) 0.01(0.04)	54.83151 14.2	0.00(.09) 0.01(0.06)
54.93179 14.2	0.08(.03) 0.01(-0.07)	54.93197 14.2	0.00(.07) 0.01(0.06)	54.93158 14.2	0.00(.05) 0.01(0.02)
55.03178 14.2	0.00(.09) 0.01(0.07)	55.03163 14.2	0.00(.12) 0.01(0.12)	55.03159 14.2	0.11(.05) 0.01(-0.10)
55.13056 14.2	0.13(.02) 0.03(-0.10)	55.13054 14.2	0.03(.03) 0.03(0.00)	55.13161 14.2	0.04(.04) 0.03(-0.01)
55.16263 14.1	0.00(.07) 0.07(0.11)	55.16347 14.1	0.00(.05) 0.06(0.08)	55.16437 14.1	0.16(.03) 0.06(-0.10)
55.26514 14.3	0.11(.03) 0.12(0.01)	55.26609 14.1	0.00(.06) 0.11(0.13)	55.26597 14.2	0.14(.04) 0.10(-0.04)
55.36739 14.3	0.10(.03) 0.02(-0.08)	55.36734 14.2	0.15(.04) 0.02(-0.13)	55.36729 14.1	0.00(.08) 0.01(0.05)
55.46883 14.3	0.00(.03) 0.01(0.01)	55.46876 14.2	0.04(.03) 0.01(-0.03)	55.46869 14.2	0.10(.04) 0.01(-0.09)
55.57018 14.3	0.00(.07) 0.01(0.06)	55.57013 14.2	0.00(.13) 0.01(0.11)	55.56998 14.2	0.00(.10) 0.01(0.09)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67161 14.2	0.03(.02) 0.04(0.01)	55.67180 14.2	0.00(.08) 0.03(0.09)	55.67140 14.2	0.12(.03) 0.03(-0.09)
55.77295 14.3	0.56(.02) 0.70(0.14)	55.77280 14.2	0.53(.03) 0.68(0.15)	55.77277 14.2	0.51(.03) 0.65(0.14)
55.87306 14.2	0.09(.04) 0.06(-0.03)	55.87296 14.2	0.00(.10) 0.05(0.11)	55.87413 14.3	0.00(.10) 0.05(0.11)
55.89567 14.1	0.15(.03) 0.04(-0.11)	55.89653 14.1	0.12(.02) 0.04(-0.08)	55.89744 14.2	0.00(.05) 0.03(0.05)
55.99954 14.3	0.00(.04) 0.02(0.04)	56.00051 14.2	0.06(.02) 0.02(-0.04)	56.00039 14.2	0.00(.09) 0.02(0.07)
56.10316 14.3	0.00(.07) 0.03(0.07)	56.10312 14.2	0.19(.04) 0.03(-0.16)	56.10305 14.1	0.07(.04) 0.02(-0.05)
56.20596 14.3	0.25(.03) 0.12(-0.13)	56.20587 14.2	0.10(.04) 0.10(0.00)	56.20581 14.2	0.00(.02) 0.08(0.08)
56.30864 14.3	0.33(.03) 0.33(0.00)	56.30859 14.2	0.21(.03) 0.27(0.06)	56.30844 14.2	0.21(.04) 0.23(0.02)
56.41143 14.2	0.30(.02) 0.27(-0.03)	56.41162 14.2	0.06(.04) 0.22(0.16)	56.41122 14.2	0.27(.04) 0.20(-0.07)
56.51412 14.3	0.01(.03) 0.04(0.03)	56.51398 14.2	0.17(.03) 0.04(-0.13)	56.51393 14.2	0.08(.04) 0.03(-0.05)
56.62871 14.1	0.14(.03) 0.02(-0.12)	56.62958 14.1	0.00(.09) 0.02(0.09)	56.63050 14.1	0.00(.08) 0.02(0.07)
56.73395 14.3	0.00(.09) 0.03(0.09)	56.73493 14.1	0.00(.13) 0.02(0.12)	56.73482 14.2	0.04(.04) 0.02(-0.02)
56.83893 14.3	0.00(.06) 0.06(0.10)	56.83888 14.2	0.00(.09) 0.05(0.09)	56.83883 14.1	0.07(.03) 0.04(-0.03)
56.94307 14.3	0.67(.04) 0.77(0.10)	56.94299 14.2	0.54(.03) 0.66(0.12)	56.94293 14.2	0.46(.04) 0.58(0.12)
57.04712 14.3	0.23(.04) 0.15(-0.08)	57.04707 14.2	0.00(.07) 0.12(0.16)	57.04692 14.2	0.16(.04) 0.10(-0.06)
57.15126 14.2	0.03(.03) 0.04(0.01)	57.15145 14.2	0.00(.14) 0.03(0.13)	57.15104 14.2	0.00(.11) 0.03(0.10)
57.25529 14.3	0.00(.22) 0.03(0.21)	57.25515 14.2	0.00(.12) 0.02(0.10)	57.25512 14.2	0.00(.14) 0.02(0.12)
57.36176 14.1	0.14(.03) 0.03(-0.11)	57.35806 14.2	0.20(.04) 0.02(-0.18)	57.36357 14.1	0.04(.04) 0.02(-0.02)
57.46837 14.3	0.12(.04) 0.07(-0.05)	57.46936 14.2	0.03(.05) 0.05(0.02)	57.46924 14.6	0.11(.05) 0.04(-0.07)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57470 14.3	0.70(.03) 0.60(-0.10)	57.57466 14.2	0.56(.03) 0.49(-0.07)	57.57461 14.1	0.37(.05) 0.41(0.04)
57.68022 14.3	0.24(.03) 0.25(0.01)	57.68014 14.1	0.14(.03) 0.20(0.06)	57.68008 14.2	0.26(.05) 0.16(-0.10)
57.78560 14.3	0.17(.04) 0.05(-0.12)	57.78556 14.2	0.00(.09) 0.04(0.10)	57.78541 14.2	0.04(.04) 0.03(-0.01)
57.89110 14.2	0.11(.03) 0.03(-0.08)	57.89129 14.2	0.00(.05) 0.02(0.03)	57.89089 14.2	0.08(.04) 0.02(-0.06)
57.99649 14.3	0.01(.03) 0.03(0.02)	57.99634 14.2	0.17(.03) 0.02(-0.15)	57.99630 14.2	0.00(.16) 0.02(0.14)
58.10070 14.2	0.00(.03) 0.05(0.06)	58.09572 14.1	0.17(.04) 0.03(-0.14)	58.10134 14.2	0.00(.10) 0.03(0.11)
58.18979 14.2	0.12(.02) 0.10(-0.02)	58.20380 14.2	0.21(.03) 0.09(-0.12)	58.19094 14.1	0.14(.02) 0.06(-0.08)
58.29544 14.1	0.96(.02) 1.03(0.07)	58.31044 14.2	1.55(.03) 1.52(-0.03)	58.31039 14.1	1.39(.04) 1.31(-0.08)
58.37864 14.1	0.49(.02) 0.59(0.10)	58.37915 14.1	0.36(.02) 0.46(0.10)	58.37904 14.1	0.32(.02) 0.37(0.05)
58.41735 14.3	0.70(.04) 0.77(0.07)	58.41726 14.2	0.71(.04) 0.60(-0.11)	58.41719 14.3	0.42(.04) 0.48(0.06)
58.47162 14.1	0.74(.03) 0.80(0.06)	58.47192 14.1	0.52(.02) 0.63(0.11)	58.47194 14.1	0.47(.02) 0.51(0.04)
58.52408 14.3	0.18(.03) 0.21(0.03)	58.52403 14.2	0.22(.03) 0.15(-0.07)	58.52388 14.2	0.10(.03) 0.12(0.02)
58.56439 14.1	0.12(.01) 0.11(-0.01)	58.56448 14.1	0.14(.02) 0.08(-0.06)	58.56453 14.2	0.04(.02) 0.07(0.03)
58.63092 14.2	0.15(.01) 0.06(-0.09)	58.63111 14.2	0.03(.02) 0.04(0.01)	58.63070 14.2	0.07(.02) 0.04(-0.03)
58.73765 14.3	0.04(.02) 0.04(0.00)	58.73750 14.2	0.04(.02) 0.03(-0.01)	58.73746 14.2	0.00(.11) 0.02(0.10)
58.84309 14.2	0.02(.01) 0.04(0.02)	58.84306 14.2	0.10(.02) 0.03(-0.07)	58.82971 14.1	0.00(.03) 0.02(0.02)
58.92403 14.2	0.01(.01) 0.04(0.03)	58.92566 14.1	0.07(.01) 0.03(-0.04)		
59.03102 14.1	0.11(.02) 0.10(-0.01)	59.03097 14.1	0.10(.01) 0.08(-0.02)	59.04614 14.1	0.21(.02) 0.07(-0.14)
59.11526 14.1	0.51(.01) 0.52(0.01)	59.15435 14.2	1.59(.03) 1.67(0.08)	59.15429 15.3	1.52(.03) 1.44(-0.08)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20942 14.1	0.58(.01) 0.58(0.00)	59.20974 14.1	0.40(.01) 0.45(0.05)	59.20975 14.1	0.34(.01) 0.36(0.02)
59.26252 14.3	0.15(.02) 0.17(0.02)	59.26247 14.2	0.17(.02) 0.13(-0.04)	59.26232 14.2	0.09(.03) 0.10(0.01)
59.30337 14.1	0.10(.01) 0.10(0.00)	59.30347 14.1	0.08(.01) 0.07(-0.01)	59.30351 14.2	0.12(.01) 0.06(-0.06)
59.37071 14.2	0.11(.02) 0.07(-0.04)	59.37090 14.2	0.01(.02) 0.05(0.04)	59.37049 14.2	0.00(.04) 0.04(0.06)
59.39901 14.1	0.07(.01) 0.07(0.00)	59.39883 14.1	0.10(.01) 0.05(-0.05)	59.39933 14.1	0.04(.01) 0.04(0.00)
59.47879 14.3	0.14(.02) 0.13(-0.01)	59.47863 14.2	0.08(.02) 0.09(0.01)	59.47860 14.2	0.00(.07) 0.07(0.12)
59.56691 14.2	1.04(.01) 1.08(0.04)	59.56748 14.1	0.84(.01) 0.89(0.05)	59.56758 14.2	0.78(.01) 0.73(-0.05)
59.58555 14.2	1.84(.02) 1.86(0.02)	59.58545 14.2	1.47(.03) 1.58(0.11)	59.58670 14.3	1.27(.02) 1.39(0.12)
59.65826 14.2	0.32(.01) 0.30(-0.02)	59.67258 14.2	0.24(.02) 0.17(-0.07)	59.67246 14.2	0.03(.04) 0.13(0.10)
59.76660 14.1	0.05(.01) 0.07(0.02)	59.76654 14.2	0.04(.01) 0.05(0.01)	59.76659 14.1	0.05(.01) 0.04(-0.01)
59.85189 14.1	0.08(.01) 0.04(-0.04)	59.85243 14.1	0.02(.01) 0.03(0.01)	59.85231 14.1	0.04(.01) 0.03(-0.01)
59.94722 14.1	0.07(.01) 0.04(-0.03)	59.94755 14.1	0.01(.01) 0.03(0.02)	59.94756 14.1	0.03(.01) 0.02(-0.01)
60.04234 14.1	0.07(.01) 0.05(-0.02)	60.04244 14.1	0.01(.01) 0.04(0.03)	60.04249 14.2	0.00(.03) 0.03(0.05)
60.13918 14.1	0.14(.01) 0.08(-0.06)	60.13901 14.1	0.07(.01) 0.06(-0.01)	60.13951 14.1	0.08(.01) 0.05(-0.03)
60.21994 14.3	0.23(.06) 0.23(0.00)			60.21974 14.2	0.04(.07) 0.14(0.10)
60.30005 14.1	1.80(.01) 1.94(0.14)	60.30061 14.1	1.52(.01) 1.65(0.13)	60.30072 14.2	1.34(.01) 1.42(0.08)
60.32806 14.2	1.23(.04) 1.33(0.10)	60.32804 14.2	0.97(.05) 1.07(0.10)	60.32923 14.3	0.94(.06) 0.84(-0.10)
60.39251 14.2	0.83(.01) 0.82(-0.01)	60.39418 14.1	0.69(.01) 0.66(-0.03)	60.39372 14.1	0.53(.01) 0.53(0.00)
60.50219 14.1	0.34(.01) 0.36(0.02)	60.50214 14.2	0.29(.01) 0.28(-0.01)	60.50219 14.1	0.22(.00) 0.22(0.00)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58853	0.08(.01)	60.58907	0.08(.00)	60.58896	0.05(.00)
14.1	0.10(0.02)	14.1	0.07(-0.01)	14.1	0.06(0.01)
60.68502	0.05(.01)	60.68536	0.06(.01)	60.68538	0.01(.01)
14.1	0.05(0.00)	14.1	0.04(-0.02)	14.2	0.03(0.02)
60.78133	0.04(.01)	60.78142	0.03(.00)	60.78148	0.01(.00)
14.1	0.04(0.00)	14.1	0.03(0.00)	14.2	0.02(0.01)
60.87935	0.03(.01)	60.87918	0.04(.00)	60.87969	0.01(.01)
14.1	0.04(0.01)	14.1	0.03(-0.01)	14.1	0.02(0.01)
61.03317	0.11(.00)	61.03375	0.10(.01)	61.03385	0.18(.01)
14.2	0.12(0.01)	14.1	0.10(0.00)	14.2	0.08(-0.10)
61.12677	1.23(.01)	61.12845	1.21(.01)	61.12812	0.91(.01)
14.2	1.31(0.08)	14.1	1.16(-0.05)	14.1	0.97(0.06)
61.23776	0.20(.00)	61.23782	0.17(.01)	61.23776	0.12(.01)
14.1	0.20(0.00)	14.2	0.16(-0.01)	14.1	0.13(0.01)
61.32511	0.07(.01)	61.32571	0.07(.00)	61.32566	0.11(.01)
14.1	0.06(-0.01)	14.1	0.05(-0.02)	14.2	0.04(-0.07)
61.42282	0.07(.00)	61.42335	0.02(.01)	61.42315	0.01(.01)
14.1	0.04(-0.03)	14.1	0.03(0.01)	14.1	0.02(0.01)
61.52031	0.04(.01)	61.52040	0.04(.01)	61.52050	0.04(.01)
14.1	0.04(0.00)	14.1	0.03(-0.01)	14.2	0.02(-0.02)
61.61953	0.09(.00)	61.61946	0.00(.01)	61.61987	0.00(.01)
14.1	0.06(-0.03)	14.1	0.05(0.05)	14.1	0.04(0.04)
61.76626	0.81(.01)	61.76718	0.70(.01)	61.76694	0.67(.01)
14.2	0.80(-0.01)	14.1	0.68(-0.02)	14.0	0.57(-0.10)
61.86102	0.35(δ.01)	61.86271	0.27(.01)	61.86239	0.20(.01)
14.2	0.34(-0.01)	14.1	0.26(-0.01)	14.1	0.21(0.01)
61.97352	0.05(.01)	61.97339	0.07(.00)	61.97334	0.05(.01)
14.2	0.06(0.01)	14.2	0.05(-0.02)	14.1	0.04(-0.01)
62.06174	0.05(.01)	62.06235	0.08(.01)	62.06230	0.05(.01)
14.1	0.04(-0.01)	14.2	0.03(-0.05)	14.2	0.03(-0.02)
62.16072	0.04(.01)	62.16116	0.07(.00)	62.16096	0.05(.01)
14.1	0.05(0.01)	14.1	0.04(-0.03)	14.1	0.03(-0.02)
62.25929	0.06(.01)	62.25937	0.07(.01)	62.25949	0.05(.01)
14.1	0.08(0.02)	14.1	0.07(0.00)	14.2	0.05(0.00)
62.35987	0.45(.01)	62.35963	0.35(.01)	62.36005	0.30(.01)
14.1	0.43(-0.02)	14.1	0.35(0.00)	14.2	0.30(0.00)
62.49939	1.17(.00)	62.50031	0.97(.01)	62.50008	0.85(.01)
14.2	1.28(0.11)	14.1	1.03(0.06)	13.9	0.87(0.02)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59525 14.2	0.13(.00) 0.13(0.00)	62.59698 14.1	0.11(.01) 0.10(-0.01)	62.59666 14.1	0.04(.01) 0.08(0.04)
62.70910 14.2	0.08(.00) 0.05(-0.03)	62.70898 14.2	0.02(.01) 0.04(0.02)	62.70893 14.1	0.04(.01) 0.03(-0.01)
62.79836 14.1	0.02(.00) 0.04(0.02)	62.79899 14.2	0.03(.00) 0.04(0.01)	62.79894 14.2	0.02(.01) 0.03(0.01)
62.89853 14.1	0.08(.00) 0.10(0.02)	62.89898 14.1	0.09(.01) 0.08(-0.01)	62.89878 14.1	0.04(.00) 0.07(0.03)
62.99827 14.1	1.46(.01) 1.58(0.12)	62.99836 14.1	1.39(.00) 1.51(0.12)	62.99848 14.2	1.32(.01) 1.45(0.13)
63.10005 14.1	0.06(.00) 0.08(0.02)	63.09981 14.1	0.11(.00) 0.07(-0.04)	63.10023 14.1	0.08(.01) 0.06(-0.02)
63.23250 14.2	0.05(.00) 0.02(-0.03)	63.23344 14.1	0.03(.00) 0.02(-0.01)	63.23321 13.9	0.00(.02) 0.02(0.03)
63.32949 14.2	0.03(.00) 0.02(-0.01)	63.33125 14.1	0.03(.01) 0.02(-0.01)	63.33092 14.1	0.04(.01) 0.02(-0.02)
63.44468 14.2	0.07(.00) 0.05(-0.02)	63.44456 14.2	0.04(.01) 0.04(0.00)	63.44451 14.1	0.01(.01) 0.03(0.02)
63.53499 14.1	0.39(.01) 0.35(-0.04)	63.53562 14.2	0.37(.01) 0.33(-0.04)	63.53558 14.2	0.28(.01) 0.30(0.02)
63.63634 14.1	0.12(.01) 0.11(-0.01)	63.63679 14.1	0.11(.01) 0.10(-0.01)	63.63660 14.1	0.07(.01) 0.09(0.02)
63.73725 14.0	0.05(.01) 0.02(-0.03)	63.73734 14.1	0.02(.00) 0.02(0.00)	63.73746 14.2	0.01(.01) 0.02(0.01)
63.84023 14.1	0.01(.00) 0.02(0.01)	63.83998 14.1	0.00(.01) 0.01(0.02)	63.84041 14.1	0.01(.01) 0.01(0.00)
63.96561 14.2	0.00(.02) 0.02(0.03)	63.96656 14.1	0.00(.01) 0.02(0.02)	63.96634 13.9	0.14(.01) 0.02(-0.12)
64.06374 14.2	0.06(.00) 0.08(0.02)	64.06551 14.1	0.07(.01) 0.08(0.01)	64.06519 14.1	0.08(.01) 0.07(-0.01)
64.18027 14.2	0.10(.01) 0.11(0.01)	64.18015 14.2	0.13(.01) 0.11(-0.02)	64.17997 14.2	0.07(.01) 0.10(0.03)
64.27163 14.1	0.00(.02) 0.02(0.03)	64.27227 14.2	0.01(.01) 0.02(0.01)	64.27216 14.1	0.07(.01) 0.02(-0.05)
64.37418 14.2	0.04(.01) 0.01(-0.03)	64.37453 14.2	0.06(.01) 0.01(-0.05)	64.37434 14.2	0.06(.01) 0.01(-0.05)
64.47593 14.1	0.06(.01) 0.01(-0.05)	64.47619 14.1	0.07(.01) 0.01(-0.06)	64.47644 14.2	0.03(.01) 0.01(-0.02)

H = 27 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.58039	0.04(.01)	64.58013	0.01(.01)	64.58059	0.03(.01)
14.2	0.03(-0.01)	14.1	0.02(0.01)	14.2	0.02(-0.01)
64.69875	0.32(.01)	64.69968	0.11(.01)	64.69942	0.22(.01)
14.2	0.26(-0.06)	14.2	0.25(0.14)	14.1	0.26(0.04)
64.79743	0.06(.01)	64.79939	0.02(.01)	64.79942	0.00(.01)
14.2	0.02(-0.04)	14.2	0.02(0.00)	14.1	0.01(0.01)
64.91585	0.06(.01)	64.91570	-0.01(.01)	64.91555	0.01(.01)
14.2	0.01(-0.05)	14.3	0.01(0.02)	14.2	0.01(0.00)
65.00821	0.02(.01)	65.00878	0.01(.01)	65.00880	0.01(.01)
14.1	0.01(-0.01)	14.1	0.01(0.00)	14.1	0.01(0.00)
65.11198	0.04(.00)	65.11236	0.04(.00)	65.11214	0.00(.01)
14.2	0.01(-0.03)	14.2	0.01(-0.03)	14.2	0.01(0.01)
65.21490	0.27(.01)	65.21516	0.27(.00)	65.21542	0.32(.01)
14.1	0.24(-0.03)	14.0	0.27(0.00)	14.2	0.29(-0.03)
65.32056	0.02(.00)	65.32031	0.02(.01)	65.32067	0.01(.01)
14.2	0.01(-0.01)	14.1	0.01(-0.01)	14.1	0.01(0.00)
65.43185	0.00(.01)	65.43279	0.00(.05)	65.43255	0.03(.00)
14.2	0.00(0.00)	14.2	0.00(0.04)	14.1	0.00(-0.03)
65.53166	0.00(.03)	65.53365	0.00(.03)	65.53368	0.03(.01)
14.2	0.00(0.02)	14.2	0.00(0.02)	14.1	0.00(-0.03)
65.65142	0.07(.01)	65.65128	0.01(.01)	65.65113	0.03(.01)
14.2	0.01(-0.06)	14.3	0.01(0.00)	14.2	0.01(-0.02)
65.74483	0.09(.01)	65.74542	0.10(.01)	65.74545	0.06(.01)
14.1	0.08(-0.01)	14.1	0.09(-0.01)	14.1	0.10(0.04)
65.84978	0.00(.03)	65.85017	0.01(.01)	65.84997	0.04(.01)
14.2	0.01(0.03)	14.2	0.01(0.00)	14.2	0.01(-0.03)
65.95388	0.00(.01)	65.95415	0.00(.01)	65.95442	0.05(.01)
14.1	0.00(0.01)	14.1	0.00(0.01)	14.2	0.00(-0.05)
66.06075	0.00(.00)	66.06049	0.00(.02)	66.06085	0.02(.01)
14.2	0.00(0.00)	14.1	0.00(0.01)	14.1	0.00(-0.02)
66.16498	0.00(.04)	66.16592	0.00(.00)	66.16568	0.03(.01)
14.2	0.00(0.03)	14.2	0.00(0.00)	14.1	0.00(-0.03)
66.26590	0.04(.01)	66.26791	0.03(.01)	66.26795	0.01(.01)
14.2	0.02(-0.02)	14.2	0.02(-0.01)	14.1	0.03(0.02)

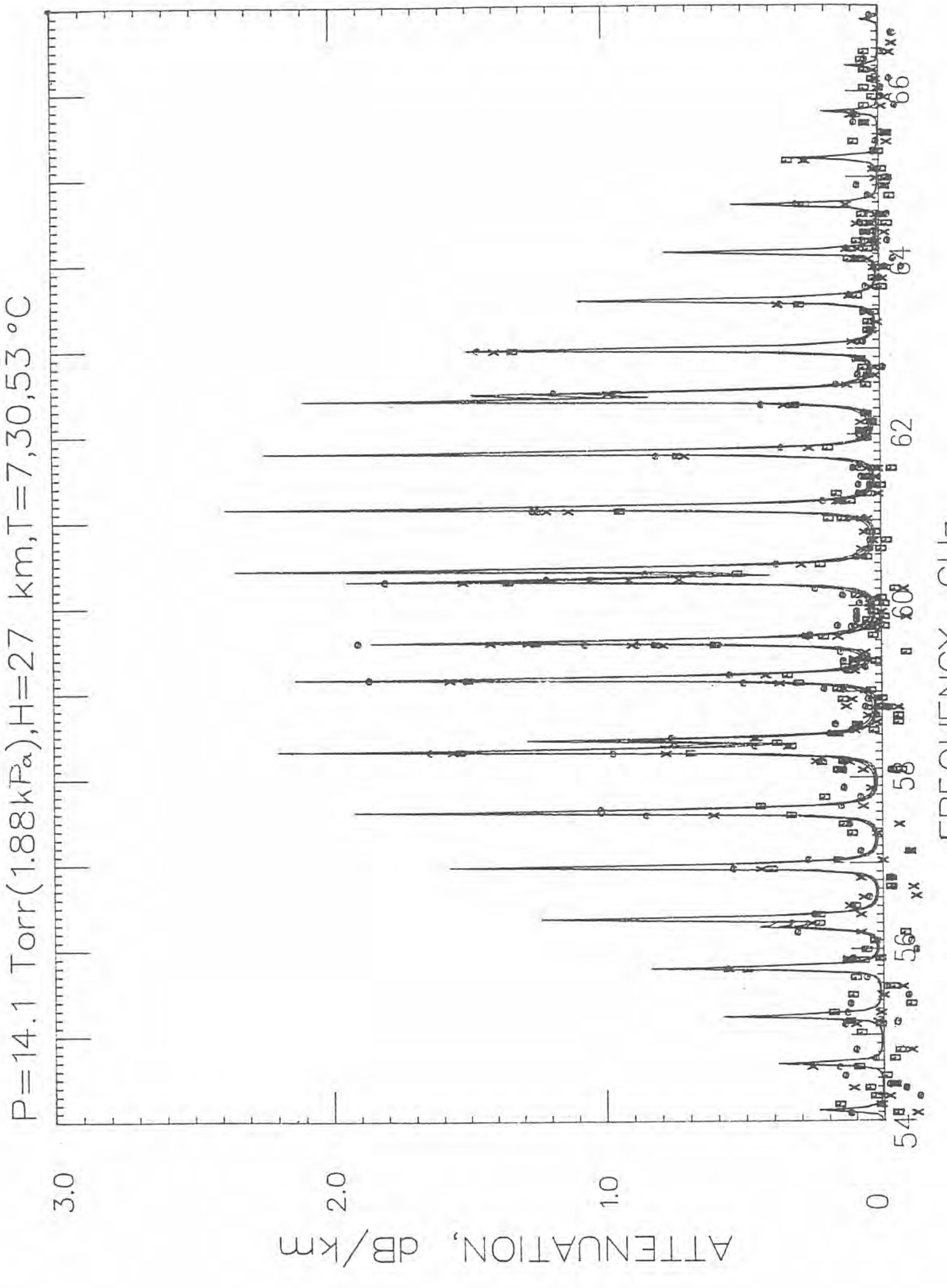

Figure A-2a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 27 km (see B.) for frequencies between 54 and 66 GHz.

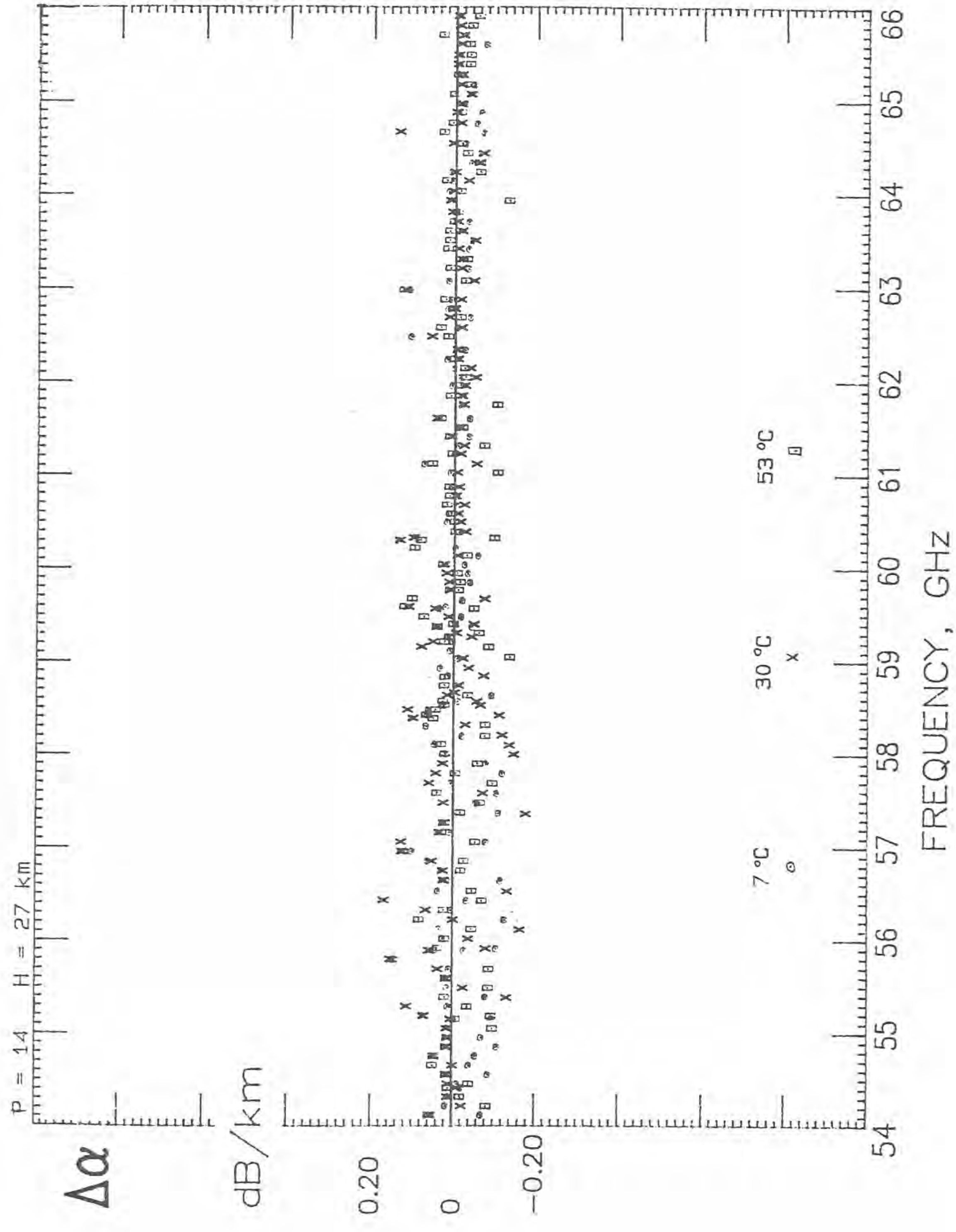

Figure A-2b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **B**.

C.

H = 24 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**24.40(07)**	**22.40(06)** 3.253	**22.30(22)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.063	0.066	0.061

H = 24 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89570 22.3	0.00(.10) 0.01(0.09)	53.89566 22.4	0.11(.03) 0.01(-0.10)	53.89561 22.4	0.00(.07) 0.01(0.05)
53.99445 22.4	0.11(.02) 0.01(-0.10)	53.99437 22.4	0.02(.02) 0.01(-0.01)	53.99432 22.4	0.01(.02) 0.01(0.00)
54.09307 22.4	0.14(.02) 0.08(-0.06)	54.09303 22.4	0.00(.04) 0.09(0.10)	54.09290 22.3	0.04(.03) 0.09(0.05)
54.19181 22.5	0.10(.03) 0.05(-0.05)	54.19199 22.4	0.00(.02) 0.05(0.05)	54.19162 22.3	0.12(.03) 0.05(-0.07)
54.29045 22.4	0.00(.05) 0.01(0.04)	54.29031 22.3	0.15(.02) 0.01(-0.14)	54.29029 22.4	0.06(.03) 0.01(-0.05)
54.38789 22.4	0.05(.02) 0.01(-0.04)	54.38788 22.4	0.05(.02) 0.01(-0.04)	54.38895 22.4	0.09(.03) 0.01(-0.08)
54.42941 22.5	0.03(.03) 0.01(-0.02)	54.43026 22.3	0.07(.03) 0.01(-0.06)	54.43116 22.0	0.03(.04) 0.01(-0.02)
54.53056 22.5	0.01(.03) 0.02(0.01)	54.53151 22.4	-0.09(.02) 0.02(0.11)	54.53142 21.9	0.00(.03) 0.02(0.02)
54.63146 22.3	0.04(.03) 0.14(0.10)	54.63142 22.4	0.24(.03) 0.14(-0.10)	54.63138 22.4	0.24(.03) 0.14(-0.10)
54.73156 22.4	0.18(.02) 0.09(-0.09)	54.73149 22.4	0.11(.03) 0.09(-0.02)	54.73143 23.3	0.04(.03) 0.08(0.04)
54.83155 22.4	0.10(.03) 0.02(-0.08)	54.83150 22.4	0.00(.06) 0.02(0.06)	54.83137 22.3	0.00(.13) 0.02(0.13)
54.93163 22.5	0.12(.03) 0.02(-0.10)	54.93182 22.4	0.00(.17) 0.02(0.16)	54.93144 22.3	0.00(.07) 0.01(0.05)
55.03162 22.4	0.00(.06) 0.02(0.05)	55.03148 22.3	0.04(.02) 0.02(-0.02)	55.03145 22.4	0.07(.04) 0.02(-0.05)
55.13039 22.4	0.14(.02) 0.07(-0.07)	55.13038 22.4	0.09(.03) 0.07(-0.02)	55.13147 22.4	0.00(.04) 0.06(0.07)
55.16245 22.5	0.22(.03) 0.15(-0.07)	55.16331 22.3	0.00(.04) 0.14(0.15)	55.16423 22.0	0.24(.03) 0.13(-0.11)
55.26497 22.5	0.29(.03) 0.23(-0.06)	55.26593 22.4	0.21(.04) 0.21(0.00)	55.26584 22.0	0.34(.05) 0.20(-0.14)
55.36723 22.3	0.06(.02) 0.04(-0.02)	55.36719 22.4	0.17(.04) 0.04(-0.13)	55.36715 22.4	0.03(.03) 0.03(0.00)
55.46868 22.4	0.00(.09) 0.03(0.10)	55.46860 22.4	0.07(.03) 0.02(-0.05)	55.46855 22.6	0.03(.04) 0.02(-0.01)
55.57001 22.4	0.12(.02) 0.03(-0.09)	55.56997 22.4	0.00(.17) 0.03(0.17)	55.56985 22.3	0.07(.02) 0.03(-0.04)

H = 24 km

6.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$	29.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$	52.4°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67145 22.5	0.10(.03) 0.09(-0.01)	55.67163 22.4	0.02(.02) 0.08(0.06)	55.67126 22.3	0.09(.04) 0.07(-0.02)
55.77279 22.4	0.79(.03) 0.80(0.01)	55.77265 22.3	0.93(.03) 0.78(-0.15)	55.77262 22.4	0.64(.03) 0.76(0.12)
55.87289 22.4	0.15(.03) 0.14(-0.01)	55.87280 22.4	0.11(.03) 0.12(0.01)	55.87399 22.4	0.01(.03) 0.11(0.10)
55.89549 22.5	0.12(.03) 0.10(-0.02)	55.89637 22.3	0.01(.03) 0.09(0.08)	55.89730 22.2	0.00(.04) 0.08(0.09)
55.99936 22.5	0.07(.03) 0.06(-0.01)	56.00035 22.4	0.00(.04) 0.05(0.07)	56.00026 22.0	0.07(.04) 0.04(-0.03)
56.10300 22.3	0.18(.03) 0.08(-0.10)	56.10295 22.4	0.12(.03) 0.06(-0.06)	56.10291 22.5	0.00(.03) 0.05(0.05)
56.20580 22.4	0.17(.03) 0.24(0.07)	56.20572 22.4	0.22(.04) 0.20(-0.02)	56.20567 22.5	0.03(.03) 0.16(0.13)
56.30847 22.4	0.59(.02) 0.62(0.03)	56.30843 22.4	0.54(.02) 0.52(-0.02)	56.30830 22.3	0.45(.03) 0.44(-0.01)
56.41127 22.5	0.48(.04) 0.53(0.05)	56.41146 22.4	0.32(.03) 0.46(0.14)	56.41108 22.3	0.45(.05) 0.40(-0.05)
56.51396 22.4	0.14(.03) 0.11(-0.03)	56.51382 22.3	0.13(.02) 0.09(-0.04)	56.51379 22.4	0.03(.03) 0.08(0.05)
56.62853 22.6	0.11(.03) 0.06(-0.05)	56.62942 22.3	0.00(.06) 0.05(0.06)	56.63036 22.2	0.00(.10) 0.04(0.11)
56.73377 22.5	0.02(.03) 0.07(0.05)	56.73477 22.4	0.00(.09) 0.05(0.10)	56.73468 22.0	0.00(.04) 0.05(0.06)
56.83876 22.3	0.15(.03) 0.14(-0.01)	56.83872 22.4	0.00(.03) 0.12(0.12)	56.83868 22.5	0.17(.03) 0.10(-0.07)
56.94291 22.4	0.98(.03) 1.13(0.15)	56.94283 22.4	1.05(.03) 1.00(-0.05)	56.94278 22.5	0.84(.04) 0.89(0.05)
57.04695 22.4	0.36(.03) 0.34(-0.02)	57.04691 22.4	0.20(.02) 0.28(0.08)	57.04678 22.3	0.18(.03) 0.24(0.06)
57.15109 22.5	0.27(.03) 0.10(-0.17)	57.15128 22.4	0.00(.11) 0.08(0.15)	57.15090 22.3	0.11(.03) 0.07(-0.04)
57.25513 22.4	0.00(.09) 0.07(0.12)	57.25499 22.3	0.12(.04) 0.05(-0.07)	57.25496 22.4	0.00(.05) 0.04(0.06)
57.36156 22.5	0.08(.03) 0.08(0.00)	57.35789 22.5	0.17(.03) 0.06(-0.11)	57.36342 21.9	0.00(.09) 0.05(0.10)
57.46818 22.5	0.19(.04) 0.16(-0.03)	57.46920 22.4	0.24(.04) 0.13(-0.11)	57.46911 22.0	0.17(.05) 0.10(-0.07)

H = 24 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57454 22.3	1.05(.04) 1.03(-0.02)	57.57450 22.4	0.87(.03) 0.87(0.00)	57.57446 22.5	0.71(.03) 0.74(0.03)
57.68006 22.4	0.66(.02) 0.53(-0.13)	57.67997 22.4	0.36(.04) 0.43(0.07)	57.67993 22.5	0.48(.05) 0.36(-0.12)
57.78543 22.4	0.29(.04) 0.13(-0.16)	57.78540 22.4	0.19(.04) 0.10(-0.09)	57.78528 22.3	0.15(.03) 0.08(-0.07)
57.89094 22.5	0.18(.03) 0.08(-0.10)	57.89113 22.4	0.03(.04) 0.06(0.03)	57.89074 22.3	0.00(.06) 0.05(0.07)
57.99632 22.4	0.07(.03) 0.08(0.01)	57.99618 22.3	0.19(.03) 0.06(-0.13)	57.99615 22.4	0.00(.04) 0.05(0.05)
58.10051 22.3	0.17(.02) 0.11(-0.06)	58.09555 22.3	0.22(.02) 0.09(-0.13)	58.10118 22.3	0.00(.05) 0.07(0.10)
58.18959 22.4	0.28(.02) 0.24(-0.04)	58.20363 22.4	0.25(.03) 0.22(-0.03)	58.19078 22.3	0.23(.02) 0.15(-0.08)
58.29524 22.3	1.43(.02) 1.57(0.14)	58.31028 22.4	1.70(.03) 1.83(0.13)	58.31024 22.4	1.57(.03) 1.60(0.03)
58.37844 22.3	1.05(.02) 1.18(0.13)	58.37897 22.3	0.84(.02) 0.94(0.10)	58.37888 22.4	0.66(.03) 0.76(0.10)
58.41718 22.4	1.20(.04) 1.23(0.03)	58.41710 22.4	0.99(.04) 0.99(0.00)	58.41705 22.5	0.77(.04) 0.81(0.04)
58.47141 22.3	1.16(.03) 1.15(-0.01)	58.47176 22.3	0.81(.02) 0.93(0.12)	58.47178 22.3	0.73(.02) 0.77(0.04)
58.52391 22.4	0.48(.02) 0.45(-0.03)	58.52387 22.4	0.39(.02) 0.34(-0.05)	58.52374 22.3	0.15(.03) 0.27(0.12)
58.56420 22.3	0.39(.02) 0.26(-0.13)	58.56431 22.3	0.28(.01) 0.20(-0.08)	58.56438 22.3	0.11(.02) 0.15(0.04)
58.63075 22.5	0.18(.02) 0.15(-0.03)	58.63094 22.4	0.10(.02) 0.11(0.01)	58.63055 22.3	0.15(.02) 0.09(-0.06)
58.73748 22.4	0.05(.03) 0.09(0.04)	58.73734 22.3	0.15(.02) 0.07(-0.03)	58.73731 22.4	0.13(.03) 0.06(-0.07)
58.84290 22.4	0.08(.01) 0.09(0.01)	58.84291 22.5	0.07(.01) 0.07(0.00)	58.82957 21.9	0.15(.02) 0.05(-0.10)
58.92383 22.4	0.06(.01) 0.11(0.05)	58.92548 22.4	0.11(.01) 0.08(-0.03)		
59.03082 22.3	0.14(.02) 0.24(0.10)	59.03079 22.4	0.18(.01) 0.19(0.01)	59.04598 22.4	0.27(.02) 0.18(-0.09)
59.11506 22.3	0.96(.01) 0.97(0.01)	59.15419 22.4	1.70(.03) 1.84(0.14)	59.15414 22.5	1.50(.03) 1.59(0.09)

H = 24 km

6.7°C				29.7°C				52.4°C			
f_x [GHz]	P [torr]	$\alpha_x(\delta\alpha)$ dB/km	$\alpha_M(\pm\Delta\alpha)$ dB/km	f_x [GHz]	P [torr]	$\alpha_x(\delta\alpha)$ dB/km	$\alpha_M(\pm\Delta\alpha)$ dB/km	f_x [GHz]	P [torr]	$\alpha_x(\delta\alpha)$ dB/km	$\alpha_M(\pm\Delta\alpha)$ dB/km
59.20921	22.3	1.05(.01)	1.07(0.02)	59.20956	22.3	0.79(.01)	0.85(0.06)	59.20959	22.3	0.66(.01)	0.70(0.04)
59.26235	22.4	0.32(.02)	0.38(0.06)	59.26231	22.4	0.35(.02)	0.30(-0.05)	59.26218	22.3	0.21(.03)	0.23(0.02)
59.30317	22.3	0.32(.02)	0.24(-0.08)	59.30329	22.3	0.13(.01)	0.18(0.05)	59.30336	22.3	0.23(.01)	0.14(-0.09)
59.37054	22.5	0.14(.02)	0.17(0.03)	59.37074	22.4	0.06(.02)	0.13(0.07)	59.37034	22.3	0.11(.02)	0.10(-0.01)
59.39881	22.4	0.17(.01)	0.17(0.00)	59.39866	22.4	0.19(.01)	0.13(-0.06)	59.39917	22.4	0.09(.01)	0.10(0.01)
59.47861	22.4	0.27(.01)	0.29(0.02)	59.47847	22.3	0.11(.02)	0.22(0.11)	59.47844	22.4	0.14(.02)	0.17(0.03)
59.56671	22.3	1.40(.01)	1.48(0.08)	59.56730	22.4	1.20(.01)	1.24(0.04)	59.56742	22.3	0.98(.01)	1.04(0.06)
59.58537	22.4	1.80(.02)	1.93(0.13)	59.58528	22.4	1.63(.02)	1.64(0.01)	59.58656	22.4	1.31(.02)	1.43(0.12)
59.65806	22.4	0.65(.01)	0.63(-0.02)	59.67241	22.4	0.39(.03)	0.37(-0.02)	59.67231	22.6	0.40(.03)	0.29(-0.11)
59.76640	22.3	0.14(.01)	0.16(0.02)	59.76635	22.4	0.15(.01)	0.12(-0.03)	59.76644	22.3	0.10(.01)	0.10(0.00)
59.85169	22.3	0.13(.01)	0.11(-0.02)	59.85225	22.3	0.06(.01)	0.08(0.02)	59.85215	22.4	0.07(.01)	0.06(-0.01)
59.94700	22.3	0.11(.01)	0.10(-0.01)	59.94737	22.3	0.05(.01)	0.07(0.02)	59.94740	22.3	0.10(.01)	0.06(-0.04)
60.04214	22.3	0.12(.01)	0.12(0.00)	60.04226	22.3	0.12(.01)	0.09(-0.03)	60.04234	22.3	0.06(.01)	0.07(0.01)
60.13897	22.3	0.20(.01)	0.20(0.00)	60.13882	22.3	0.16(.01)	0.15(-0.01)	60.13934	22.4	0.11(.01)	0.12(0.01)
60.21976	22.4	0.68(.07)	0.51(-0.17)					60.21959	22.4	0.26(.06)	0.31(0.05)
60.29984	22.4	1.98(.01)	2.11(0.13)	60.30043	22.4	1.69(.01)	1.79(0.10)	60.30056	22.3	1.44(.01)	1.54(0.10)
60.32787	22.3	1.78(.04)	1.87(0.09)	60.32787	22.5	1.42(.05)	1.54(0.12)	60.32907	22.4	1.08(.07)	1.25(0.17)
60.39231	22.4	1.51(.01)	1.52(0.01)	60.39400	22.4	1.27(.01)	1.25(-0.02)	60.39355	22.4	1.02(.01)	1.01(-0.01)
60.50198	22.3	0.68(.01)	0.77(0.09)	60.50196	22.4	0.59(.01)	0.61(0.02)	60.50203	22.3	0.47(.01)	0.48(0.01)

H = 24 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58833 22.3	0.21(.01) 0.23(0.02)	60.58888 22.3	0.15(.01) 0.18(0.03)	60.58880 22.4	0.11(.00) 0.14(0.03)
60.68481 22.3	0.10(.01) 0.12(0.02)	60.68518 22.3	0.12(.01) 0.09(-0.03)	60.68521 22.3	0.09(.01) 0.07(-0.02)
60.78112 22.3	0.10(.01) 0.09(-0.01)	60.78124 22.3	0.09(.00) 0.07(-0.02)	60.78132 22.3	0.06(.00) 0.06(0.00)
60.87914 22.4	0.11(.01) 0.10(-0.01)	60.87900 22.3	0.10(.00) 0.08(-0.02)	60.87952 22.4	0.06(.01) 0.06(0.00)
61.03296 22.3	0.26(.00) 0.29(0.03)	61.03356 22.4	0.21(.01) 0.23(0.02)	61.03368 22.3	0.27(.01) 0.18(-0.09)
61.12655 22.3	1.71(.01) 1.83(0.12)	61.12826 22.4	1.60(.01) 1.62(0.02)	61.12796 22.3	1.32(.01) 1.39(0.07)
61.23756 22.3	0.46(.00) 0.46(0.00)	61.23764 22.3	0.38(.01) 0.36(-0.02)	61.23760 22.3	0.34(.01) 0.29(-0.05)
61.32495 22.3	0.18(.00) 0.16(-0.02)	61.32553 22.3	0.12(.00) 0.12(0.00)	61.32550 22.3	0.13(.01) 0.10(-0.03)
61.42261 22.3	0.12(.01) 0.10(-0.02)	61.42316 22.3	0.13(.01) 0.08(-0.05)	61.42299 22.4	0.09(.01) 0.06(-0.03)
61.52010 22.3	0.10(.01) 0.09(-0.01)	61.52021 22.3	0.08(.01) 0.07(-0.01)	61.52034 22.3	0.06(.00) 0.06(0.00)
61.61932 22.4	0.17(.00) 0.14(-0.03)	61.61927 22.3	0.05(.01) 0.11(0.06)	61.61970 22.4	0.06(.01) 0.09(0.03)
61.76605 22.3	1.28(.01) 1.32(0.04)	61.76698 22.5	1.18(.01) 1.15(-0.03)	61.76678 22.3	1.06(.01) 0.98(-0.08)
61.86080 22.3	0.68(.01) 0.70(0.02)	61.86252 22.4	0.57(.01) 0.55(-0.02)	61.86223 22.3	0.45(.01) 0.46(0.01)
61.97331 22.4	0.13(.01) 0.15(0.02)	61.97321 22.3	0.11(.01) 0.12(0.01)	61.97318 22.3	0.10(.01) 0.10(0.00)
62.06153 22.3	0.13(.01) 0.10(-0.03)	62.06216 22.4	0.12(.01) 0.08(-0.04)	62.06213 22.3	0.07(.01) 0.07(0.00)
62.16051 22.4	0.12(.01) 0.11(-0.01)	62.16097 22.4	0.10(.00) 0.09(-0.01)	62.16080 22.3	0.11(.01) 0.07(-0.04)
62.25908 22.3	0.22(.01) 0.20(-0.02)	62.25919 22.4	0.15(.01) 0.16(0.01)	62.25932 22.3	0.12(.00) 0.13(0.01)
62.35966 22.3	0.89(.01) 0.87(-0.02)	62.35944 22.3	0.75(.01) 0.72(-0.03)	62.35987 22.4	0.60(.01) 0.61(0.01)
62.49918 22.3	1.47(.00) 1.59(0.12)	62.50012 22.5	1.26(.01) 1.31(0.05)	62.49991 22.3	1.20(.00) 1.11(-0.09)

H = 24 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59504 22.3	0.33(.00) 0.31(-0.02)	62.59679 22.4	0.26(.00) 0.23(-0.03)	62.59650 22.3	0.16(.01) 0.19(0.03)
62.70889 22.4	0.13(.00) 0.12(-0.01)	62.70880 22.3	0.08(.00) 0.10(0.02)	62.70876 22.3	0.10(.01) 0.08(-0.02)
62.79815 22.3	0.08(.01) 0.11(0.03)	62.79879 22.4	0.07(.00) 0.09(0.02)	62.79877 22.3	0.04(.01) 0.07(0.03)
62.89832 22.4	0.23(.00) 0.22(-0.01)	62.89879 22.4	0.21(.01) 0.19(-0.02)	62.89861 22.3	0.13(.01) 0.16(0.03)
62.99806 22.4	1.49(.00) 1.59(0.10)	62.99817 22.4	1.39(.01) 1.53(0.14)	62.99831 22.3	1.31(.01) 1.46(0.15)
63.09984 22.3	0.20(.01) 0.19(-0.01)	63.09962 22.3	0.20(.01) 0.17(-0.03)	63.10006 22.4	0.17(.01) 0.14(-0.03)
63.23229 22.3	0.07(.00) 0.06(-0.01)	63.23325 22.5	0.06(.01) 0.05(-0.01)	63.23304 22.3	0.06(.00) 0.04(-0.02)
63.32927 22.3	0.07(.00) 0.05(-0.02)	63.33105 22.4	0.07(.01) 0.05(-0.02)	63.33075 22.3	0.07(.01) 0.04(-0.03)
63.44447 22.4	0.12(.00) 0.11(-0.01)	63.44437 22.3	0.07(.01) 0.09(0.02)	63.44434 22.2	0.08(.00) 0.08(0.00)
63.53478 22.3	0.63(.01) 0.60(-0.03)	63.53543 22.5	0.61(.01) 0.57(-0.04)	63.53541 22.3	0.52(.01) 0.53(0.01)
63.63613 22.4	0.29(.00) 0.25(-0.04)	63.63660 22.4	0.23(.01) 0.22(-0.01)	63.63643 22.3	0.22(.01) 0.20(-0.02)
63.73703 22.3	0.05(.00) 0.06(0.01)	63.73715 22.3	0.07(.00) 0.05(-0.02)	63.73730 22.3	0.04(.01) 0.05(0.01)
63.84002 22.3	0.04(.00) 0.04(0.00)	63.83979 22.3	0.03(.00) 0.03(0.00)	63.84024 22.4	0.00(.02) 0.03(0.04)
63.96540 22.3	0.03(.01) 0.05(0.02)	63.96637 22.5	0.01(.01) 0.04(0.03)	63.96616 22.3	0.13(.01) 0.04(-0.09)
64.06351 22.3	0.15(.01) 0.18(0.03)	64.06531 22.4	0.17(.01) 0.18(0.01)	64.06502 22.3	0.19(.01) 0.16(-0.03)
64.18004 22.4	0.18(.01) 0.24(0.06)	64.17995 22.3	0.23(.01) 0.22(-0.01)	64.17981 22.3	0.12(.01) 0.21(0.09)
64.27141 22.3	0.00(.01) 0.05(0.05)	64.27207 22.4	0.03(.01) 0.04(0.01)	64.27200 22.6	0.01(.01) 0.04(0.03)
64.37395 22.3	0.04(.01) 0.03(-0.01)	64.37434 22.4	0.05(.01) 0.02(-0.03)	64.37416 22.3	0.04(.01) 0.02(-0.02)
64.47572 22.3	0.05(.01) 0.03(-0.02)	64.47599 22.3	0.01(.01) 0.02(0.01)	64.47627 22.3	0.03(.01) 0.02(-0.01)

H = 24 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.58018 22.3	0.09(.01) 0.06(-0.03)	64.57994 22.3	0.07(.00) 0.06(-0.01)	64.58041 22.4	0.05(.01) 0.05(0.00)
64.69852 22.3	0.42(.01) 0.37(-0.05)	64.69949 22.3	0.27(.01) 0.37(0.10)	64.69925 22.3	0.39(.01) 0.38(-0.01)
64.79721 22.3	0.07(.01) 0.04(-0.03)	64.79920 22.4	0.00(.00) 0.04(0.04)	64.79926 22.3	0.06(.01) 0.04(-0.02)
64.91563 22.3	0.11(.01) 0.02(-0.09)	64.91550 22.4	0.00(.03) 0.02(0.05)	64.91538 22.3	0.01(.01) 0.01(0.00)
65.00799 22.4	0.04(.01) 0.01(-0.03)	65.00859 22.4	0.01(.01) 0.01(0.00)	65.00863 22.6	0.04(.01) 0.01(-0.03)
65.11175 22.3	0.07(.00) 0.03(-0.04)	65.11216 22.4	0.06(.00) 0.03(-0.03)	65.11197 22.3	0.01(.01) 0.03(0.02)
65.21468 22.3	0.28(.01) 0.26(-0.02)	65.21497 22.3	0.31(.00) 0.30(-0.01)	65.21525 22.3	0.29(.01) 0.33(0.04)
65.32035 22.3	0.05(.01) 0.03(-0.02)	65.32011 22.3	0.01(.00) 0.03(0.02)	65.32050 22.3	0.06(.01) 0.03(-0.03)
65.43164 22.4	0.03(.01) 0.01(-0.02)	65.43260 22.3	0.00(.05) 0.01(0.05)	65.43237 22.3	0.02(.01) 0.01(-0.01)
65.53144 22.3	0.00(.03) 0.01(0.03)	65.53345 22.4	0.01(.01) 0.01(0.00)	65.53352 22.3	0.03(.01) 0.01(-0.02)
65.65121 22.3	0.12(.01) 0.02(-0.10)	65.65108 22.4	0.04(.01) 0.02(-0.02)	65.65096 22.4	0.02(.01) 0.02(0.00)
65.74461 22.4	0.11(.00) 0.11(0.00)	65.74523 22.4	0.12(.01) 0.13(0.01)	65.74527 22.6	0.13(.01) 0.15(0.02)
65.84956 22.3	0.01(.01) 0.02(0.01)	65.84997 22.4	0.01(.01) 0.02(0.01)	65.84978 22.4	0.03(.01) 0.02(-0.01)
65.95366 22.3	0.04(.00) 0.01(-0.03)	65.95396 22.3	0.01(.00) 0.01(0.00)	65.95424 22.3	0.06(.01) 0.01(-0.05)
66.06053 22.3	0.00(.04) 0.00(0.03)	66.06030 22.3	0.00(.04) 0.00(0.03)	66.06068 22.3	0.00(.01) 0.00(0.00)
66.16476 22.4	0.00(.04) 0.01(0.04)	66.16574 22.3	0.00(.03) 0.01(0.03)	66.16550 22.3	0.00(.02) 0.01(0.02)
66.26568 22.3	0.05(.01) 0.04(-0.01)	66.26772 22.4	0.06(.01) 0.04(-0.02)	66.26778 22.3	0.00(.00) 0.05(0.05)

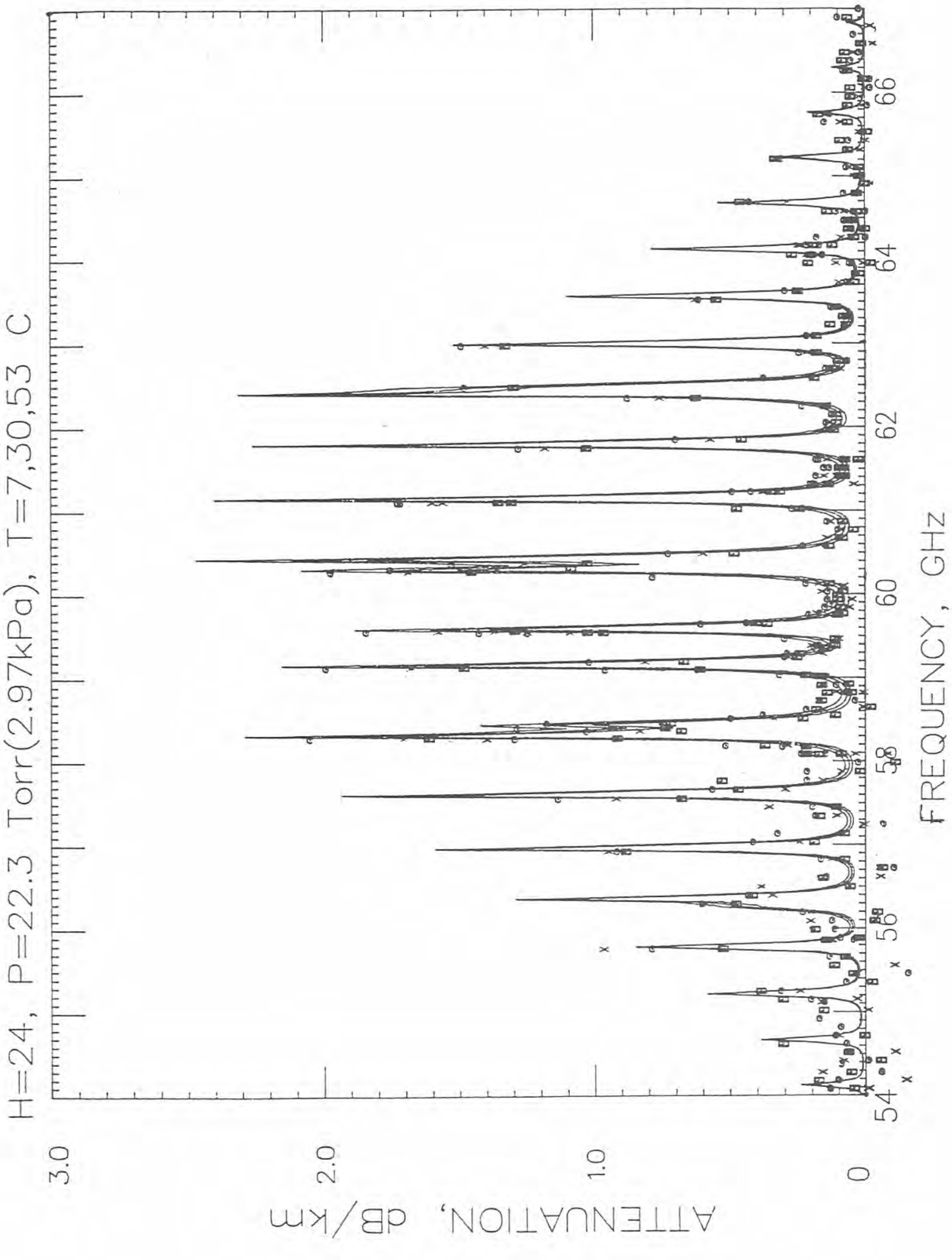

Figure A-3a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 24 km (see **C.**) for frequencies between 54 and 66 GHz.

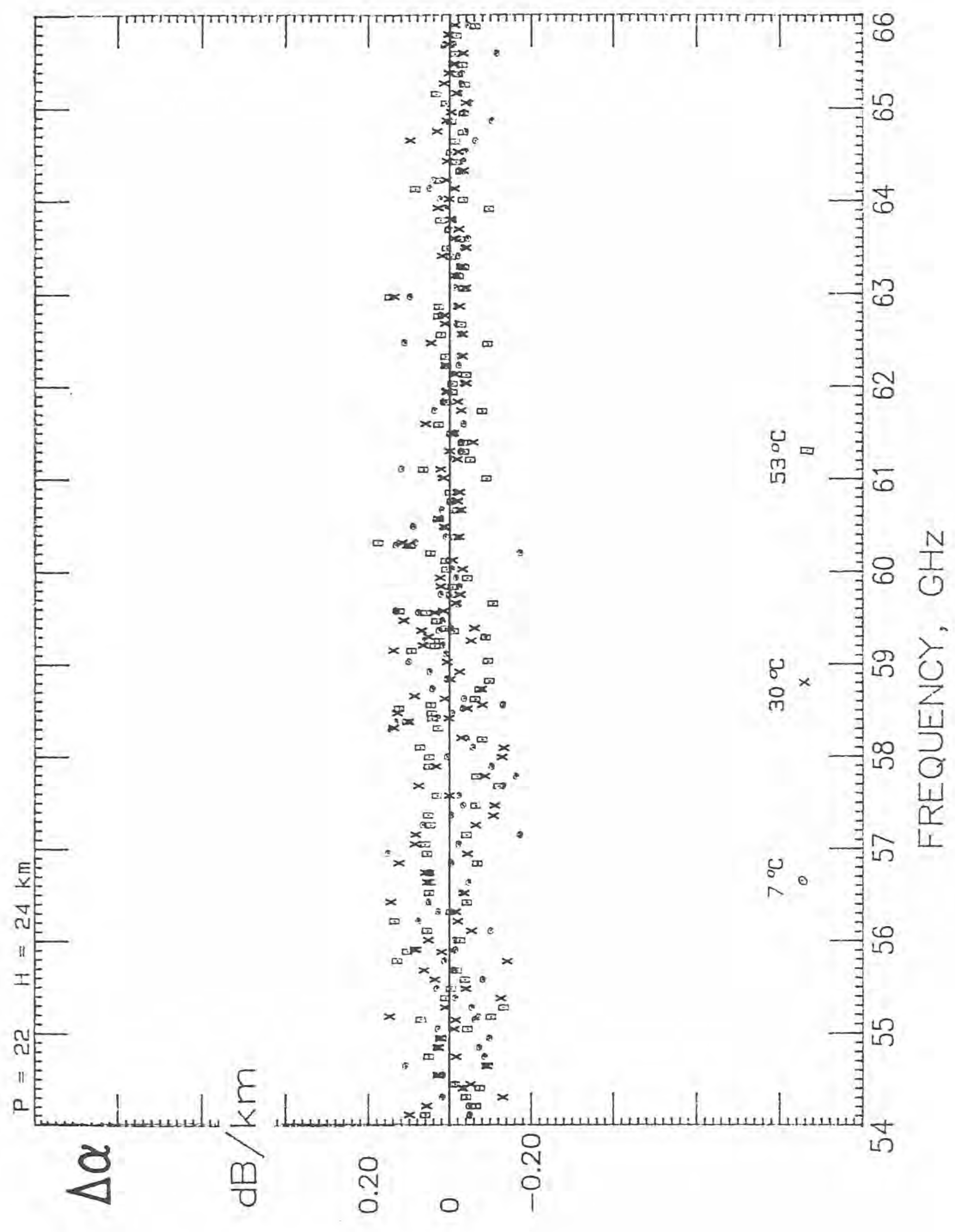

Figure A-3b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **C**.

D.

H = 21 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**35.60(06)**	**35.60(09)** 4.751	**35.70(27)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.062	0.065	0.064

H = 21 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89544 35.6	0.01(.03) 0.02(0.01)	53.89541 35.5	0.00(.07) 0.02(0.06)	53.89539 35.5	0.12(.03) 0.02(-0.10)
53.99419 35.6	0.14(.02) 0.03(-0.11)	53.99413 35.6	0.02(.02) 0.03(0.01)	53.99409 35.5	0.00(.02) 0.03(0.03)
54.09281 35.7	0.21(.02) 0.13(-0.08)	54.09279 35.6	0.03(.03) 0.14(0.11)	54.09268 35.6	0.06(.03) 0.15(0.09)
54.19156 35.5	0.18(.02) 0.09(-0.09)	54.19174 35.6	0.05(.02) 0.10(0.05)	54.19140 35.6	0.07(.03) 0.10(0.03)
54.29019 35.5	0.00(.03) 0.03(0.04)	54.29007 35.6	0.00(.06) 0.03(0.07)	54.29005 35.6	0.06(.04) 0.03(-0.03)
54.38762 35.6	0.09(.02) 0.03(-0.06)	54.38764 35.6	0.12(.03) 0.02(-0.10)	54.38873 35.6	0.00(.05) 0.02(0.04)
54.42915 35.5	0.13(.03) 0.03(-0.10)	54.43001 35.7	0.01(.02) 0.03(0.02)	54.43093 35.4	0.05(.04) 0.03(-0.02)
54.53028 35.6	0.10(.02) 0.05(-0.05)	54.53127 35.6	0.05(.02) 0.05(0.00)	54.53119 35.7	0.10(.03) 0.05(-0.05)
54.63120 35.6	0.24(.03) 0.22(-0.02)	54.63118 35.5	0.29(.03) 0.23(-0.06)	54.63115 35.6	0.32(.03) 0.23(-0.09)
54.73130 35.6	0.18(.03) 0.17(-0.01)	54.73124 35.6	0.24(.03) 0.17(-0.07)	54.73121 35.7	0.20(.03) 0.17(-0.03)
54.83128 35.7	0.17(.03) 0.06(-0.11)	54.83126 35.6	0.03(.03) 0.05(0.02)	54.83115 35.6	0.00(.05) 0.05(0.07)
54.93137 35.6	0.12(.03) 0.04(-0.08)	54.93156 35.6	0.01(.03) 0.04(0.03)	54.93121 35.6	0.03(.03) 0.04(0.01)
55.03135 35.5	0.09(.03) 0.06(-0.03)	55.03124 35.6	0.10(.02) 0.05(-0.05)	55.03122 35.6	0.15(.04) 0.05(-0.10)
55.13011 35.6	0.26(.03) 0.16(-0.10)	55.13014 35.6	0.16(.03) 0.15(-0.01)	55.13125 35.5	0.05(.04) 0.14(0.09)
55.16218 35.6	0.27(.03) 0.27(0.00)	55.16306 35.7	0.30(.03) 0.26(-0.04)	55.16399 35.4	0.33(.03) 0.26(-0.07)
55.26469 35.6	0.43(.03) 0.38(-0.05)	55.26569 35.6	0.27(.03) 0.37(0.10)	55.26561 35.7	0.47(.03) 0.35(-0.12)
55.36697 35.6	0.20(.03) 0.10(-0.10)	55.36694 35.5	0.18(.04) 0.09(-0.09)	55.36691 35.5	0.08(.03) 0.08(0.00)
55.46842 35.6	-0.08(.03) 0.07(0.15)	55.46836 35.6	0.12(.03) 0.06(-0.06)	55.46832 36.5	0.15(.03) 0.05(-0.10)
55.56974 35.7	0.06(.02) 0.09(0.03)	55.56972 35.6	0.02(.03) 0.07(0.05)	55.56961 35.6	0.07(.02) 0.07(0.00)

H = 21 km

6.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	29.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	52.4°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67119 35.6	0.25(.03) 0.20(-0.05)	55.67138 35.6	0.10(.02) 0.17(0.07)	55.67102 35.6	0.27(.03) 0.16(-0.11)
55.77253 35.5	0.77(.03) 0.87(0.10)	55.77240 35.6	0.76(.03) 0.85(0.09)	55.77238 35.6	0.66(.04) 0.83(0.17)
55.87262 35.6	0.33(.03) 0.30(-0.03)	55.87255 35.6	0.33(.03) 0.27(-0.06)	55.87376 35.6	0.18(.03) 0.24(0.06)
55.89522 35.5	0.24(.03) 0.23(-0.01)	55.89611 35.7	0.09(.02) 0.20(0.11)	55.89705 35.6	0.18(.03) 0.18(0.00)
55.99909 35.6	0.00(.02) 0.14(0.14)	56.00010 35.6	0.08(.03) 0.11(0.03)	56.00001 35.8	0.16(.04) 0.10(-0.06)
56.10272 35.6	0.23(.03) 0.18(-0.05)	56.10270 35.5	0.31(.03) 0.15(-0.16)	56.10268 35.5	0.06(.04) 0.12(0.06)
56.20553 35.6	0.43(.02) 0.43(0.00)	56.20546 35.6	0.45(.04) 0.36(-0.09)	56.20543 35.5	0.21(.03) 0.30(0.09)
56.30820 35.7	1.02(.02) 0.98(-0.04)	56.30818 35.6	0.97(.02) 0.85(-0.12)	56.30807 35.6	0.74(.03) 0.75(0.01)
56.41100 35.6	0.87(.03) 0.90(0.03)	56.41120 35.6	0.63(.03) 0.80(0.17)	56.41085 35.6	0.75(.04) 0.72(-0.03)
56.51369 35.6	0.34(.03) 0.26(-0.08)	56.51357 35.6	0.35(.03) 0.22(-0.13)	56.51355 35.6	0.12(.04) 0.18(0.06)
56.62825 35.5	0.18(.03) 0.15(-0.03)	56.62916 35.8	0.06(.03) 0.12(0.06)	56.63012 35.6	0.15(.03) 0.10(-0.05)
56.73349 35.6	0.10(.03) 0.16(0.06)	56.73452 35.6	0.06(.03) 0.13(0.07)	56.73442 36.3	0.03(.03) 0.11(0.08)
56.83849 35.6	0.26(.03) 0.33(0.07)	56.83846 35.5	0.27(.03) 0.27(0.00)	56.83844 35.5	0.11(.03) 0.23(0.12)
56.94264 35.6	1.26(.04) 1.42(0.16)	56.94258 35.6	1.23(.04) 1.29(0.06)	56.94255 36.5	1.01(.05) 1.17(0.16)
57.04667 35.7	0.64(.03) 0.68(0.04)	57.04665 35.6	0.52(.04) 0.58(0.06)	57.04654 35.6	0.37(.03) 0.50(0.13)
57.15083 35.6	0.20(.04) 0.23(0.03)	57.15102 35.6	-0.07(.04) 0.19(0.26)	57.15066 35.6	0.31(.04) 0.16(-0.15)
57.25486 35.6	0.08(.04) 0.16(0.08)	57.25473 35.6	0.10(.04) 0.13(0.03)	57.25471 35.6	0.02(.04) 0.11(0.09)
57.36129 35.5	0.25(.03) 0.18(-0.07)	57.35764 35.6	0.14(.03) 0.15(0.01)	57.36318 35.4	0.12(.04) 0.12(0.00)
57.46790 35.6	0.48(.04) 0.36(-0.12)	57.46894 35.6	0.29(.04) 0.30(0.01)	57.46885 35.7	0.23(.04) 0.24(0.01)

H = 21 km

6.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	29.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	52.4°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57426 35.6	1.46(.03) 1.48(0.02)	57.57424 35.5	1.45(.03) 1.29(-0.16)	57.57422 35.5	1.19(.05) 1.13(-0.06)
57.67979 35.6	0.96(.03) 0.99(0.03)	57.67972 35.6	0.72(.04) 0.83(0.11)	57.67969 36.3	0.82(.05) 0.71(-0.11)
57.78516 35.7	0.45(.04) 0.30(-0.15)	57.78514 35.6	0.10(.05) 0.24(0.14)	57.78503 35.6	0.12(.04) 0.20(0.08)
57.89067 35.5	0.35(.03) 0.19(-0.16)	57.89087 35.6	0.26(.04) 0.15(-0.11)	57.89051 35.6	0.24(.05) 0.12(-0.12)
57.99604 35.6	0.14(.03) 0.19(0.05)	57.99592 35.6	0.19(.03) 0.15(-0.04)	57.99591 35.6	0.25(.04) 0.12(-0.13)
58.10019 35.6	0.26(.02) 0.27(0.01)	58.09528 35.9	0.25(.03) 0.21(-0.04)	58.10092 35.5	0.16(.03) 0.17(0.01)
58.18927 35.6	0.57(.02) 0.54(-0.03)	58.20337 35.6	0.35(.03) 0.50(0.15)	58.19051 35.6	0.42(.02) 0.35(-0.07)
58.29492 35.8	2.02(.03) 2.09(0.07)	58.31002 35.5	2.02(.04) 2.10(0.08)	58.30999 35.5	1.80(.03) 1.83(0.03)
58.37813 35.5	1.90(.02) 1.99(0.09)	58.37869 35.5	1.58(.02) 1.63(0.05)	58.37863 35.5	1.31(.02) 1.36(0.05)
58.41691 35.5	1.77(.03) 1.81(0.04)	58.41684 35.6	1.47(.03) 1.49(0.02)	58.41681 36.5	1.26(.04) 1.24(-0.02)
58.47109 35.6	1.58(.03) 1.54(-0.04)	58.47147 35.5	1.22(.02) 1.27(0.05)	58.47152 35.5	1.04(.02) 1.06(0.02)
58.52363 35.7	0.91(.02) 0.88(-0.03)	58.52361 35.6	0.58(.02) 0.69(0.11)	58.52350 35.6	0.59(.03) 0.56(-0.03)
58.56388 35.5	0.61(.02) 0.58(-0.03)	58.56402 35.5	0.44(.02) 0.45(0.01)	58.56412 35.8	0.37(.02) 0.36(-0.01)
58.63048 35.5	0.34(.02) 0.35(0.01)	58.63068 35.6	0.24(.02) 0.27(0.03)	58.63031 35.6	0.30(.02) 0.21(-0.09)
58.73720 35.6	0.18(.02) 0.23(0.05)	58.73708 35.6	0.21(.03) 0.18(-0.03)	58.73706 35.6	0.00(.03) 0.14(0.14)
58.84261 35.6	0.29(.01) 0.22(-0.07)	58.84264 35.6	0.18(.02) 0.17(-0.01)	58.82931 35.4	0.24(.02) 0.13(-0.11)
58.92351 35.6	0.21(.01) 0.27(0.06)	58.92519 35.5	0.29(.01) 0.21(-0.08)		
59.03049 35.8	0.47(.01) 0.54(0.07)	59.03050 35.6	0.41(.01) 0.42(0.01)	59.04574 35.5	0.48(.02) 0.40(-0.08)
59.11475 35.5	1.47(.01) 1.52(0.05)	59.15393 35.6	1.80(.04) 1.95(0.15)	59.15390 36.3	1.57(.03) 1.70(0.13)

H = 21 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20889	1.63(.01)	59.20928	1.32(.01)	59.20933	1.08(.01)
35.6	1.63(0.00)	35.5	1.34(0.02)	35.5	1.13(0.05)
59.26206	0.81(.02)	59.26204	0.62(.03)	59.26193	0.66(.03)
35.7	0.81(0.00)	35.6	0.64(0.02)	35.6	0.52(-0.14)
59.30286	0.62(.01)	59.30299	0.42(.01)	59.30309	0.37(.01)
35.5	0.54(-0.08)	35.5	0.42(0.00)	35.8	0.34(-0.03)
59.37026	0.47(.02)	59.37046	0.31(.02)	59.37010	0.17(.02)
35.5	0.40(-0.07)	35.6	0.31(0.00)	35.6	0.24(0.07)
59.39849	0.42(.01)	59.39837	0.32(.01)	59.39891	0.24(.01)
35.5	0.40(-0.02)	35.5	0.31(-0.01)	35.5	0.24(0.00)
59.47833	0.62(.02)	59.47820	0.41(.02)	59.47819	0.37(.02)
35.6	0.63(0.01)	35.6	0.49(0.08)	35.6	0.39(0.02)
59.56639	1.72(.01)	59.56701	1.46(.01)	59.56715	1.30(.01)
35.6	1.79(0.07)	35.6	1.51(0.05)	35.5	1.28(-0.02)
59.58508	1.95(.02)	59.58501	1.57(.02)	59.58632	1.33(.03)
35.6	2.02(0.07)	35.6	1.72(0.15)	35.6	1.48(0.15)
59.65774	1.10(.01)	59.67215	0.73(.02)	59.67205	0.56(.04)
35.6	1.14(0.04)	35.6	0.75(0.02)	35.8	0.60(0.04)
59.76607	0.42(.01)	59.76607	0.32(.01)	59.76617	0.25(.01)
35.8	0.39(-0.03)	35.6	0.30(-0.02)	35.5	0.23(-0.02)
59.85137	0.28(.01)	59.85195	0.20(.01)	59.85189	0.10(.01)
35.5	0.27(-0.01)	35.5	0.20(0.00)	35.5	0.16(0.06)
59.94667	0.26(.01)	59.94708	0.13(.01)	59.94713	0.15(.01)
35.6	0.24(-0.02)	35.5	0.18(0.05)	35.5	0.14(-0.01)
60.04182	0.27(.01)	60.04197	0.18(.01)	60.04207	0.16(.01)
35.5	0.29(0.02)	35.5	0.22(0.04)	35.8	0.17(0.01)
60.13865	0.46(.01)	60.13854	0.36(.01)	60.13908	0.29(.01)
35.5	0.48(0.02)	35.5	0.37(0.01)	35.5	0.29(0.00)
60.21947	0.96(.05)			60.21934	0.62(.07)
35.6	1.03(0.07)			35.6	0.65(0.03)
60.29951	2.30(.01)	60.30014	1.96(.01)	60.30029	1.65(.01)
35.6	2.41(0.11)	35.6	2.03(0.07)	35.5	1.73(0.08)
60.32757	2.32(.05)	60.32761	1.91(.06)	60.32883	1.62(.08)
35.6	2.44(0.12)	35.6	2.02(0.11)	35.6	1.69(0.07)
60.39198	2.34(.01)	60.39371	1.97(.01)	60.39329	1.64(.01)
35.6	2.42(0.08)	35.5	2.00(0.03)	35.6	1.66(0.02)
60.50165	1.35(.01)	60.50167	1.12(.01)	60.50177	0.91(.01)
35.8	1.45(0.10)	35.6	1.17(0.05)	35.5	0.95(0.04)

H = 21 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58801	0.56(.00)	60.58860	0.41(.00)	60.58854	0.30(.00)
35.5	0.55(-0.01)	35.5	0.43(0.02)	35.5	0.34(0.04)
60.68448	0.28(.01)	60.68489	0.28(.01)	60.68494	0.16(.00)
35.6	0.30(0.02)	35.5	0.23(-0.05)	35.5	0.18(0.02)
60.78080	0.28(.01)	60.78094	0.18(.00)	60.78105	0.17(.00)
35.5	0.23(-0.05)	35.5	0.18(0.00)	35.8	0.14(-0.03)
60.87882	0.24(.01)	60.87870	0.23(.00)	60.87925	0.15(.01)
35.4	0.25(0.01)	35.5	0.19(-0.04)	35.5	0.15(0.00)
61.03263	0.61(.00)	61.03326	0.50(.01)	61.03341	0.47(.01)
35.6	0.64(0.03)	35.6	0.51(0.01)	35.5	0.42(-0.05)
61.12622	2.04(.01)	61.12796	1.85(.01)	61.12770	1.65(.01)
35.5	2.23(0.19)	35.5	1.97(0.12)	35.5	1.72(0.07)
61.23722	0.94(.01)	61.23734	0.72(.01)	61.23733	0.67(.01)
35.8	0.94(0.00)	35.6	0.76(0.04)	35.6	0.63(-0.04)
61.32457	0.39(.01)	61.32523	0.28(.00)	61.32522	0.27(.01)
35.5	0.38(-0.01)	35.5	0.30(0.02)	35.5	0.24(-0.03)
61.42228	0.27(.01)	61.42286	0.22(.01)	61.42271	0.18(.01)
35.6	0.24(-0.03)	35.5	0.19(-0.03)	35.5	0.15(-0.03)
61.51977	0.23(.01)	61.51991	0.20(.01)	61.52007	0.14(.01)
35.5	0.23(0.00)	35.4	0.18(-0.02)	35.5	0.15(0.01)
61.61916	0.34(.01)	61.61897	0.18(.01)	61.61942	0.21(.01)
35.5	0.34(0.00)	35.5	0.27(0.09)	35.8	0.22(0.01)
61.76572	1.78(.01)	61.76669	1.58(.01)	61.76651	1.43(.01)
35.5	1.84(0.06)	35.5	1.63(0.05)	35.5	1.43(0.00)
61.86045	1.19(.01)	61.86223	1.07(.01)	61.86196	0.86(.01)
35.5	1.27(0.08)	35.5	1.04(-0.03)	35.5	0.89(0.03)
61.97298	0.31(.01)	61.97291	0.32(.00)	61.97291	0.25(.01)
35.5	0.36(0.05)	35.6	0.29(-0.03)	35.6	0.24(-0.01)
62.06120	0.27(.01)	62.06186	0.26(.01)	62.06186	0.20(.00)
35.6	0.26(-0.01)	35.6	0.21(-0.05)	35.5	0.17(-0.03)
62.16018	0.30(.01)	62.16068	0.23(.00)	62.16052	0.21(.01)
35.6	0.28(-0.02)	35.4	0.22(-0.01)	35.5	0.18(-0.03)
62.25874	0.49(.00)	62.25889	0.40(.01)	62.25904	0.32(.01)
35.4	0.48(-0.01)	35.4	0.39(-0.01)	35.6	0.32(0.00)
62.35933	1.54(.01)	62.35914	1.31(.01)	62.35959	1.12(.01)
35.5	1.54(0.00)	35.4	1.31(0.00)	35.8	1.13(0.01)
62.49884	1.85(.00)	62.49983	1.59(.00)	62.49964	1.49(.01)
35.5	1.99(0.14)	35.5	1.67(0.08)	35.5	1.43(-0.06)

H = 21 km

6.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km
62.59470 35.5	0.68(.00) 0.67(-0.01)	62.59649 35.5	0.53(.01) 0.42(0.05)	62.59622 35.5	0.37(.01) 0.52(-0.01)
62.70855 35.6	0.30(.00) 0.29(-0.01)	62.70850 35.6	0.23(.00) 0.23(0.00)	62.70848 35.6	0.23(.01) 0.19(-0.04)
62.79782 35.6	0.23(.01) 0.26(0.03)	62.79849 35.6	0.21(.00) 0.22(0.01)	62.79849 35.5	0.18(.01) 0.18(0.00)
62.89798 35.6	0.51(.01) 0.49(-0.02)	62.89848 35.5	0.44(.01) 0.42(-0.02)	62.89833 35.5	0.34(.01) 0.36(0.02)
62.99772 35.5	1.54(.01) 1.64(0.10)	62.99787 35.4	1.44(.01) 1.56(0.12)	62.99803 35.6	1.40(.01) 1.49(0.09)
63.09951 35.5	0.42(.01) 0.43(0.01)	63.09932 35.5	0.41(.01) 0.37(-0.04)	63.09977 35.8	0.36(.01) 0.32(-0.04)
63.23195 35.5	0.17(.01) 0.15(-0.02)	63.23294 35.5	0.15(.00) 0.13(-0.02)	63.23276 35.5	0.15(.01) 0.11(-0.04)
63.32892 35.5	0.15(.01) 0.13(-0.02)	63.33074 35.5	0.14(.01) 0.12(-0.02)	63.33047 35.5	0.14(.01) 0.10(-0.04)
63.44413 35.5	0.25(.00) 0.25(0.00)	63.44406 35.6	0.22(.00) 0.22(0.00)	63.44407 35.6	0.20(.01) 0.19(-0.01)
63.53444 35.6	0.89(.01) 0.87(-0.02)	63.53513 35.6	0.82(.01) 0.84(0.02)	63.53513 35.5	0.76(.01) 0.80(0.04)
63.63579 35.6	0.48(.01) 0.50(0.02)	63.63630 35.5	0.46(.01) 0.45(-0.01)	63.63615 35.5	0.39(.01) 0.41(0.02)
63.73670 35.5	0.17(.01) 0.15(-0.02)	63.73684 35.5	0.14(.00) 0.13(-0.01)	63.73701 35.5	0.14(.01) 0.11(-0.03)
63.83968 35.5	0.09(.00) 0.09(0.00)	63.83949 35.5	0.08(.01) 0.08(0.00)	63.83995 35.8	0.06(.01) 0.07(0.01)
63.96506 35.5	0.08(.01) 0.12(0.04)	63.96606 35.5	0.09(.01) 0.11(0.02)	63.96588 35.5	0.24(.01) 0.10(-0.14)
64.06316 35.5	0.30(.01) 0.35(0.05)	64.06501 35.5	0.35(.01) 0.34(-0.01)	64.06474 35.5	0.35(.01) 0.33(-0.02)
64.17970 35.6	0.40(.01) 0.42(0.02)	64.17965 35.6	0.40(.01) 0.41(0.01)	64.17953 35.5	0.37(.01) 0.40(0.03)
64.27107 35.6	0.07(.01) 0.12(0.05)	64.27176 35.6	0.14(.01) 0.11(-0.03)	64.27172 35.5	0.10(.01) 0.10(0.00)
64.37359 35.5	0.09(.00) 0.06(-0.03)	64.37405 35.6	0.11(.01) 0.06(-0.05)	64.37387 35.8	0.08(.01) 0.05(-0.03)
64.47536 35.5	0.10(.01) 0.06(-0.04)	64.47568 35.5	0.10(.01) 0.06(-0.04)	64.47597 35.8	0.04(.01) 0.05(0.01)

H = 21 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.57983 35.6	0.12(.01) 0.13(0.01)	64.57963 35.5	0.15(.01) 0.13(-0.02)	64.58012 35.8	0.10(.01) 0.12(0.02)
64.69818 35.5	0.46(.01) 0.44(-0.02)	64.69917 35.5	0.37(.01) 0.47(0.10)	64.69897 35.5	0.46(.01) 0.49(0.03)
64.79686 35.8	0.12(.01) 0.09(-0.03)	64.79888 35.8	0.06(.01) 0.09(0.03)	64.79897 35.5	0.06(.01) 0.08(0.02)
64.91528 35.5	0.12(.01) 0.04(-0.08)	64.91518 35.9	0.03(.00) 0.04(0.01)	64.91509 35.5	0.01(.01) 0.04(0.03)
65.00764 35.5	0.03(.01) 0.04(0.01)	65.00828 35.5	0.04(.01) 0.03(-0.01)	65.00835 35.5	0.07(.01) 0.03(-0.04)
65.11139 35.5	0.09(.00) 0.07(-0.02)	65.11185 35.5	0.09(.00) 0.07(-0.02)	65.11168 35.8	0.05(.01) 0.06(0.01)
65.21433 35.5	0.30(.01) 0.29(-0.01)	65.21465 35.5	0.32(.00) 0.32(0.00)	65.21494 35.8	0.33(.01) 0.36(0.03)
65.32000 35.6	0.08(.01) 0.07(-0.01)	65.31980 35.5	0.09(.01) 0.07(-0.02)	65.32022 35.5	0.09(.01) 0.07(-0.02)
65.43129 35.5	0.01(.01) 0.03(0.02)	65.43229 35.5	0.01(.01) 0.03(0.02)	65.43208 35.5	0.05(.01) 0.02(-0.03)
65.53109 35.8	0.00(.02) 0.02(0.03)	65.53313 35.8	0.02(.01) 0.02(0.00)	65.53323 35.5	0.03(.01) 0.02(-0.01)
65.65085 35.6	0.12(.01) 0.04(-0.08)	65.65076 35.9	0.07(.01) 0.04(-0.03)	65.65067 35.5	0.03(.01) 0.04(0.01)
65.74426 35.5	0.10(.00) 0.14(0.04)	65.74492 35.5	0.17(.01) 0.17(0.00)	65.74500 35.5	0.18(.01) 0.19(0.01)
65.84919 35.5	0.04(.01) 0.05(0.01)	65.84966 35.6	0.01(.01) 0.05(0.04)	65.84949 35.8	0.06(.01) 0.05(-0.01)
65.95330 35.5	0.01(.01) 0.02(0.01)	65.95363 35.5	-0.01(.00) 0.02(0.03)	65.95393 35.8	0.02(.01) 0.02(0.00)
66.06017 35.6	0.01(.01) 0.01(0.00)	66.05997 35.5	0.01(.01) 0.01(0.00)	66.06040 35.5	0.03(.01) 0.01(-0.02)
66.16440 35.5	0.01(.01) 0.02(0.01)	66.16541 35.5	0.04(.01) 0.02(-0.02)	66.16521 35.5	0.03(.01) 0.02(-0.01)
66.26532 35.8	0.08(.01) 0.06(-0.02)	66.26740 35.8	0.03(.01) 0.07(0.04)	66.26749 35.5	0.01(.00) 0.08(0.07)

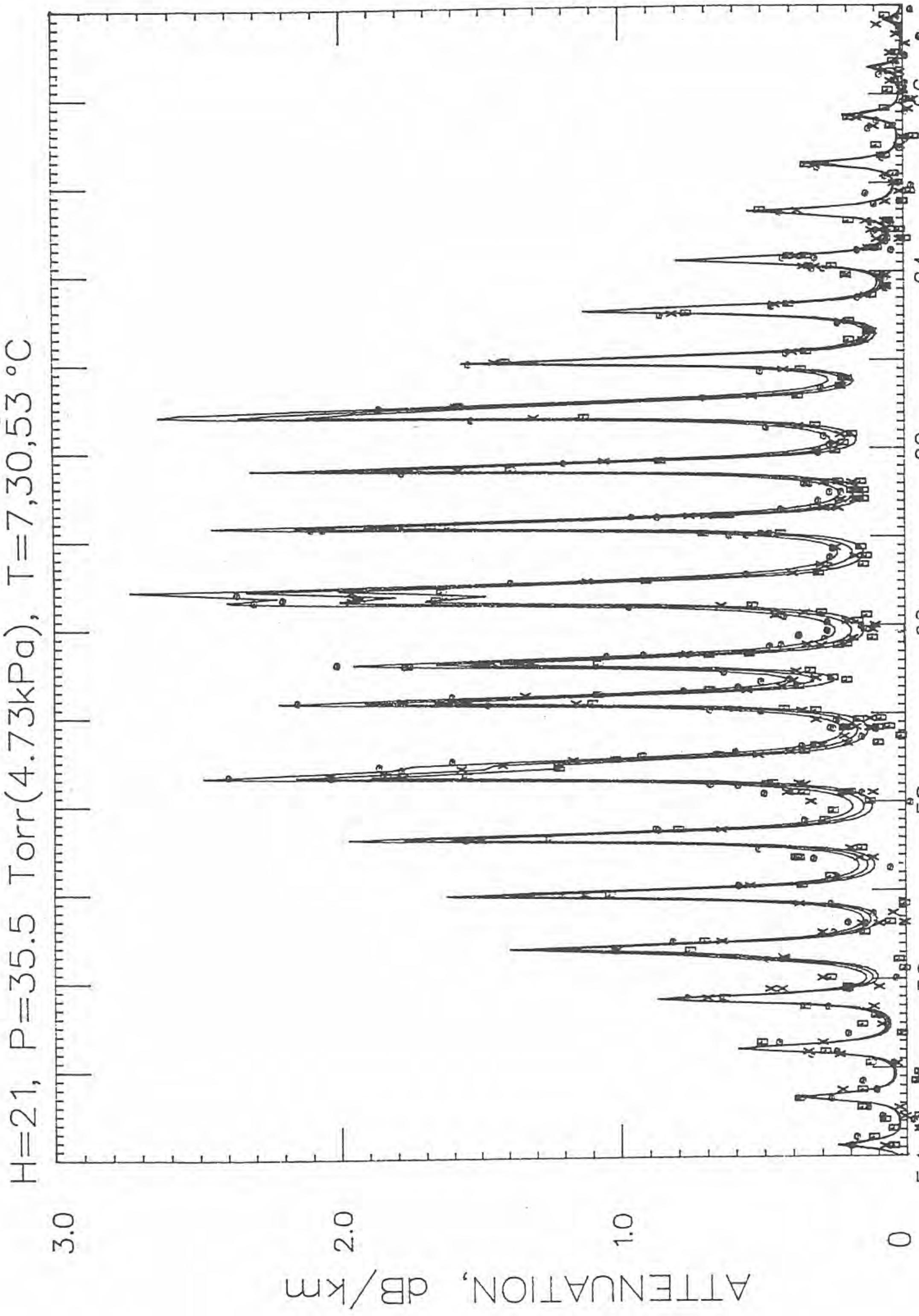

Figure A-4a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 21 km (see **D.**) for frequencies between 54 and 66 GHz.

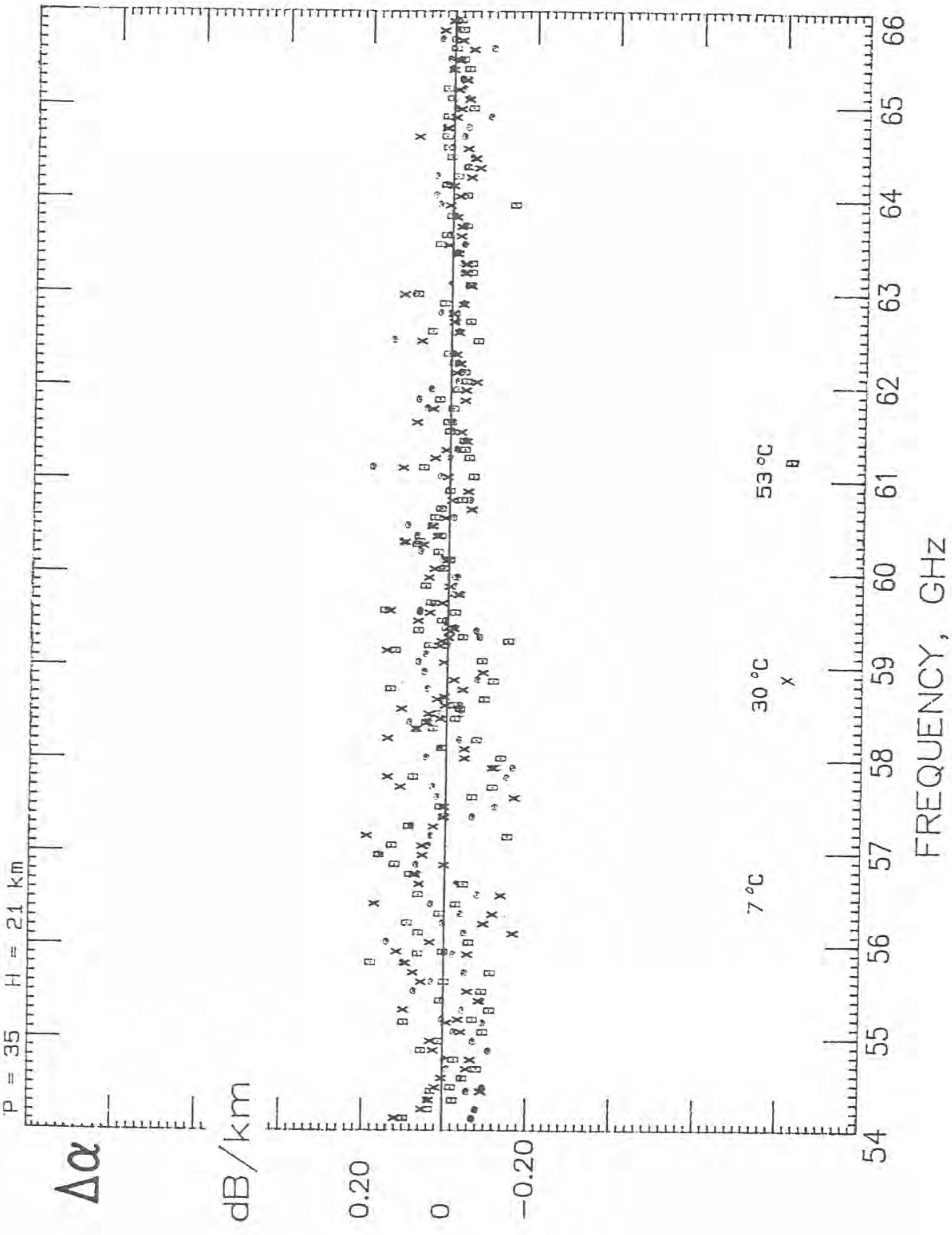

Figure A-4b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **D**.

E.

$H = 18$ km

Statistics Summary:

T	[°C]	6.70(24)	29.70(34)	52.40(08)
P	[torr] [kPa]	**56.90(07)**	**57.00(11)** 7.595	**57.00(20)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.082	0.069	0.068

H = 18 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89502 57.0	0.00(.11) 0.04(0.12)	53.89502 57.0	0.00(.03) 0.04(0.04)	53.89502 57.0	0.00(.04) 0.04(0.05)
53.99377 56.9	0.21(.02) 0.07(-0.14)	53.99373 57.0	0.06(.02) 0.07(0.01)	53.99373 57.6	0.10(.02) 0.07(-0.03)
54.09238 57.1	0.29(.02) 0.18(-0.11)	54.09240 57.0	0.10(.02) 0.19(0.09)	54.09231 56.9	0.18(.03) 0.21(0.03)
54.19113 56.9	0.15(.02) 0.16(0.01)	54.19135 57.0	0.08(.03) 0.17(0.09)	54.19103 56.9	0.15(.03) 0.17(0.02)
54.28976 56.9	0.11(.02) 0.08(-0.03)	54.28968 56.9	0.06(.02) 0.07(0.01)	54.28969 56.9	0.07(.04) 0.07(0.00)
54.38718 56.9	0.15(.02) 0.06(-0.09)	54.38715 56.9	0.07(.03) 0.06(-0.01)	54.38836 57.0	0.00(.10) 0.06(0.13)
54.42871 56.8	0.04(.02) 0.07(0.03)	54.42962 56.9	0.14(.03) 0.07(-0.07)	54.43056 56.9	0.16(.04) 0.06(-0.10)
54.52985 56.9	0.20(.02) 0.12(-0.08)	54.53087 56.9	0.27(.02) 0.11(-0.16)	54.53082 57.5	0.10(.03) 0.11(0.01)
54.63077 57.0	0.31(.03) 0.30(-0.01)	54.63077 57.0	0.38(.03) 0.32(-0.06)	54.63078 56.9	0.35(.04) 0.33(-0.02)
54.73088 56.9	0.20(.02) 0.28(0.08)	54.73084 57.0	0.27(.03) 0.28(0.01)	54.73084 56.9	0.34(.02) 0.28(-0.06)
54.83084 57.0	0.20(.03) 0.13(-0.07)	54.83086 57.0	0.03(.02) 0.12(0.09)	54.83078 56.9	0.00(.04) 0.12(0.13)
54.93094 56.9	0.23(.03) 0.11(-0.12)	54.93116 57.0	0.02(.03) 0.10(0.08)	54.93084 56.9	0.08(.04) 0.09(0.01)
55.03092 56.9	0.23(.04) 0.14(-0.09)	55.03083 56.9	0.25(.03) 0.13(-0.12)	55.03084 56.9	0.16(.05) 0.12(-0.04)
55.12967 56.9	0.31(.03) 0.30(-0.01)	55.12974 56.9	0.29(.04) 0.29(0.00)	55.13087 57.0	0.38(.03) 0.28(-0.10)
55.16174 56.8	0.34(.03) 0.42(0.08)	55.16266 57.1	0.30(.04) 0.42(0.12)	55.16361 57.0	0.42(.04) 0.41(-0.01)
55.26425 56.9	0.65(.03) 0.53(-0.12)	55.26529 56.9	0.47(.03) 0.52(0.05)	55.26524 56.7	0.39(.04) 0.51(0.12)
55.36653 57.0	0.15(.03) 0.23(0.08)	55.36653 57.0	0.35(.04) 0.21(-0.14)	55.36654 56.9	0.07(.03) 0.19(0.12)
55.46799 56.9	0.11(.03) 0.17(0.06)	55.46795 57.0	0.08(.03) 0.15(0.07)	55.46795 56.9	0.27(.03) 0.13(-0.14)
55.56930 57.0	0.23(.03) 0.20(-0.03)	55.56932 57.0	0.15(.03) 0.18(0.03)	55.56923 56.9	0.26(.03) 0.16(-0.10)

H = 18 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67075 56.9	0.40(.03) 0.40(0.00)	55.67097 57.0	0.23(.02) 0.36(0.13)	55.67065 56.9	0.42(.03) 0.33(-0.09)
55.77209 56.9	0.84(.03) 0.94(0.10)	55.77200 56.9	0.87(.03) 0.92(0.05)	55.77201 56.9	0.76(.03) 0.90(0.14)
55.87217 56.9	0.64(.03) 0.58(-0.06)	55.87214 56.9	0.59(.02) 0.53(-0.06)	55.87338 57.0	0.39(.04) 0.47(0.08)
55.89478 56.8	0.44(.03) 0.49(0.05)	55.89570 56.9	0.36(.03) 0.43(0.07)	55.89667 56.9	0.45(.03) 0.38(-0.07)
55.99864 56.9	0.21(.02) 0.32(0.11)	55.99969 56.9	0.22(.02) 0.27(0.05)	55.99964 56.7	0.28(.04) 0.23(-0.05)
56.10228 57.0	0.42(.03) 0.39(-0.03)	56.10229 57.0	0.49(.04) 0.33(-0.16)	56.10229 56.9	0.22(.04) 0.28(0.06)
56.20509 56.9	0.63(.03) 0.71(0.08)	56.20505 57.0	0.62(.04) 0.61(-0.01)	56.20506 57.8	0.56(.03) 0.52(-0.04)
56.30776 57.0	1.23(.03) 1.34(0.11)	56.30777 57.0	1.16(.03) 1.20(0.04)	56.30768 56.9	0.96(.03) 1.08(0.12)
56.41056 56.9	1.30(.03) 1.30(0.00)	56.41078 57.0	1.17(.03) 1.18(0.01)	56.41047 56.9	1.19(.04) 1.07(-0.12)
56.51324 56.9	0.63(.03) 0.58(-0.05)	56.51316 56.9	0.62(.03) 0.49(-0.13)	56.51317 56.9	0.41(.04) 0.42(0.01)
56.62780 56.8	0.47(.02) 0.37(-0.10)	56.62875 57.1	0.22(.02) 0.30(0.08)	56.62973 56.9	0.14(.03) 0.25(0.11)
56.73304 56.9	0.41(.03) 0.39(-0.02)	56.73410 56.9	0.50(.03) 0.33(-0.17)	56.73405 56.8	0.35(.03) 0.27(-0.08)
56.83804 57.0	0.60(.02) 0.69(0.09)	56.83804 57.0	0.67(.03) 0.58(-0.09)	56.83805 57.0	0.47(.04) 0.50(0.03)
56.94220 56.9	1.46(.04) 1.65(0.19)	56.94216 57.0	1.33(.04) 1.50(0.17)	56.94217 56.9	1.32(.05) 1.38(0.06)
57.04622 57.1	1.28(.04) 1.16(-0.12)	57.04623 57.0	0.93(.03) 1.02(0.09)	57.04615 57.0	0.97(.03) 0.89(-0.08)
57.15038 56.9	0.60(.04) 0.54(-0.06)	57.15060 57.0	0.42(.04) 0.45(0.03)	57.15027 56.9	0.34(.04) 0.38(0.04)
57.25440 56.9	0.29(.04) 0.40(0.11)	57.25432 56.9	0.42(.04) 0.32(-0.10)	57.25433 56.9	0.14(.04) 0.27(0.13)
57.36084 56.8	0.52(.03) 0.44(-0.08)	57.35722 56.9	0.31(.04) 0.36(0.05)	57.36279 56.9	0.45(.04) 0.30(-0.15)
57.46744 56.9	0.81(.04) 0.77(-0.04)	57.46852 56.9	0.80(.03) 0.64(-0.16)	57.46847 56.7	0.43(.06) 0.53(0.10)

H = 18 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57382	1.87(.05)	57.57381	1.75(.04)	57.57383	1.37(.04)
57.0	1.87(0.00)	57.0	1.65(-0.10)	57.0	1.46(0.09)
57.67934	1.55(.03)	57.67930	1.25(.04)	57.67931	1.21(.06)
57.0	1.56(0.01)	57.0	1.34(0.09)	57.6	1.16(-0.05)
57.78470	0.91(.04)	57.78471	0.49(.05)	57.78464	0.58(.05)
57.1	0.69(-0.22)	57.0	0.56(0.07)	56.9	0.46(-0.12)
57.89021	0.59(.03)	57.89044	0.49(.04)	57.89011	0.25(.04)
56.9	0.47(-0.12)	57.0	0.37(-0.12)	56.9	0.30(0.05)
57.99559	0.57(.03)	57.99550	0.34(.04)	57.99552	0.36(.04)
56.9	0.46(-0.11)	56.9	0.37(0.03)	56.9	0.29(-0.07)
58.09969	0.66(.02)	58.09486	0.49(.03)	58.10049	0.36(.03)
56.9	0.64(-0.02)	57.0	0.50(0.01)	57.2	0.41(0.05)
58.18876	1.13(.02)	58.20294	1.09(.03)	58.19009	0.87(.01)
56.9	1.12(-0.01)	56.9	1.02(-0.07)	56.9	0.74(-0.13)
58.29443	2.44(.03)	58.30959	2.44(.03)	58.30961	2.19(.04)
56.9	2.60(0.16)	57.0	2.41(-0.03)	57.0	2.10(-0.09)
58.37762	2.64(.02)	58.37823	2.15(.02)	58.37820	1.89(.02)
56.9	2.78(0.14)	57.0	2.34(0.19)	57.2	1.99(0.10)
58.41645	2.47(.04)	58.41642	1.94(.03)	58.41642	1.65(.04)
57.0	2.52(0.05)	57.0	2.10(0.16)	56.9	1.77(0.12)
58.47058	2.03(.03)	58.47101	1.59(.02)	58.47109	1.36(.02)
56.9	2.09(0.06)	57.1	1.72(0.13)	56.9	1.44(0.08)
58.52317	1.58(.03)	58.52318	1.11(.03)	58.52310	0.95(.04)
57.1	1.53(-0.05)	57.0	1.23(0.12)	56.9	1.01(0.06)
58.56338	1.12(.02)	58.56356	0.97(.01)	58.56370	0.78(.02)
56.9	1.17(0.05)	56.9	0.92(-0.05)	57.2	0.74(-0.04)
58.63002	0.89(.03)	58.63025	0.65(.03)	58.62991	0.49(.03)
56.9	0.80(-0.09)	57.0	0.62(-0.03)	56.9	0.49(0.00)
58.73674	0.68(.03)	58.73665	0.45(.02)	58.73666	0.25(.03)
56.9	0.56(-0.12)	56.9	0.43(-0.02)	56.9	0.34(0.09)
58.84215	0.52(.02)	58.84222	0.47(.02)	58.82891	0.53(.02)
56.9	0.53(0.01)	56.9	0.41(-0.06)	56.9	0.32(-0.21)
58.92300	0.57(.01)	58.92472	0.57(.01)		
56.9	0.63(0.06)	57.0	0.50(-0.07)		
59.02999	1.02(.02)	59.03003	0.85(.01)	59.04533	0.79(.02)
56.9	1.11(0.09)	57.0	0.88(0.03)	56.9	0.80(0.01)
59.11423	1.93(.01)	59.15349	2.11(.03)	59.15350	1.77(.03)
56.8	2.06(0.13)	57.0	2.10(-0.01)	57.1	1.82(0.05)

H = 18 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20837	2.13(.01)	59.20881	1.76(.01)	59.20889	1.47(.01)
56.9	2.15(0.02)	57.1	1.81(0.05)	56.9	1.54(0.07)
59.26159	1.50(.02)	59.26160	1.21(.02)	59.26153	0.95(.03)
57.0	1.49(-0.01)	57.0	1.20(-0.01)	56.9	0.99(0.04)
59.30235	1.11(.01)	59.30252	0.87(.01)	59.30267	0.81(.01)
56.9	1.15(0.04)	56.9	0.91(0.04)	57.2	0.73(-0.08)
59.36980	0.90(.02)	59.37003	0.78(.02)	59.36969	0.49(.02)
56.9	0.92(0.02)	57.0	0.72(-0.06)	56.9	0.57(0.08)
59.39797	0.93(.01)	59.39791	0.79(.01)	59.39847	0.60(.01)
57.1	0.92(-0.01)	56.9	0.72(-0.07)	57.2	0.57(-0.03)
59.47786	1.23(.02)	59.47778	0.96(.02)	59.47779	0.80(.03)
56.9	1.23(0.00)	56.9	0.97(0.01)	56.9	0.78(-0.02)
59.56588	2.01(.01)	59.56654	1.73(.01)	59.56671	1.47(.01)
56.9	2.09(0.08)	57.2	1.76(0.03)	57.2	1.50(0.03)
59.58461	2.06(.02)	59.58457	1.76(.03)	59.58591	1.53(.02)
56.9	2.20(0.14)	56.9	1.86(0.10)	57.0	1.59(0.06)
59.65722	1.70(.01)	59.67171	1.25(.03)	59.67166	0.96(.04)
56.9	1.74(0.04)	56.9	1.28(0.03)	56.7	1.05(0.09)
59.76556	0.79(.01)	59.76561	0.65(.01)	59.76574	0.57(.01)
56.9	0.87(0.08)	57.0	0.68(0.03)	56.9	0.54(-0.03)
59.85086	0.62(.01)	59.85147	0.46(.01)	59.85146	0.43(.01)
56.9	0.64(0.02)	56.9	0.49(0.03)	57.2	0.39(-0.04)
59.94616	0.57(.01)	59.94661	0.43(.01)	59.94669	0.34(.01)
56.9	0.59(0.02)	57.2	0.45(0.02)	56.9	0.35(0.01)
60.04130	0.70(.01)	60.04149	0.51(.01)	60.04164	0.40(.01)
56.9	0.69(-0.01)	56.9	0.53(0.02)	57.2	0.42(0.02)
60.13812	1.12(.01)	60.13806	0.81(.01)	60.13864	0.63(.01)
57.1	1.06(-0.06)	56.8	0.82(0.01)	57.2	0.66(0.03)
60.21900	1.40(.05)			60.21893	1.18(.07)
56.9	1.82(0.42)			56.9	1.19(0.01)
60.29900	2.84(.01)	60.29966	2.37(.01)	60.29984	1.92(.01)
56.9	2.93(0.09)	57.2	2.45(0.08)	57.2	2.08(0.16)
60.32710	3.12(.04)	60.32717	2.47(.05)	60.32842	2.25(.08)
57.0	3.12(0.00)	56.9	2.60(0.13)	57.0	2.20(-0.05)
60.39146	3.19(.01)	60.39323	2.69(.01)	60.39285	2.26(.01)
56.9	3.32(0.13)	56.9	2.78(0.09)	56.9	2.35(0.09)
60.50114	2.24(.01)	60.50119	1.83(.01)	60.50133	1.49(.01)
56.8	2.34(0.10)	57.0	1.92(0.09)	56.9	1.60(0.11)

H = 18 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58749 56.9	1.22(.01) 1.21(-0.01)	60.58812 57.0	0.93(.01) 0.95(0.02)	60.58809 57.2	0.74(.01) 0.76(0.02)
60.68396 56.9	0.71(.01) 0.73(0.02)	60.68441 57.2	0.61(.01) 0.57(-0.04)	60.68450 56.9	0.48(.01) 0.45(-0.03)
60.78028 56.9	0.59(.01) 0.58(-0.01)	60.78047 56.9	0.47(.00) 0.45(-0.02)	60.78062 57.2	0.34(.00) 0.36(0.02)
60.87829 57.1	0.59(.01) 0.60(0.01)	60.87823 56.9	0.55(.00) 0.47(-0.08)	60.87881 57.2	0.37(.01) 0.38(0.01)
61.03211 56.9	1.24(.00) 1.26(0.02)	61.03277 57.2	1.03(.01) 1.03(0.00)	61.03296 57.2	0.84(.01) 0.85(0.01)
61.12568 57.0	2.35(.01) 2.55(0.20)	61.12748 56.9	2.11(.01) 2.24(0.13)	61.12725 57.1	1.81(.01) 1.96(0.15)
61.23670 56.9	1.61(.01) 1.66(0.05)	61.23686 56.9	1.34(.01) 1.37(0.03)	61.23689 57.2	1.07(.01) 1.15(0.08)
61.32410 56.8	0.90(.00) 0.86(-0.04)	61.32474 57.0	0.67(.00) 0.68(0.01)	61.32478 56.9	0.61(.01) 0.55(-0.06)
61.42175 56.9	0.61(.01) 0.58(-0.03)	61.42238 56.9	0.46(.01) 0.46(0.00)	61.42227 57.2	0.36(.01) 0.37(0.01)
61.51924 56.9	0.59(.00) 0.56(-0.03)	61.51942 57.1	0.48(.01) 0.45(-0.03)	61.51962 56.9	0.36(.01) 0.36(0.00)
61.61845 57.1	0.79(.00) 0.77(-0.02)	61.61849 56.9	0.58(.01) 0.62(0.04)	61.61898 56.9	0.53(.01) 0.51(-0.02)
61.76519 56.9	2.18(.01) 2.28(0.10)	61.76619 57.3	1.99(.01) 2.03(0.04)	61.76606 56.9	1.79(.01) 1.80(0.01)
61.85991 57.0	1.82(.01) 1.93(0.11)	61.86175 56.9	1.58(.01) 1.64(0.06)	61.86151 57.2	1.36(.01) 1.43(0.07)
61.97243 57.2	0.84(.01) 0.83(-0.01)	61.97243 56.9	0.72(.00) 0.68(-0.04)	61.97246 57.1	0.59(.01) 0.56(-0.03)
62.06066 57.2	0.68(.01) 0.63(-0.05)	62.06137 56.9	0.57(.01) 0.50(-0.07)	62.06141 56.9	0.47(.01) 0.41(-0.06)
62.15965 57.2	0.73(.01) 0.67(-0.06)	62.16018 56.9	0.55(.00) 0.54(-0.01)	62.16007 57.2	0.47(.01) 0.44(-0.03)
62.25820 57.2	1.11(.01) 1.06(-0.05)	62.25839 57.2	0.88(.01) 0.87(-0.01)	62.25859 56.9	0.70(.01) 0.72(0.02)
62.35879 57.1	2.26(.01) 2.33(0.07)	62.35865 56.9	1.99(.01) 2.02(0.03)	62.35914 56.9	1.71(.01) 1.77(0.06)
62.49831 56.9	2.43(.01) 2.56(0.13)	62.49932 57.3	2.10(.01) 2.18(0.08)	62.49918 56.9	1.90(.01) 1.89(-0.01)

$H = 18$ km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59415 57.0	1.27(.01) 1.30(0.03)	62.59600 56.9	1.07(.01) 1.05(-0.02)	62.59576 57.2	0.82(.01) 0.86(0.04)
62.70800 57.2	0.73(.01) 0.69(-0.04)	62.70800 56.9	0.53(.00) 0.56(0.03)	62.70803 57.2	0.48(.01) 0.46(-0.02)
62.79728 57.2	0.59(.00) 0.62(0.03)	62.79800 56.9	0.51(.00) 0.51(0.00)	62.79803 56.9	0.42(.01) 0.43(0.01)
62.89744 57.1	0.95(.00) 0.96(0.01)	62.89798 56.9	0.85(.01) 0.84(-0.01)	62.89787 57.2	0.71(.01) 0.73(0.02)
62.99717 57.2	1.66(.00) 1.75(0.09)	62.99736 57.1	1.60(.00) 1.65(0.05)	62.99757 56.9	1.44(.01) 1.56(0.12)
63.09896 57.1	0.84(.00) 0.85(0.01)	63.09882 56.9	0.77(.01) 0.75(-0.02)	63.09933 56.9	0.68(.01) 0.66(-0.02)
63.23141 56.9	0.40(.00) 0.37(-0.03)	63.23243 57.3	0.35(.00) 0.31(-0.04)	63.23230 57.0	0.24(.01) 0.27(0.03)
63.32837 57.0	0.34(.00) 0.33(-0.01)	63.33025 56.9	0.33(.01) 0.28(-0.05)	63.33001 57.2	0.26(.01) 0.24(-0.02)
63.44357 57.2	0.54(.00) 0.52(-0.02)	63.44357 56.9	0.45(.01) 0.47(0.02)	63.44361 57.2	0.42(.00) 0.42(0.00)
63.53390 57.2	1.11(.01) 1.10(-0.01)	63.53463 56.9	1.04(.01) 1.07(0.03)	63.53467 56.9	0.99(.01) 1.02(0.03)
63.63524 57.2	0.79(.00) 0.82(0.03)	63.63580 56.9	0.75(.01) 0.76(0.01)	63.63568 57.2	0.68(.01) 0.71(0.03)
63.73614 57.2	0.32(.01) 0.34(0.02)	63.73634 57.1	0.34(.00) 0.30(-0.04)	63.73655 56.9	0.29(.01) 0.27(-0.02)
63.83912 57.1	0.22(.00) 0.22(0.00)	63.83899 56.9	0.18(.01) 0.20(0.02)	63.83949 56.9	0.16(.01) 0.18(0.02)
63.96451 56.9	0.23(.01) 0.27(0.04)	63.96556 57.3	0.23(.01) 0.25(0.02)	63.96541 57.0	0.30(.01) 0.23(-0.07)
64.06260 56.9	0.53(.00) 0.57(0.04)	64.06450 56.9	0.59(.01) 0.57(-0.02)	64.06426 57.1	0.57(.01) 0.55(-0.02)
64.17914 57.2	0.55(.01) 0.63(0.08)	64.17915 56.9	0.58(.01) 0.62(0.04)	64.17907 56.9	0.55(.01) 0.61(0.06)
64.27052 57.2	0.22(.01) 0.26(0.04)	64.27126 56.9	0.23(.01) 0.24(0.01)	64.27126 56.9	0.26(.01) 0.23(-0.03)
64.37302 57.2	0.21(.01) 0.15(-0.06)	64.37354 56.9	0.24(.01) 0.14(-0.10)	64.37341 56.8	0.15(.01) 0.13(-0.02)
64.47481 57.1	0.23(.01) 0.15(-0.08)	64.47517 57.1	0.17(.01) 0.14(-0.03)	64.47550 57.2	0.12(.01) 0.13(0.01)

H = 18 km

6.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km
64.57928 56.9	0.29(.01) 0.26(-0.03)	64.57912 57.2	0.27(.01) 0.26(-0.01)	64.57966 56.9	0.30(.01) 0.25(-0.05)
64.69763 56.9	0.56(.01) 0.50(-0.06)	64.69865 57.2	0.47(.01) 0.53(0.06)	64.69849 57.1	0.51(.01) 0.56(0.05)
64.79631 56.9	0.21(.01) 0.20(-0.01)	64.79838 56.9	0.19(.01) 0.19(0.00)	64.79850 56.9	0.21(.01) 0.19(-0.02)
64.91473 56.9	0.21(.01) 0.10(-0.11)	64.91468 57.0	0.06(.00) 0.09(0.03)	64.91463 56.9	0.07(.01) 0.09(0.02)
65.00708 57.1	0.08(.01) 0.09(0.01)	65.00777 57.2	0.10(.01) 0.09(-0.01)	65.00789 56.9	0.13(.01) 0.08(-0.05)
65.11082 57.2	0.16(.00) 0.14(-0.02)	65.11133 56.9	0.18(.01) 0.14(-0.04)	65.11121 56.8	0.11(.01) 0.14(0.03)
65.21377 57.1	0.34(.01) 0.31(-0.03)	65.21413 57.1	0.34(.00) 0.35(0.01)	65.21448 57.2	0.35(.01) 0.38(0.03)
65.31944 56.9	0.15(.00) 0.14(-0.01)	65.31927 57.2	0.17(.01) 0.15(-0.02)	65.31975 56.9	0.15(.01) 0.15(0.00)
65.43073 56.8	0.05(.01) 0.06(0.01)	65.43177 57.2	0.06(.00) 0.06(0.00)	65.43161 57.2	0.06(.01) 0.06(0.00)
65.53053 56.9	0.03(.01) 0.05(0.02)	65.53263 56.9	0.04(.01) 0.05(0.01)	65.53275 56.9	0.12(.01) 0.05(-0.07)
65.65029 56.9	0.18(.01) 0.08(-0.10)	65.65025 57.0	0.07(.01) 0.08(0.01)	65.65020 56.9	0.08(.01) 0.08(0.00)
65.74369 57.1	0.15(.00) 0.17(0.02)	65.74439 57.2	0.18(.00) 0.19(0.01)	65.74452 56.9	0.19(.01) 0.22(0.03)
65.84861 57.2	0.08(.01) 0.09(0.01)	65.84914 56.9	0.06(.01) 0.10(0.04)	65.84901 56.9	0.10(.01) 0.10(0.00)
65.95274 57.1	0.05(.01) 0.04(-0.01)	65.95311 57.1	0.03(.01) 0.04(0.01)	65.95346 57.2	0.00(.01) 0.04(0.04)
66.05961 56.9	0.01(.00) 0.03(0.02)	66.05945 57.2	0.01(.01) 0.03(0.02)	66.05992 56.9	0.01(.01) 0.03(0.02)
66.16383 56.9	0.03(.00) 0.04(0.01)	66.16488 57.2	0.05(.00) 0.04(-0.01)	66.16473 57.2	0.03(.01) 0.04(0.01)
66.26476 56.9	0.09(.00) 0.08(-0.01)	66.26688 56.9	0.06(.01) 0.10(0.04)	66.26701 56.8	0.06(.01) 0.11(0.05)

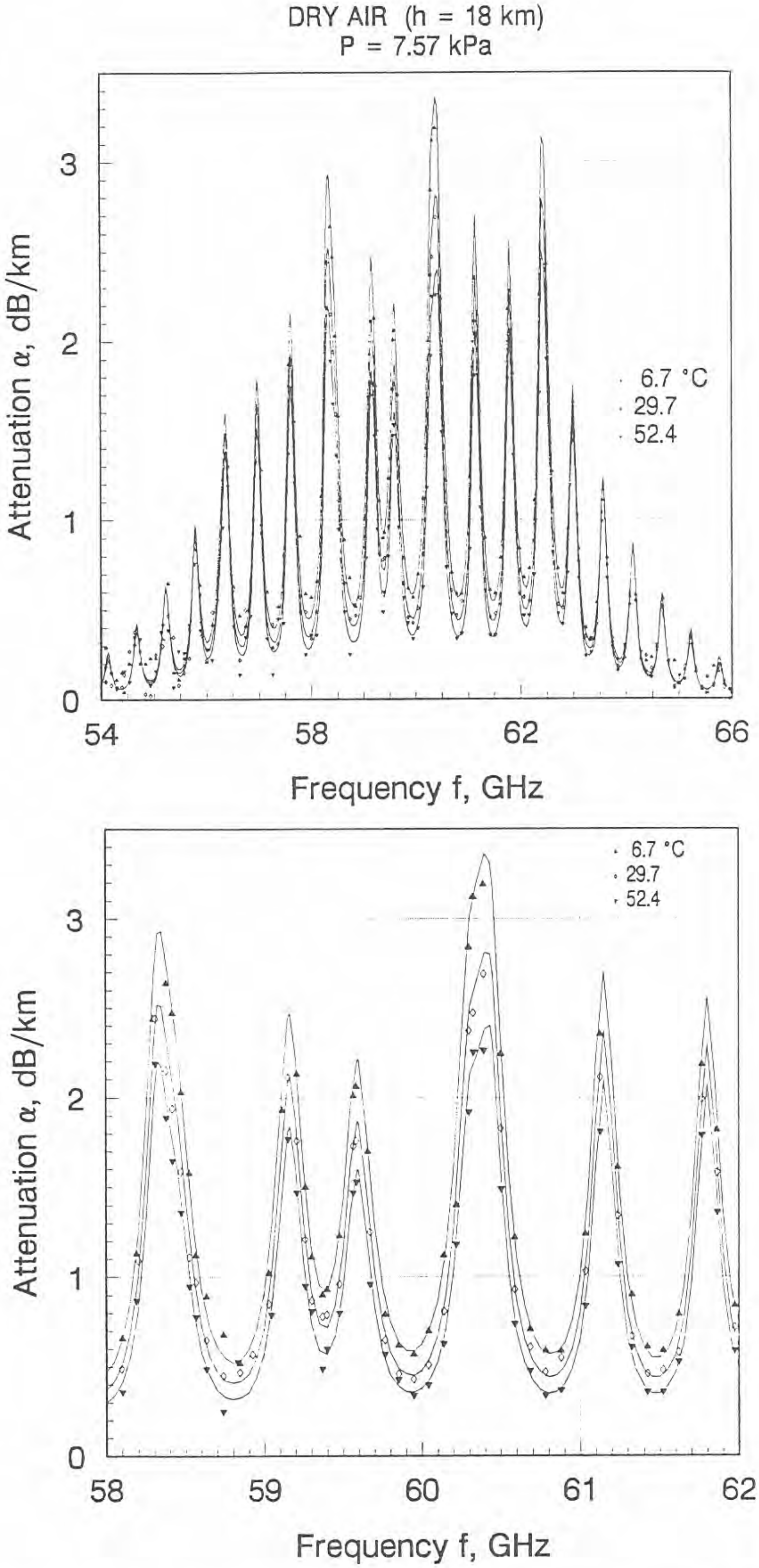

Figure A-5a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 18 km (see E.) for frequencies between 54 and 66 GHz.

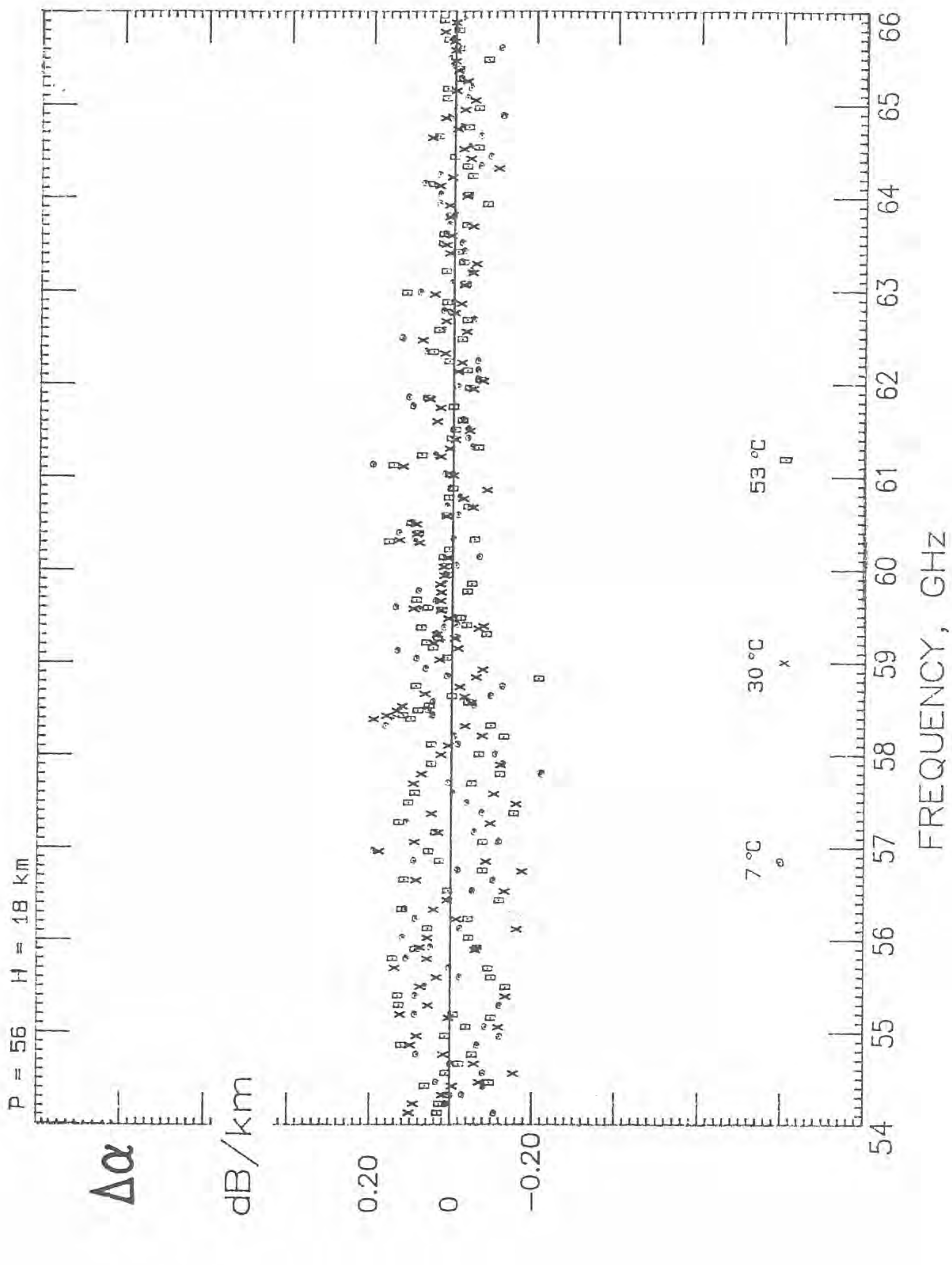

Figure A-5b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **E**.

F.

H = 15 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**90.80(06)**	**90.80(11)** 12.106	**90.80(20)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.079	0.079	0.078

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89435 90.7	0.00(.05) 0.09(0.11)	53.89439 90.8	0.17(.03) 0.09(-0.08)	53.89444 90.7	0.03(.03) 0.09(0.06)
53.99310 90.7	0.10(.02) 0.14(0.04)	53.99311 90.8	0.12(.02) 0.14(0.02)	53.99315 90.5	0.14(.03) 0.14(0.00)
54.09171 90.8	0.35(.02) 0.23(-0.12)	54.09177 90.7	0.15(.02) 0.25(0.10)	54.09173 90.8	0.28(.03) 0.26(-0.02)
54.19045 90.8	0.31(.02) 0.23(-0.08)	54.19072 90.8	0.12(.02) 0.24(0.12)	54.19045 90.9	0.33(.03) 0.25(-0.08)
54.28908 90.8	0.21(.02) 0.16(-0.05)	54.28905 90.7	0.17(.02) 0.16(-0.01)	54.28910 90.8	0.18(.04) 0.16(-0.02)
54.38650 90.7	0.20(.02) 0.15(-0.05)	54.38661 90.8	0.13(.02) 0.14(0.01)	54.38778 90.8	0.00(.03) 0.14(0.14)
54.42803 90.7	0.24(.02) 0.16(-0.08)	54.42898 90.6	0.23(.02) 0.15(-0.08)	54.42997 90.7	0.25(.04) 0.14(-0.11)
54.52916 90.8	0.30(.02) 0.23(-0.07)	54.53024 90.8	0.12(.03) 0.23(0.11)	54.53024 90.9	0.26(.03) 0.22(-0.04)
54.63010 90.7	0.24(.02) 0.39(0.15)	54.63013 90.8	0.54(.03) 0.40(-0.14)	54.63019 90.7	0.40(.03) 0.41(0.01)
54.73019 90.8	0.33(.02) 0.39(0.06)	54.73020 90.8	0.39(.03) 0.40(0.01)	54.73025 90.3	0.44(.04) 0.41(-0.03)
54.83016 90.8	0.36(.03) 0.27(-0.09)	54.83022 90.7	0.22(.03) 0.26(0.04)	54.83018 90.8	0.17(.03) 0.25(0.08)
54.93026 90.8	0.34(.03) 0.24(-0.10)	54.93052 90.8	0.12(.03) 0.23(0.11)	54.93024 90.9	0.22(.04) 0.21(-0.01)
55.03023 90.8	0.25(.03) 0.31(0.06)	55.03020 90.7	0.27(.03) 0.28(0.01)	55.03025 90.8	0.27(.04) 0.26(-0.01)
55.12898 90.8	0.50(.03) 0.50(0.00)	55.12910 90.8	0.35(.04) 0.48(0.13)	55.13028 90.8	0.53(.03) 0.47(-0.06)
55.16105 90.6	0.51(.03) 0.59(0.08)	55.16202 90.8	0.57(.03) 0.58(0.01)	55.16302 90.7	0.58(.04) 0.57(-0.01)
55.26355 90.9	0.74(.03) 0.67(-0.07)	55.26464 90.8	0.79(.04) 0.67(-0.12)	55.26464 91.4	0.60(.04) 0.66(0.06)
55.36584 90.7	0.34(.03) 0.47(0.13)	55.36589 90.8	0.54(.04) 0.43(-0.11)	55.36595 90.7	0.40(.03) 0.40(0.00)
55.46729 90.8	0.38(.03) 0.39(0.01)	55.46730 90.8	0.42(.03) 0.35(-0.07)	55.46736 90.3	0.44(.05) 0.31(-0.13)
55.56861 90.8	0.55(.03) 0.45(-0.10)	55.56867 90.7	0.37(.03) 0.40(0.03)	55.56864 90.8	0.31(.03) 0.36(0.05)

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67005 90.8	0.66(.03) 0.71(0.05)	55.67032 90.8	0.51(.04) 0.65(0.14)	55.67005 90.9	0.59(.03) 0.60(0.01)
55.77138 90.8	0.98(.03) 1.09(0.11)	55.77135 90.7	1.09(.03) 1.05(-0.04)	55.77140 90.8	0.90(.03) 1.01(0.11)
55.87147 90.8	0.97(.03) 0.94(-0.03)	55.87148 90.8	0.86(.02) 0.87(0.01)	55.87278 90.8	0.74(.04) 0.79(0.05)
55.89407 90.7	0.97(.03) 0.87(-0.10)	55.89505 90.6	0.60(.03) 0.79(0.19)	55.89607 90.7	0.70(.03) 0.71(0.01)
55.99793 90.9	0.61(.03) 0.70(0.09)	55.99903 90.9	0.64(.02) 0.60(-0.04)	55.99904 90.7	0.52(.04) 0.52(0.00)
56.10159 90.7	0.75(.03) 0.79(0.04)	56.10163 90.8	0.79(.04) 0.67(-0.12)	56.10170 90.7	0.59(.04) 0.58(-0.01)
56.20439 90.7	1.13(.03) 1.13(0.00)	56.20440 90.8	1.00(.04) 0.98(-0.02)	56.20446 91.2	0.86(.05) 0.86(0.00)
56.30705 90.8	1.50(.03) 1.67(0.17)	56.30712 90.7	1.35(.03) 1.51(0.16)	56.30708 90.8	1.46(.04) 1.38(-0.08)
56.40985 90.8	1.53(.04) 1.69(0.16)	56.41013 90.8	1.34(.03) 1.53(0.19)	56.40985 90.9	1.26(.04) 1.40(0.14)
56.51254 90.8	1.05(.03) 1.12(0.07)	56.51250 90.7	0.99(.03) 0.97(-0.02)	56.51256 90.8	0.74(.04) 0.84(0.10)
56.62709 90.7	0.75(.03) 0.83(0.08)	56.62809 90.7	0.77(.02) 0.70(-0.07)	56.62912 90.7	0.57(.03) 0.59(0.02)
56.73232 90.9	0.84(.03) 0.87(0.03)	56.73344 90.8	0.81(.03) 0.73(-0.08)	56.73344 91.3	0.66(.04) 0.62(-0.04)
56.83734 90.7	1.11(.03) 1.25(0.14)	56.83738 90.8	1.19(.04) 1.08(-0.11)	56.83745 90.8	1.03(.04) 0.94(-0.09)
56.94149 90.7	1.75(.04) 1.92(0.17)	56.94151 90.8	1.68(.04) 1.74(0.06)	56.94157 91.0	1.54(.05) 1.59(0.05)
57.04551 90.8	1.63(.03) 1.71(0.08)	57.04557 90.7	1.45(.04) 1.51(0.06)	57.04554 90.8	1.20(.04) 1.35(0.15)
57.14966 90.8	1.18(.03) 1.13(-0.05)	57.14993 90.8	0.76(.04) 0.95(0.19)	57.14966 90.9	0.95(.04) 0.81(-0.14)
57.25368 90.8	0.81(.04) 0.91(0.10)	57.25366 90.7	0.66(.03) 0.75(0.09)	57.25372 90.8	0.52(.04) 0.63(0.11)
57.36012 90.7	1.15(.06) 0.99(-0.16)	57.35656 90.8	0.90(.03) 0.81(-0.09)	57.36217 90.7	0.80(.06) 0.68(-0.12)
57.46671 90.9	1.47(.04) 1.44(-0.03)	57.46785 90.8	1.36(.04) 1.22(-0.14)	57.46785 91.0	0.90(.04) 1.03(0.13)

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57310	2.10(.04)	57.57315	1.79(.03)	57.57321	1.81(.05)
90.7	2.25(0.15)	90.8	1.98(0.19)	90.8	1.76(-0.05)
57.67862	2.06(.04)	57.67863	1.74(.05)	57.67870	1.68(.04)
90.7	2.13(0.07)	90.8	1.85(0.11)	90.4	1.63(-0.05)
57.78398	1.51(.04)	57.78406	1.22(.04)	57.78402	1.03(.03)
90.8	1.39(-0.12)	90.7	1.15(-0.07)	90.8	0.96(-0.07)
57.88948	1.11(.03)	57.88976	0.82(.04)	57.88949	0.66(.04)
90.8	1.07(-0.04)	90.8	0.86(0.04)	90.9	0.70(0.04)
57.99486	1.12(.03)	57.99483	0.80(.03)	57.99490	0.78(.05)
90.8	1.07(-0.05)	90.7	0.86(0.06)	90.8	0.69(-0.09)
58.09890	1.41(.02)	58.09419	1.22(.03)	58.09982	0.89(.02)
90.9	1.39(-0.02)	90.6	1.09(-0.13)	90.8	0.91(0.02)
58.18797	2.09(.02)	58.20227	1.79(.04)	58.18943	1.47(.02)
90.8	2.02(-0.07)	90.9	1.78(-0.01)	90.7	1.39(-0.08)
58.29363	2.98(.03)	58.30891	2.71(.03)	58.30898	2.45(.03)
90.7	3.17(0.19)	90.8	2.82(0.11)	90.9	2.45(0.00)
58.37682	3.25(.02)	58.37750	2.75(.02)	58.37752	2.33(.02)
91.0	3.42(0.17)	90.6	2.92(0.17)	91.0	2.51(0.18)
58.41573	3.05(.04)	58.41574	2.81(.04)	58.41580	2.20(.04)
90.7	3.25(0.20)	90.8	2.74(-0.07)	90.3	2.34(0.14)
58.46980	2.77(.04)	58.47028	2.21(.02)	58.47041	1.87(.02)
91.0	2.85(0.08)	90.7	2.37(0.16)	90.8	2.00(0.13)
58.52244	2.37(.02)	58.52251	1.99(.03)	58.52247	1.51(.03)
90.7	2.40(0.03)	90.7	1.96(-0.03)	90.8	1.63(0.12)
58.56258	2.04(.02)	58.56282	1.66(.02)	58.56304	1.38(.02)
90.7	2.07(0.03)	90.8	1.67(0.01)	90.8	1.37(-0.01)
58.62928	1.62(.02)	58.62956	1.31(.03)	58.62928	1.15(.03)
90.8	1.63(0.01)	90.8	1.30(-0.01)	90.9	1.04(-0.11)
58.73600	1.33(.03)	58.73598	0.95(.03)	58.73603	0.92(.04)
90.8	1.27(-0.06)	90.7	1.00(0.05)	90.8	0.79(-0.13)
58.84141	1.23(.02)	58.84154	0.97(.02)	58.82828	0.90(.02)
90.7	1.23(0.00)	90.8	0.96(-0.01)	90.7	0.76(-0.14)
58.92219	1.30(.01)	58.92398	1.20(.01)		
90.8	1.39(0.09)	90.9	1.10(-0.10)		
59.02919	1.75(.02)	59.02930	1.54(.01)	59.04470	1.32(.03)
90.7	1.96(0.21)	90.9	1.59(0.05)	90.9	1.40(0.08)
59.11343	2.48(.01)	59.15281	2.34(.03)	59.15287	1.92(.03)
91.0	2.63(0.15)	90.8	2.38(0.04)	91.3	2.05(0.13)

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20757 90.9	2.61(.01) 2.71(0.10)	59.20808 90.7	2.16(.01) 2.28(0.12)	59.20821 90.8	1.84(.01) 1.94(0.10)
59.26085 90.8	2.28(.02) 2.36(0.08)	59.26093 90.7	2.00(.03) 1.94(-0.06)	59.26089 90.8	1.59(.03) 1.61(0.02)
59.30154 90.8	2.14(.01) 2.10(-0.04)	59.30178 90.8	1.71(.01) 1.69(-0.02)	59.30200 90.8	1.37(.01) 1.38(0.01)
59.36905 90.8	1.94(.02) 1.87(-0.07)	59.36934 90.8	1.48(.02) 1.48(0.00)	59.36906 90.9	1.28(.03) 1.19(-0.09)
59.39716 90.9	1.89(.01) 1.86(-0.03)	59.39717 90.8	1.56(.01) 1.47(-0.09)	59.39779 90.7	1.16(.01) 1.19(0.03)
59.47712 90.8	2.09(.02) 2.10(0.01)	59.47709 90.7	1.67(.02) 1.69(0.02)	59.47715 90.8	1.34(.02) 1.38(0.04)
59.56507 90.9	2.49(.01) 2.56(0.07)	59.56580 91.0	2.06(.01) 2.13(0.07)	59.56603 90.8	1.79(.01) 1.80(0.01)
59.58385 90.8	2.55(.03) 2.61(0.06)	59.58388 90.8	2.13(.02) 2.17(0.04)	59.58528 90.8	1.74(.03) 1.85(0.11)
59.65641 90.8	2.33(.01) 2.42(0.09)	59.67102 90.9	1.82(.02) 1.90(0.08)	59.67102 90.7	1.43(.03) 1.58(0.15)
59.76475 90.7	1.68(.01) 1.74(0.06)	59.76486 91.0	1.31(.01) 1.37(0.06)	59.76505 90.8	1.09(.01) 1.11(0.02)
59.85004 91.0	1.36(.01) 1.43(0.07)	59.85074 90.6	1.11(.01) 1.12(0.01)	59.85077 91.0	0.95(.01) 0.88(-0.07)
59.94535 90.9	1.36(.01) 1.36(0.00)	59.94587 90.7	0.97(.01) 1.06(0.09)	59.94600 90.8	0.86(.01) 0.83(-0.03)
60.04049 90.7	1.61(.01) 1.54(-0.07)	60.04074 90.7	1.12(.01) 1.20(0.08)	60.04096 90.8	0.93(.01) 0.96(0.03)
60.13730 90.9	2.12(.01) 2.07(-0.05)	60.13732 90.8	1.66(.01) 1.64(-0.02)	60.13795 90.8	1.29(.01) 1.33(0.04)
60.21825 90.8	2.93(.06) 2.85(-0.08)			60.21828 90.8	1.83(.07) 1.92(0.09)
60.29818 90.9	3.63(.01) 3.70(0.07)	60.29890 90.9	3.00(.01) 3.09(0.09)	60.29915 90.8	2.48(.01) 2.62(0.14)
60.32634 90.8	3.94(.05) 3.90(-0.04)	60.32647 90.8	3.04(.05) 3.27(0.23)	60.32776 90.8	2.44(.07) 2.79(0.35)
60.39064 90.7	3.94(.01) 4.11(0.17)	60.39247 90.9	3.36(.01) 3.47(0.11)	60.39216 90.7	2.77(.01) 2.96(0.19)
60.50031 90.7	3.17(.01) 3.34(0.17)	60.50043 91.0	2.67(.01) 2.77(0.10)	60.50063 90.8	2.19(.01) 2.33(0.14)

H = 15 km

6.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km
60.58666 90.9	2.25(.01) 2.31(0.06)	60.58736 90.6	1.80(.01) 1.85(0.05)	60.58739 91.0	1.43(.01) 1.51(0.08)
60.68315 91.0	1.61(.01) 1.62(0.01)	60.68366 90.6	1.31(.01) 1.27(-0.04)	60.68380 90.8	1.00(.01) 1.02(0.02)
60.77945 90.7	1.34(.01) 1.34(0.00)	60.77970 90.7	1.05(.00) 1.05(0.00)	60.77993 90.8	0.83(.00) 0.84(0.01)
60.87746 90.9	1.36(.01) 1.37(0.01)	60.87748 90.8	1.11(.00) 1.08(-0.03)	60.87812 90.7	0.84(.01) 0.87(0.03)
61.03128 90.9	2.08(.01) 2.16(0.08)	61.03202 91.0	1.75(.01) 1.80(0.05)	61.03226 90.8	1.53(.01) 1.51(-0.02)
61.12484 91.0	2.79(.02) 2.95(0.16)	61.12672 90.7	2.44(.01) 2.56(0.12)	61.12655 90.7	2.06(.01) 2.24(0.18)
61.23587 90.7	2.37(.01) 2.48(0.11)	61.23610 90.8	2.03(.01) 2.09(0.06)	61.23618 91.0	1.66(.01) 1.79(0.13)
61.32327 91.0	1.75(.00) 1.73(-0.02)	61.32398 90.6	1.39(.00) 1.40(0.01)	61.32407 90.8	1.16(.01) 1.16(0.00)
61.42093 90.9	1.35(.00) 1.32(-0.03)	61.42161 91.0	1.08(.01) 1.06(-0.02)	61.42156 90.8	0.90(.01) 0.86(-0.04)
61.51841 90.7	1.32(.01) 1.28(-0.04)	61.51866 90.8	1.06(.01) 1.03(-0.03)	61.51891 90.8	0.85(.01) 0.84(-0.01)
61.61761 90.9	1.64(.00) 1.59(-0.05)	61.61772 90.7	1.27(.01) 1.31(0.04)	61.61826 91.0	1.05(.01) 1.09(0.04)
61.76435 90.7	2.68(.01) 2.77(0.09)	61.76543 91.0	2.33(.01) 2.44(0.11)	61.76534 90.8	2.09(.01) 2.16(0.07)
61.85906 91.0	2.46(.01) 2.62(0.16)	61.86097 90.7	2.17(.01) 2.26(0.09)	61.86080 90.7	1.87(.01) 1.98(0.11)
61.97160 90.9	1.72(.01) 1.71(-0.01)	61.97166 90.8	1.46(.00) 1.41(-0.05)	61.97174 91.0	1.14(.01) 1.18(0.04)
62.05983 90.7	1.47(.01) 1.42(-0.05)	62.06060 90.7	1.26(.01) 1.15(-0.11)	62.06069 90.8	1.01(.01) 0.95(-0.06)
62.15881 90.7	1.55(.01) 1.50(-0.05)	62.15940 91.0	1.24(.00) 1.23(-0.01)	62.15936 90.8	1.01(.01) 1.01(0.00)
62.25737 90.6	2.08(.01) 2.04(-0.04)	62.25762 90.8	1.73(.01) 1.70(-0.03)	62.25788 90.8	1.44(.01) 1.44(0.00)
62.35796 90.7	3.02(.01) 3.14(0.12)	62.35788 90.7	2.64(.01) 2.74(0.10)	62.35843 91.1	2.32(.01) 2.41(0.09)
62.49746 90.7	3.06(.00) 3.22(0.16)	62.49854 91.0	2.67(.01) 2.79(0.12)	62.49846 90.8	2.40(.01) 2.44(0.04)

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59328 91.0	2.16(.00) 2.20(0.04)	62.59521 90.7	1.84(.00) 1.83(-0.01)	62.59505 90.7	1.45(.01) 1.55(0.10)
62.70716 90.9	1.56(.01) 1.46(-0.10)	62.70722 90.7	1.17(.01) 1.21(0.04)	62.70731 91.0	1.05(.01) 1.00(-0.05)
62.79644 90.7	1.31(.01) 1.34(0.03)	62.79723 90.7	1.11(.00) 1.12(0.01)	62.79731 90.8	0.94(.01) 0.95(0.01)
62.89660 90.7	1.62(.00) 1.64(0.02)	62.89720 91.0	1.44(.01) 1.45(0.01)	62.89715 90.8	1.24(.01) 1.28(0.04)
62.99633 90.7	1.92(.00) 2.01(0.09)	62.99658 90.8	1.84(.01) 1.87(0.03)	62.99685 90.8	1.65(.01) 1.74(0.09)
63.09812 90.7	1.41(.01) 1.44(0.03)	63.09804 90.7	1.27(.01) 1.29(0.02)	63.09860 91.1	1.17(.01) 1.15(-0.02)
63.23056 90.7	0.84(.01) 0.83(-0.01)	63.23166 91.0	0.77(.00) 0.71(-0.06)	63.23157 90.8	0.61(.01) 0.62(0.01)
63.32750 91.0	0.77(.01) 0.74(-0.03)	63.32946 90.7	0.67(.01) 0.65(-0.02)	63.32929 90.7	0.61(.01) 0.57(-0.04)
63.44272 90.9	0.98(.01) 0.97(-0.01)	63.44278 90.8	0.89(.01) 0.88(-0.01)	63.44288 91.0	0.80(.01) 0.80(0.00)
63.53305 90.7	1.36(.01) 1.34(-0.02)	63.53384 90.7	1.30(.01) 1.29(-0.01)	63.53394 90.8	1.17(.01) 1.24(0.07)
63.63439 90.7	1.15(.01) 1.17(0.02)	63.63499 90.9	1.06(.01) 1.11(0.05)	63.63496 90.8	1.01(.01) 1.04(0.03)
63.73529 90.7	0.69(.00) 0.70(0.01)	63.73555 90.8	0.64(.01) 0.64(0.00)	63.73582 90.8	0.61(.01) 0.57(-0.04)
63.83827 90.7	0.52(.01) 0.52(0.00)	63.83819 90.7	0.43(.01) 0.46(0.03)	63.83876 91.0	0.42(.01) 0.41(-0.01)
63.96365 90.7	0.52(.01) 0.57(0.05)	63.96476 91.0	0.50(.01) 0.53(0.03)	63.96468 90.8	0.62(.01) 0.48(-0.14)
64.06172 91.0	0.75(.01) 0.82(0.07)	64.06370 90.7	0.81(.01) 0.81(0.00)	64.06353 90.7	0.83(.01) 0.79(-0.04)
64.17828 90.9	0.78(.01) 0.84(0.06)	64.17834 90.8	0.74(.01) 0.83(0.09)	64.17834 90.8	0.77(.02) 0.82(0.05)
64.26966 90.7	0.52(.01) 0.52(0.00)	64.27046 90.7	0.42(.01) 0.49(0.07)	64.27053 90.7	0.43(.01) 0.46(0.03)
64.37216 90.7	0.37(.01) 0.35(-0.02)	64.37273 90.6	0.40(.01) 0.33(-0.07)	64.37268 90.7	0.33(.01) 0.30(-0.03)
64.47395 90.7	0.39(.01) 0.34(-0.05)	64.47437 90.8	0.37(.01) 0.32(-0.05)	64.47477 91.1	0.32(.01) 0.30(-0.02)

H = 15 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.57841 90.7	0.47(.01) 0.45(-0.02)	64.57832 90.7	0.47(.00) 0.45(-0.02)	64.57892 91.1	0.43(.01) 0.45(0.02)
64.69676 90.7	0.62(.01) 0.59(-0.03)	64.69785 91.0	0.55(.01) 0.61(0.06)	64.69775 90.7	0.60(.01) 0.63(0.03)
64.79544 90.6	0.36(.01) 0.37(0.01)	64.79757 90.7	0.35(.00) 0.37(0.02)	64.79775 90.8	0.35(.01) 0.36(0.01)
64.91384 91.0	0.26(.01) 0.22(-0.04)	64.91387 91.0	0.19(.00) 0.21(0.02)	64.91389 90.8	0.23(.01) 0.20(-0.03)
65.00622 90.7	0.19(.01) 0.20(0.01)	65.00697 90.7	0.23(.00) 0.20(-0.03)	65.00715 90.7	0.26(.01) 0.19(-0.07)
65.10994 90.7	0.27(.00) 0.26(-0.01)	65.11053 90.6	0.33(.01) 0.27(-0.06)	65.11047 90.7	0.28(.01) 0.27(-0.01)
65.21290 90.7	0.42(.01) 0.36(-0.06)	65.21333 90.7	0.38(.00) 0.39(0.01)	65.21374 91.0	0.39(.01) 0.42(0.03)
65.31856 90.7	0.27(.00) 0.25(-0.02)	65.31847 90.7	0.29(.01) 0.26(-0.03)	65.31902 90.8	0.28(.01) 0.27(-0.01)
65.42985 90.7	0.13(.01) 0.15(0.02)	65.43095 91.0	0.15(.01) 0.14(-0.01)	65.43086 90.7	0.15(.01) 0.14(-0.01)
65.52966 90.6	0.12(.01) 0.12(0.00)	65.53182 90.7	0.11(.01) 0.12(0.01)	65.53199 90.8	0.14(.01) 0.12(-0.02)
65.64940 90.9	0.22(.01) 0.15(-0.07)	65.64942 91.0	0.17(.01) 0.16(-0.01)	65.64945 90.8	0.16(.01) 0.16(0.00)
65.74282 90.6	0.20(.01) 0.20(0.00)	65.74358 90.7	0.20(.01) 0.23(0.03)	65.74377 90.7	0.25(.01) 0.25(0.00)
65.84772 90.7	0.15(.01) 0.15(0.00)	65.84833 90.6	0.14(.01) 0.16(0.02)	65.84827 90.7	0.18(.01) 0.18(0.00)
65.95185 90.7	0.11(.01) 0.09(-0.02)	65.95229 90.7	0.06(.01) 0.09(0.03)	65.95271 91.1	0.05(.01) 0.09(0.04)
66.05872 90.7	0.01(.00) 0.07(0.06)	66.05863 90.7	0.01(.01) 0.07(0.06)	66.05919 90.7	0.06(.01) 0.07(0.01)
66.16294 90.6	0.04(.01) 0.08(0.04)	66.16407 91.0	0.08(.01) 0.08(0.00)	66.16397 90.7	0.08(.01) 0.09(0.01)
66.26387 90.6	0.13(.01) 0.11(-0.02)	66.26606 90.7	0.11(.01) 0.12(0.01)	66.26624 90.8	0.07(.01) 0.14(0.07)

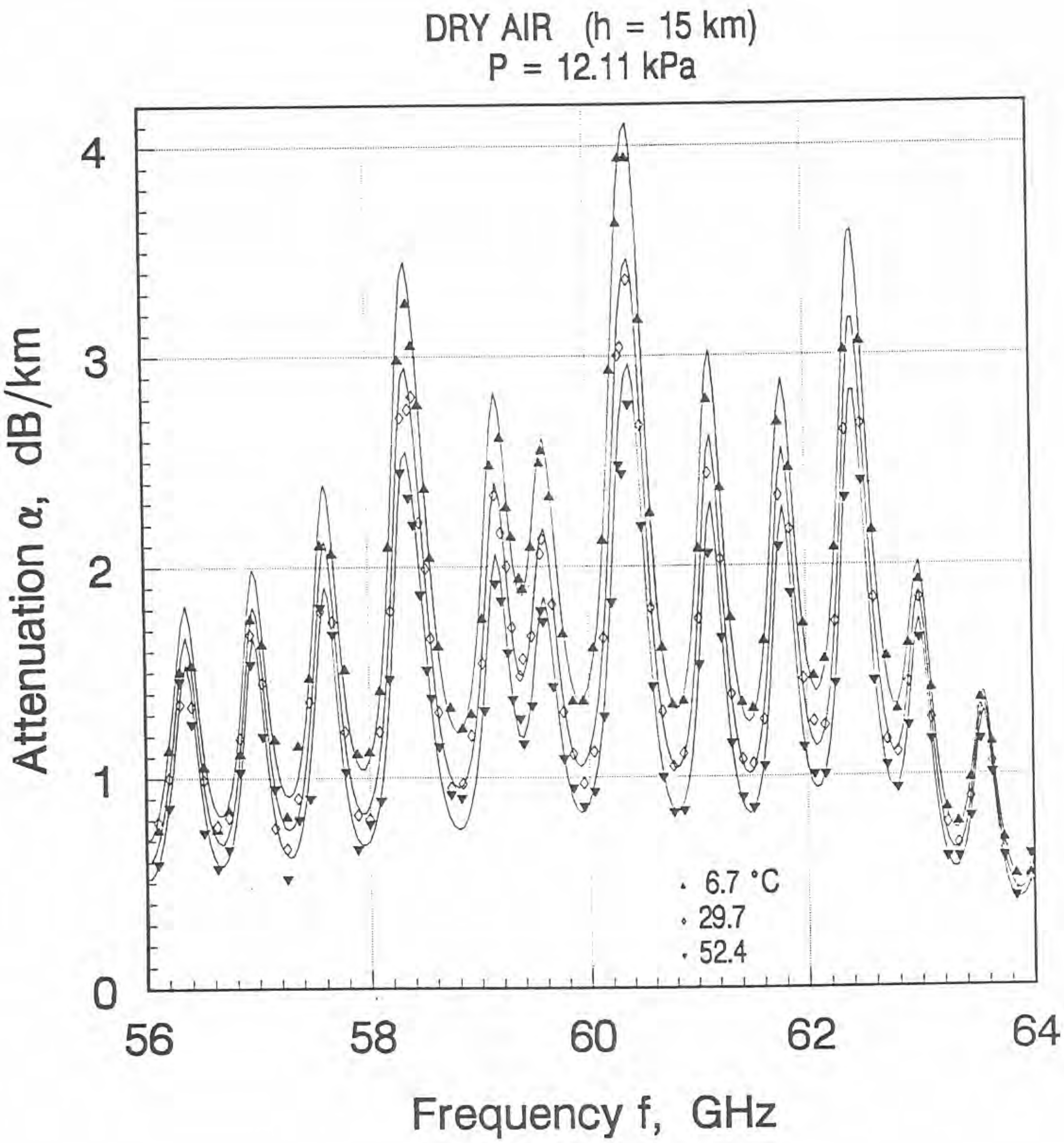

Figure A-6a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 15 km (see F.) for frequencies between 56 and 64 GHz.

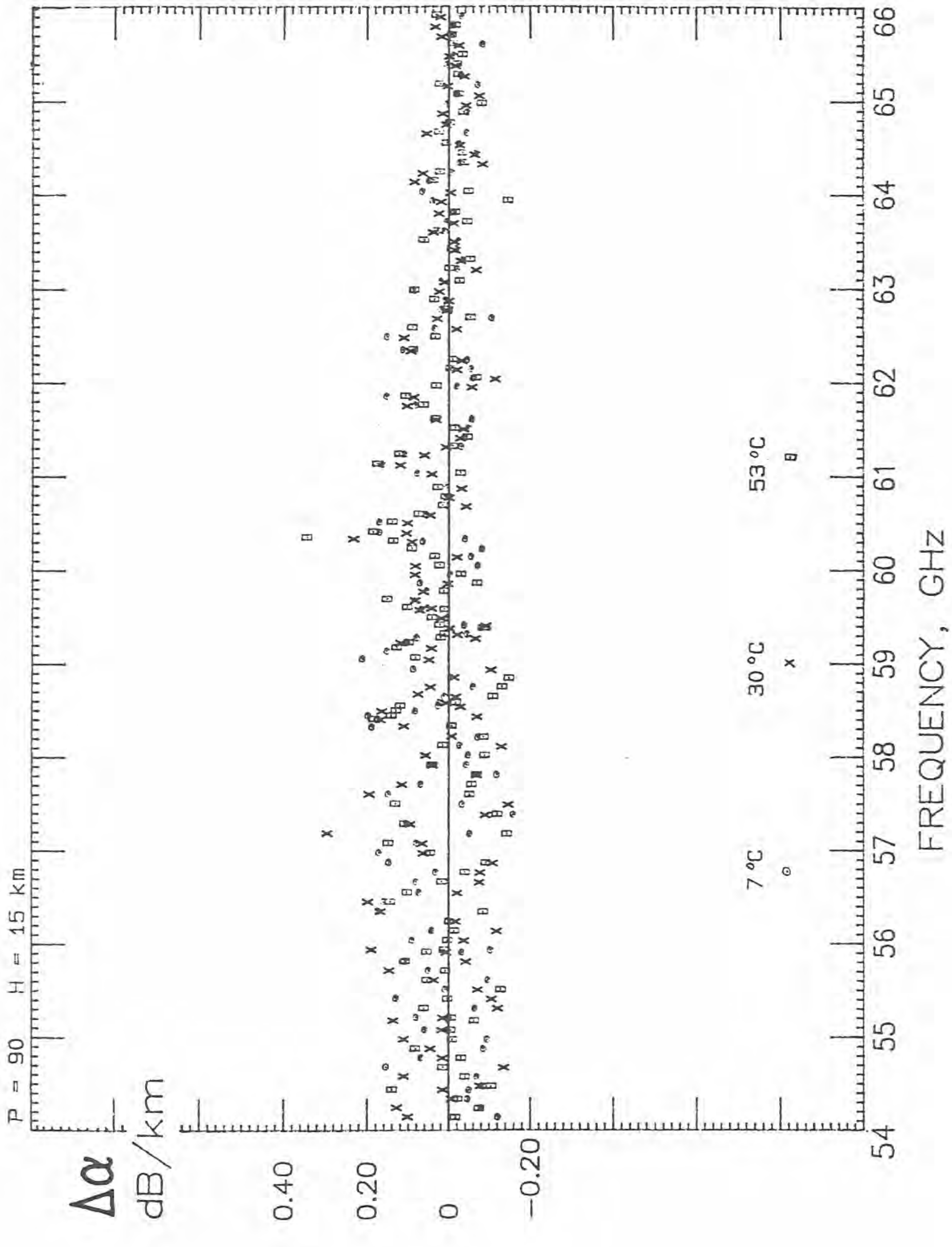

Figure A-6b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **F**.

G.

H = 12 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**146.20(18)**	**146.10(15)** 19.487	**146.10(25)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.084	0.090	0.084

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89324	0.15(.03)	53.89337	0.28(.03)	53.89350	0.29(.03)
146.2	0.20(0.05)	146.3	0.20(-0.08)	146.1	0.20(-0.09)
53.99199	0.23(.02)	53.99208	0.13(.02)	53.99221	0.37(.03)
146.2	0.25(0.02)	146.2	0.25(0.12)	146.0	0.25(-0.12)
54.09059	0.26(.02)	54.09075	0.29(.03)	54.09079	0.29(.03)
146.3	0.32(0.06)	145.9	0.33(0.04)	146.0	0.34(0.05)
54.18934	0.33(.03)	54.18969	0.30(.02)	54.18949	0.37(.04)
146.1	0.34(0.01)	145.9	0.35(0.05)	146.4	0.36(-0.01)
54.28796	0.39(.02)	54.28802	0.29(.02)	54.28814	0.36(.04)
146.3	0.32(-0.07)	146.3	0.31(0.02)	146.4	0.31(-0.05)
54.38538	0.41(.02)	54.38558	0.39(.03)	54.38683	0.39(.03)
146.4	0.32(-0.09)	146.4	0.31(-0.08)	146.0	0.30(-0.09)
54.42691	0.44(.03)	54.42795	0.41(.03)	54.42901	0.29(.04)
145.9	0.34(-0.10)	146.0	0.32(-0.09)	146.0	0.31(0.02)
54.52805	0.54(.02)	54.52920	0.44(.03)	54.52928	0.44(.03)
145.8	0.42(-0.12)	146.2	0.41(-0.03)	146.2	0.40(-0.04)
54.62897	0.45(.02)	54.62910	0.53(.03)	54.62924	0.64(.03)
146.2	0.53(0.08)	146.3	0.53(0.00)	145.9	0.54(-0.10)
54.72906	0.61(.02)	54.72916	0.62(.03)	54.72931	0.57(.02)
146.2	0.56(-0.05)	146.2	0.57(-0.05)	146.0	0.56(-0.01)
54.82903	0.61(.03)	54.82918	0.42(.02)	54.82922	0.43(.03)
146.3	0.52(-0.09)	145.9	0.50(0.08)	145.9	0.48(0.05)
54.92912	0.65(.04)	54.92948	0.41(.03)	54.92928	0.57(.04)
146.1	0.52(-0.13)	145.9	0.49(0.08)	146.4	0.46(-0.11)
55.02909	0.71(.03)	55.02915	0.46(.03)	55.02928	0.62(.05)
146.3	0.60(-0.11)	146.3	0.57(0.11)	146.4	0.53(-0.09)
55.12784	0.84(.03)	55.12805	0.74(.04)	55.12932	0.71(.03)
146.4	0.77(-0.07)	146.4	0.74(0.00)	146.0	0.71(0.00)
55.15992	0.77(.04)	55.16097	0.78(.03)	55.16204	0.84(.04)
145.9	0.82(0.05)	146.0	0.80(0.02)	146.1	0.78(-0.06)
55.26242	0.93(.03)	55.26359	0.88(.04)	55.26367	0.94(.03)
145.8	0.91(-0.02)	146.2	0.88(0.00)	146.0	0.86(-0.08)
55.36470	0.93(.03)	55.36483	0.92(.04)	55.36498	0.70(.04)
146.2	0.85(-0.08)	146.3	0.79(-0.13)	145.9	0.74(0.04)
55.46615	0.85(.03)	55.46625	0.90(.03)	55.46639	0.77(.04)
146.2	0.82(-0.03)	146.2	0.74(-0.16)	146.0	0.67(-0.10)
55.56746	1.05(.03)	55.56762	0.88(.04)	55.56767	0.66(.02)
146.3	0.92(-0.13)	145.9	0.83(-0.05)	145.9	0.75(0.09)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.66890 146.1	1.21(.03) 1.15(-0.06)	55.66927 145.9	0.78(.04) 1.06(0.28)	55.66907 146.4	0.94(.03) 0.98(0.04)
55.77023 146.3	1.35(.02) 1.40(0.05)	55.77029 146.3	1.25(.03) 1.31(0.06)	55.77042 146.4	1.02(.03) 1.24(0.22)
55.87030 146.3	1.41(.03) 1.42(0.01)	55.87041 146.3	1.47(.02) 1.31(-0.16)	55.87181 146.0	1.16(.04) 1.20(0.04)
55.89292 145.9	1.28(.03) 1.40(0.12)	55.89399 146.0	1.23(.02) 1.28(0.05)	55.89509 146.0	1.08(.04) 1.17(0.09)
55.99678 145.8	1.28(.03) 1.35(0.07)	55.99797 146.2	1.21(.03) 1.18(-0.03)	55.99806 146.0	1.07(.04) 1.05(-0.02)
56.10043 146.2	1.53(.03) 1.45(-0.08)	56.10056 146.3	1.38(.04) 1.27(-0.11)	56.10071 145.8	1.05(.03) 1.11(0.06)
56.20323 146.2	1.80(.03) 1.75(-0.05)	56.20333 146.2	1.65(.04) 1.55(-0.10)	56.20348 146.8	1.26(.04) 1.37(0.11)
56.30589 146.3	2.17(.03) 2.10(-0.07)	56.30605 145.9	1.87(.03) 1.90(0.03)	56.30610 145.9	1.58(.04) 1.73(0.15)
56.40869 146.1	2.09(.03) 2.18(0.09)	56.40906 145.9	1.76(.03) 1.97(0.21)	56.40886 146.4	1.67(.05) 1.79(0.12)
56.51136 146.3	2.04(.04) 1.92(-0.12)	56.51143 146.3	1.77(.03) 1.69(-0.08)	56.51156 146.4	1.49(.04) 1.49(0.00)
56.62593 145.9	1.68(.03) 1.70(0.02)	56.62701 146.0	1.47(.03) 1.45(-0.02)	56.62812 146.0	1.15(.03) 1.25(0.10)
56.73116 145.8	1.64(.03) 1.76(0.12)	56.73236 146.2	1.56(.04) 1.50(-0.06)	56.73245 146.6	1.26(.04) 1.29(0.03)
56.83617 146.2	1.97(.03) 2.08(0.11)	56.83630 146.3	1.87(.04) 1.81(-0.06)	56.83645 145.9	1.51(.04) 1.59(0.08)
56.94032 146.2	2.31(.04) 2.44(0.13)	56.94043 146.2	1.99(.04) 2.18(0.19)	56.94057 146.6	1.97(.05) 1.96(-0.01)
57.04433 146.3	2.55(.06) 2.41(-0.14)	57.04449 145.9	1.92(.03) 2.13(0.21)	57.04454 145.9	1.78(.04) 1.89(0.11)
57.14848 146.2	2.11(.04) 2.10(-0.01)	57.14885 145.9	1.56(.04) 1.80(0.24)	57.14866 146.4	1.61(.03) 1.55(-0.06)
57.25251 146.3	1.75(.04) 1.93(0.18)	57.25257 146.3	1.57(.04) 1.61(0.04)	57.25270 146.4	1.23(.04) 1.36(0.13)
57.35894 145.9	2.16(.04) 2.03(-0.13)	57.35547 146.4	1.87(.04) 1.69(-0.18)	57.36117 146.0	1.57(.04) 1.44(-0.13)
57.46554 145.8	2.37(.05) 2.42(0.05)	57.46677 146.2	2.24(.04) 2.06(-0.18)	57.46685 146.1	1.69(.05) 1.77(0.08)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57191 146.2	2.91(.04) 2.87(-0.04)	57.57206 146.2	2.51(.04) 2.51(0.00)	57.57221 145.8	2.11(.03) 2.20(0.09)
57.67743 146.2	2.98(.04) 2.88(-0.10)	57.67753 146.2	2.52(.06) 2.50(-0.02)	57.67767 146.0	2.27(.05) 2.18(-0.09)
57.78278 146.3	2.48(.04) 2.51(0.03)	57.78296 145.9	2.01(.04) 2.10(0.09)	57.78301 145.9	1.67(.04) 1.78(0.11)
57.88829 146.2	2.38(.04) 2.25(-0.13)	57.88866 145.9	1.78(.04) 1.84(0.06)	57.88847 146.4	1.58(.04) 1.53(-0.05)
57.99366 146.3	2.22(.04) 2.30(0.08)	57.99372 146.3	1.84(.03) 1.86(0.02)	57.99387 146.4	1.62(.04) 1.53(-0.09)
58.09761 146.2	2.62(.02) 2.67(0.05)	58.09308 146.2	2.08(.03) 2.16(0.08)	58.09872 146.2	1.77(.02) 1.81(0.04)
58.18668 146.1	3.22(.02) 3.24(0.02)	58.20117 146.2	2.75(.04) 2.80(0.05)	58.18832 146.2	2.40(.02) 2.28(-0.12)
58.29234 146.1	3.85(.03) 3.95(0.10)	58.30780 146.2	3.49(.03) 3.43(-0.06)	58.30796 146.0	2.96(.03) 2.96(0.00)11
58.37554 146.1	4.08(.02) 4.15(0.07)	58.37630 146.2	3.37(.02) 3.54(0.17)	58.37644 146.1	2.89(.03) 3.05(0.16)
58.41453 146.2	3.85(.04) 4.09(0.24)	58.41463 146.2	3.21(.03) 3.47(0.26)	58.41478 145.6	2.75(.04) 2.97(0.22)
58.46854 146.0	3.73(.04) 3.88(0.15)	58.46909 146.2	3.06(.03) 3.25(0.19)	58.46933 146.3	2.82(.02) 2.76(-0.06)
58.52122 146.3	3.45(.03) 3.60(0.15)	58.52140 145.9	2.83(.03) 2.98(0.15)	58.52145 145.9	2.38(.04) 2.50(0.12)
58.56129 146.1	3.28(.01) 3.37(0.09)	58.56163 146.1	2.76(.02) 2.76(0.00)	58.56198 146.2	2.16(.02) 2.30(0.14)
58.62808 146.1	3.04(.03) 3.02(-0.02)	58.62846 145.9	2.28(.03) 2.44(0.16)	58.62825 146.4	2.00(.03) 2.00(0.00)
58.73479 146.3	2.67(.03) 2.66(-0.01)	58.73486 146.4	2.03(.03) 2.12(0.09)	58.73500 146.4	1.65(.03) 1.72(0.07)
58.84019 146.4	2.51(.02) 2.60(0.09)	58.84042 146.4	2.13(.02) 2.07(-0.06)	58.82725 146.0	1.82(.02) 1.66(-0.16)
58.92088 146.1	2.73(.02) 2.76(0.03)	58.92278 146.1	2.28(.01) 2.22(-0.06)		
59.02789 146.1	2.96(.02) 3.19(0.23)	59.02812 146.1	2.55(.01) 2.61(0.06)	59.04367 145.8	2.35(.03) 2.23(-0.12)
59.11213 146.1	3.33(.02) 3.54(0.21)	59.15169 146.2	3.04(.03) 3.03(-0.01)	59.15185 146.4	2.48(.03) 2.57(0.09)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20631	3.55(.02)	59.20687	2.93(.02)	59.20710	2.48(.01)
146.0	3.63(0.08)	146.2	3.02(0.09)	146.2	2.55(0.07)
59.25963	3.50(.02)	59.25980	2.92(.02)	59.25986	2.45(.04)
146.3	3.53(0.03)	145.9	2.91(-0.01)	145.9	2.43(-0.02)
59.30023	3.41(.02)	59.30058	2.77(.01)	59.30093	2.35(.02)
146.1	3.42(0.01)	146.1	2.80(0.03)	146.2	2.32(-0.03)
59.36784	3.31(.02)	59.36822	2.60(.02)	59.36802	2.22(.03)
146.1	3.31(0.00)	145.9	2.68(0.08)	146.4	2.20(-0.02)
59.39587	3.33(.01)	59.39599	2.66(.01)	59.39672	2.12(.01)
146.1	3.29(-0.04)	146.1	2.67(0.01)	146.1	2.19(0.07)
59.47589	3.27(.03)	59.47596	2.59(.02)	59.47610	2.19(.03)
146.3	3.37(0.10)	146.4	2.74(0.15)	146.4	2.27(0.08)
59.56376	3.43(.01)	59.56459	2.88(.01)	59.56490	2.33(.01)
146.2	3.51(0.08)	146.1	2.89(0.01)	146.2	2.42(0.09)
59.58263	3.50(.03)	59.58274	2.98(.03)	59.58423	2.37(.03)
146.3	3.52(0.02)	146.3	2.90(-0.08)	146.0	2.43(0.06)
59.65508	3.30(.01)	59.66988	2.67(.03)	59.66998	2.21(.04)
146.1	3.45(0.15)	146.2	2.80(0.13)	145.9	2.33(0.12)
59.76343	3.02(.01)	59.76365	2.35(.01)	59.76395	1.98(.01)
146.1	3.13(0.11)	146.1	2.51(0.16)	145.8	2.05(0.07)
59.84872	2.90(.01)	59.84951	2.27(.01)	59.84966	1.79(.01)
146.1	2.92(0.02)	146.2	2.31(0.04)	146.1	1.87(0.08)
59.94408	2.88(.01)	59.94464	2.25(.01)	59.94488	1.76(.01)
146.0	2.89(0.01)	146.1	2.28(0.03)	146.2	1.83(0.07)
60.03916	3.08(.01)	60.03951	2.44(.01)	60.03988	1.91(.01)
146.1	3.13(0.05)	146.1	2.48(0.04)	146.2	2.01(0.10)
60.13599	3.65(.01)	60.13612	2.88(.01)	60.13686	2.35(.01)
146.1	3.64(-0.01)	146.1	2.94(0.06)	146.1	2.42(0.07)
60.21700	4.06(.09)	60.29769	3.84(.01)	60.21721	3.02(.08)
146.3	4.23(0.17)	146.1	3.98(0.14)	146.4	2.90(-0.12)
60.29685	4.62(.01)			60.29800	3.01(.01)
146.2	4.76(0.14)			146.2	3.37(0.36)
60.32508	4.77(.07)	60.32533	3.93(.07)	60.32671	3.38(.08)
146.4	4.89(0.12)	146.4	4.10(0.17)	146.0	3.49(0.11)
60.38930	4.84(.01)	60.39124	4.07(.01)	60.39102	3.45(.01)
146.1	5.02(0.18)	146.1	4.22(0.15)	146.2	3.61(0.16)
60.49898	4.42(.01)	60.49923	3.63(.01)	60.49951	3.10(.01)
146.1	4.58(0.16)	146.1	3.81(0.18)	145.8	3.22(0.12)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58533 146.0	3.77(.01) 3.89(0.12)	60.58612 146.2	3.06(.01) 3.18(0.12)	60.58628 146.2	2.57(.01) 2.63(0.06)
60.68186 146.0	3.15(.01) 3.24(0.09)	60.68243 146.2	2.57(.01) 2.60(0.03)	60.68267 146.3	2.08(.01) 2.12(0.04)
60.77811 146.0	2.84(.01) 2.89(0.05)	60.77847 146.1	2.25(.01) 2.31(0.06)	60.77884 146.2	1.78(.01) 1.87(0.09)
60.87614 146.1	2.79(.01) 2.87(0.08)	60.87627 146.1	2.30(.00) 2.31(0.01)	60.87702 146.1	1.81(.01) 1.88(0.07)
61.02993 146.2	3.27(.01) 3.43(0.16)	61.03079 146.1	2.75(.01) 2.86(0.11)	61.03111 146.2	2.31(.01) 2.41(0.10)
61.12349 146.1	3.61(.02) 3.77(0.16)	61.12547 146.3	3.01(.01) 3.21(0.20)	61.12539 146.2	2.65(.01) 2.77(0.12)
61.23469 146.1	3.49(.01) 3.57(0.08)	61.23485 146.2	2.89(.01) 3.01(0.12)	61.23506 145.8	2.44(.01) 2.57(0.13)
61.32192 146.0	3.09(.00) 3.11(0.02)	61.32273 146.2	2.49(.00) 2.57(0.08)	61.32292 146.2	2.12(.01) 2.15(0.03)
61.41969 146.1	2.75(.01) 2.75(0.00)	61.42035 146.0	2.22(.01) 2.24(0.02)	61.42042 146.2	1.86(.01) 1.85(-0.01)
61.51705 146.1	2.71(.00) 2.70(-0.01)	61.51741 146.1	2.22(.01) 2.20(-0.02)	61.51779 146.1	1.86(.01) 1.82(-0.04)
61.61628 146.1	2.99(.01) 2.97(-0.02)	61.61648 145.8	2.52(.01) 2.47(-0.05)	61.61715 145.8	2.05(.01) 2.08(0.03)
61.76299 146.1	3.56(.01) 3.63(0.07)	61.76418 146.1	3.06(.01) 3.14(0.08)	61.76417 146.2	2.67(.01) 2.74(0.07)
61.85769 146.1	3.50(.01) 3.60(0.10)	61.85970 146.3	3.01(.01) 3.09(0.08)	61.85963 146.2	2.55(.01) 2.70(0.15)
61.97023 146.0	3.10(.01) 3.13(0.03)	61.97039 146.2	2.64(.01) 2.62(-0.02)	61.97061 145.8	2.17(.01) 2.22(0.05)
62.05847 146.0	2.97(.01) 2.91(-0.06)	62.05935 145.8	2.48(.01) 2.41(-0.07)	62.05952 146.2	2.04(.01) 2.01(-0.03)
62.15746 146.1	3.04(.01) 3.01(-0.03)	62.15814 146.1	2.50(.00) 2.50(0.00)	62.15821 146.2	2.07(.01) 2.10(0.03)
62.25600 146.0	3.45(.01) 3.47(0.02)	62.25635 146.1	2.92(.01) 2.95(0.03)	62.25674 146.1	2.49(.01) 2.53(0.04)
62.35658 146.0	3.91(.01) 4.08(0.17)	62.35662 145.8	3.45(.01) 3.56(0.11)	62.35731 145.8	3.03(.01) 3.14(0.11)
62.49608 146.1	3.89(.01) 4.04(0.15)	62.49728 146.1	3.37(.01) 3.52(0.15)	62.49728 146.3	3.10(.01) 3.10(0.00)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59190 146.1	3.36(.01) 3.41(0.05)	62.59394 146.3	2.86(.01) 2.90(0.04)	62.59386 146.2	2.35(.01) 2.50(0.15)
62.70578 146.0	2.81(.01) 2.77(-0.04)	62.70595 146.2	2.26(.00) 2.34(0.08)	62.70617 145.8	1.97(.01) 1.99(0.02)
62.79507 146.0	2.52(.01) 2.56(0.04)	62.79596 145.8	2.15(.00) 2.19(0.04)	62.79614 146.2	1.86(.01) 1.88(0.02)
62.89524 146.1	2.62(.01) 2.62(0.00)	62.89592 146.1	2.28(.01) 2.31(0.03)	62.89600 146.2	2.01(.01) 2.05(0.04)
62.99495 146.0	2.55(.00) 2.63(0.08)	62.99531 146.1	2.35(.01) 2.38(0.03)	62.99571 146.1	2.08(.01) 2.17(0.09)
63.09673 146.0	2.27(.01) 2.25(-0.02)	63.09677 145.8	1.98(.01) 2.02(0.04)	63.09747 145.8	1.81(.01) 1.81(0.00)
63.22916 146.1	1.73(.00) 1.70(-0.03)	63.23038 146.1	1.53(.01) 1.48(-0.05)	63.23037 146.2	1.33(.01) 1.30(-0.03)
63.32610 146.1	1.54(.00) 1.56(0.02)	63.32816 146.3	1.42(.01) 1.37(-0.05)	63.32809 146.2	1.24(.01) 1.21(-0.03)
63.44133 146.0	1.61(.00) 1.65(0.04)	63.44149 146.2	1.56(.01) 1.51(-0.05)	63.44172 145.8	1.35(.01) 1.38(0.03)
63.53167 146.0	1.78(.01) 1.78(0.00)	63.53256 145.8	1.71(.01) 1.67(-0.04)	63.53275 146.2	1.55(.01) 1.57(0.02)
63.63301 146.1	1.64(.00) 1.64(0.00)	63.63370 146.1	1.43(.01) 1.54(0.11)	63.63379 146.2	1.39(.01) 1.44(0.05)
63.73389 146.0	1.26(.01) 1.31(0.05)	63.73426 146.1	1.21(.00) 1.20(-0.01)	63.73466 146.1	1.08(.01) 1.09(0.01)
63.83686 146.0	1.08(.00) 1.09(0.01)	63.83691 145.8	0.92(.01) 0.99(0.07)	63.83762 145.8	0.89(.00) 0.90(0.01)
63.96224 146.1	0.98(.01) 1.08(0.10)	63.96346 146.1	0.96(.01) 1.00(0.04)	63.96346 146.3	1.05(.01) 0.93(-0.12)
64.06030 146.1	1.10(.01) 1.18(0.08)	64.06239 146.3	1.17(.01) 1.14(-0.03)	64.06232 146.2	1.15(.01) 1.10(-0.05)
64.17686 146.0	1.06(.01) 1.13(0.07)	64.17704 146.2	1.08(.01) 1.11(0.03)	64.17720 146.3	0.92(.01) 1.08(0.16)
64.26826 146.0	0.86(.01) 0.93(0.07)	64.26917 145.8	0.83(.01) 0.88(0.05)	64.26933 146.2	0.83(.01) 0.83(0.00)
64.37077 146.2	0.79(.01) 0.75(-0.04)	64.37142 146.2	0.84(.01) 0.70(-0.14)	64.37150 146.2	0.68(.01) 0.65(-0.03)
64.47256 146.0	0.77(.01) 0.69(-0.08)	64.47308 146.1	0.73(.01) 0.66(-0.07)	64.47359 146.1	0.64(.01) 0.62(-0.02)

H = 12 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.57699	0.77(.01)	64.57701	0.77(.01)	64.57777	0.65(.01)
146.0	0.74(-0.03)	146.1	0.73(-0.04)	145.8	0.72(0.07)
64.69534	0.79(.01)	64.69653	0.71(.01)	64.69654	0.76(.01)
146.0	0.76(-0.03)	146.1	0.77(0.06)	145.9	0.78(0.02)
64.79402	0.58(.01)	64.79626	0.60(.01)	64.79654	0.65(.01)
146.2	0.63(0.05)	146.2	0.62(0.02)	146.1	0.61(-0.04)
64.91241	0.51(.01)	64.91254	0.44(.01)	64.91275	0.48(.01)
146.1	0.48(-0.03)	146.1	0.46(0.02)	146.3	0.44(-0.04)
65.00481	0.46(.01)	65.00565	0.43(.01)	65.00593	0.48(.01)
146.1	0.43(-0.03)	146.1	0.42(-0.01)	146.2	0.41(-0.07)
65.10854	0.48(.00)	65.10920	0.51(.00)	65.10928	0.47(.01)
146.1	0.45(-0.03)	146.2	0.46(-0.05)	146.2	0.46(-0.01)
65.21149	0.56(.01)	65.21202	0.49(.00)	65.21255	0.46(.01)
146.0	0.48(-0.08)	146.1	0.50(0.01)	146.1	0.52(0.06)
65.31712	0.40(.00)	65.31715	0.43(.00)	65.31788	0.39(.01)
146.0	0.40(0.00)	146.1	0.42(-0.01)	146.1	0.42(0.03)
65.42842	0.32(.01)	65.42963	0.29(.01)	65.42963	0.35(.01)
146.0	0.31(-0.01)	146.1	0.30(0.01)	145.9	0.30(-0.05)
65.52821	0.30(.01)	65.53048	0.24(.01)	65.53075	0.33(.01)
146.2	0.26(-0.04)	146.2	0.26(0.02)	146.2	0.26(-0.07)
65.64796	0.35(.01)	65.64810	0.28(.01)	65.64830	0.30(.01)
146.0	0.27(-0.08)	146.1	0.28(0.00)	146.2	0.29(-0.01)
65.74140	0.25(.01)	65.74227	0.30(.00)	65.74254	0.27(.01)
146.1	0.28(0.03)	146.1	0.30(0.00)	146.2	0.32(0.05)
65.84631	0.24(.01)	65.84698	0.23(.01)	65.84707	0.27(.01)
146.1	0.24(0.00)	146.2	0.26(0.03)	146.2	0.27(0.00)
65.95044	0.18(.01)	65.95097	0.11(.01)	65.95152	0.19(.01)
146.0	0.19(0.01)	146.1	0.19(0.08)	146.1	0.19(0.00)
66.05726	0.08(.01)	66.05729	0.10(.01)	66.05803	0.11(.01)
146.0	0.16(0.08)	146.2	0.16(0.06)	146.2	0.16(0.05)
66.16150	0.16(.00)	66.16273	0.20(.01)	66.16273	0.12(.01)
146.0	0.16(0.00)	146.1	0.16(-0.04)	145.9	0.17(0.05)
66.26241	0.19(.01)	66.26472	0.09(.01)	66.26499	0.17(.01)
146.2	0.16(-0.03)	146.2	0.18(0.09)	146.1	0.19(0.02)

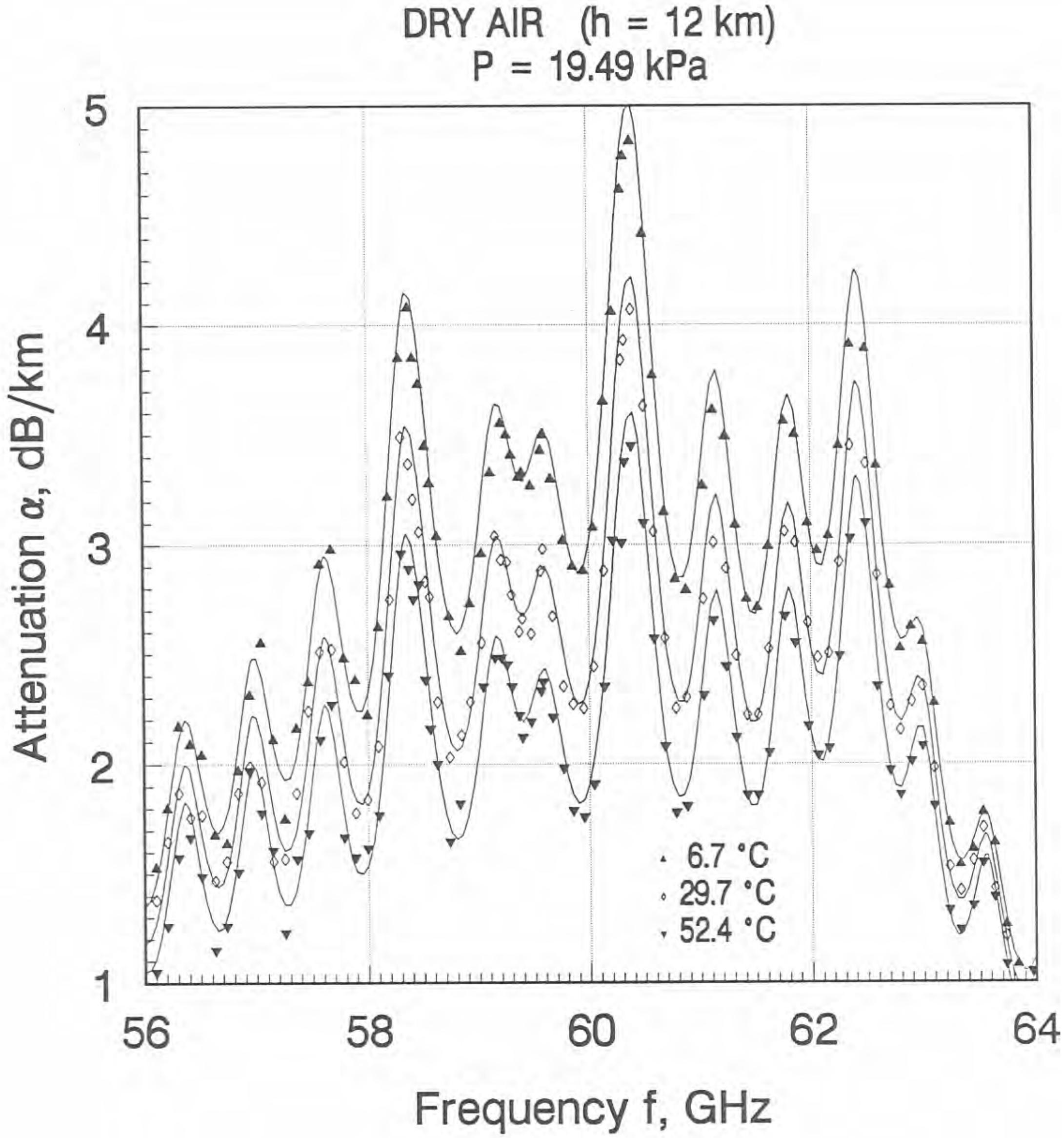

Figure A-7a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 12 km (see **G.**) for frequencies between 56 and 64 GHz.

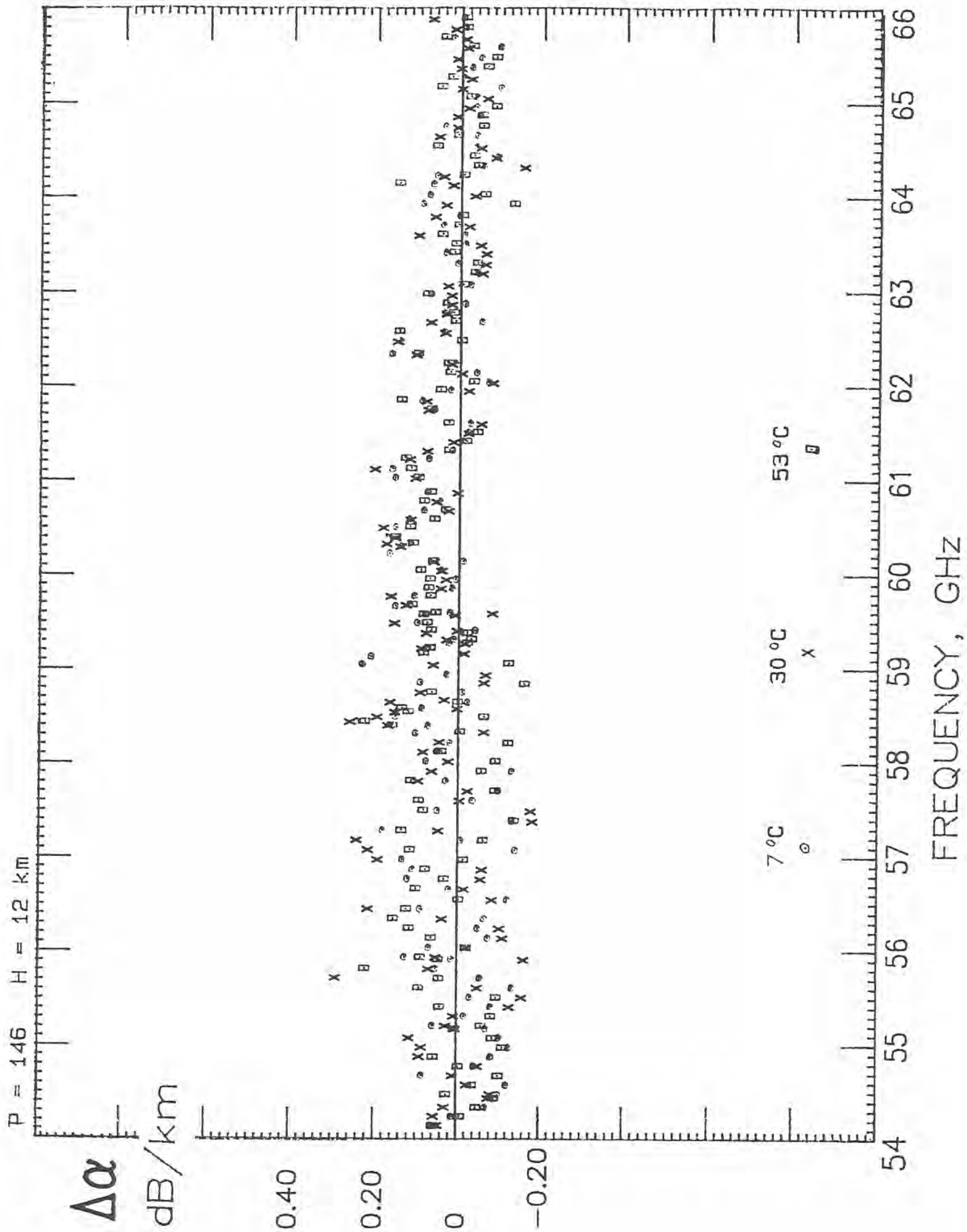

Figure A-7b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **G**.

H.

H = 9 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(34)	52.40(08)
P	[torr] [kPa]	**231.00(10)**	**231.00(11)** 30.811	**231.30(23)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.103	0.091	0.107

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89154 231.1	0.21(.03) 0.39(0.18)	53.89180 231.2	0.42(.03) 0.38(-0.04)	53.89204 231.2	0.52(.02) 0.37(-0.15)
53.99028 231.0	0.53(.02) 0.44(-0.09)	53.99051 231.1	0.31(.02) 0.43(0.12)	53.99076 232.1	0.51(.03) 0.43(-0.08)
54.08889 230.9	0.51(.02) 0.49(-0.02)	54.08916 231.1	0.48(.03) 0.49(0.01)	54.08933 231.3	0.43(.03) 0.49(0.06)
54.18762 231.2	0.49(.03) 0.54(0.05)	54.18811 231.0	0.40(.04) 0.53(0.13)	54.18804 231.2	0.49(.03) 0.53(0.04)
54.28625 230.9	0.60(.03) 0.57(-0.03)	54.28644 231.0	0.55(.02) 0.55(0.00)	54.28668 231.3	0.67(.04) 0.54(-0.13)
54.38366 230.9	0.80(.02) 0.61(-0.19)	54.38389 231.1	0.58(.03) 0.59(0.01)	54.38536 231.1	0.42(.03) 0.57(0.15)
54.42519 230.9	0.62(.02) 0.63(0.01)	54.42636 231.0	0.59(.02) 0.61(0.02)	54.42754 231.1	0.53(.03) 0.59(0.06)
54.52632 231.0	0.80(.02) 0.71(-0.09)	54.52761 231.1	0.78(.02) 0.69(-0.09)	54.52781 230.9	0.60(.03) 0.67(0.07)
54.62725 231.1	0.71(.02) 0.80(0.09)	54.62751 231.1	0.96(.03) 0.78(-0.18)	54.62775 231.2	0.87(.04) 0.76(-0.11)
54.72734 231.0	0.89(.02) 0.87(-0.02)	54.72757 231.1	0.86(.03) 0.84(-0.02)	54.72782 231.2	0.87(.03) 0.82(-0.05)
54.82730 230.9	0.99(.03) 0.91(-0.08)	54.82758 231.1	0.83(.03) 0.87(0.04)	54.82775 231.3	0.66(.04) 0.83(0.17)
54.92738 231.1	1.07(.04) 0.97(-0.10)	54.92787 231.0	0.74(.03) 0.91(0.17)	54.92780 231.2	0.84(.04) 0.86(0.02)
55.02736 230.9	0.94(.03) 1.07(0.13)	55.02755 231.0	1.01(.02) 1.00(-0.01)	55.02780 231.3	0.90(.04) 0.94(0.04)
55.12610 231.0	1.39(.02) 1.20(-0.19)	55.12645 231.2	1.00(.03) 1.13(0.13)	55.12783 231.1	0.92(.04) 1.07(0.15)
55.15818 230.9	1.24(.03) 1.24(0.00)	55.15936 230.8	1.04(.03) 1.17(0.13)	55.16056 231.1	1.05(.04) 1.12(0.07)
55.26066 231.0	1.46(.04) 1.35(-0.11)	55.26198 231.1	1.20(.03) 1.27(0.07)	55.26218 231.0	1.22(.05) 1.21(-0.01)
55.36295 231.1	1.36(.03) 1.41(0.05)	55.36322 231.1	1.40(.04) 1.31(-0.09)	55.36348 231.2	1.17(.03) 1.22(0.05)
55.46440 231.0	1.58(.03) 1.48(-0.10)	55.46463 231.2	1.27(.04) 1.36(0.09)	55.46489 231.7	1.35(.04) 1.25(-0.10)
55.56570 230.9	1.63(.03) 1.61(-0.02)	55.56599 231.1	1.34(.04) 1.47(0.13)	55.56616 231.3	1.43(.03) 1.35(-0.08)

H = 9.0 km

6.7°C f_x [GHz] P [torr]	6.7°C $\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] P [torr]	29.7°C $\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] P [torr]	52.4°C $\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km
55.66714 231.2	1.83(.03) 1.81(-0.02)	55.66764 231.0	1.49(.03) 1.66(0.17)	55.66756 231.2	1.51(.04) 1.52(0.01)
55.76847 231.0	2.00(.03) 2.00(0.00)	55.76867 231.0	1.85(.04) 1.84(-0.01)	55.76892 231.3	1.57(.04) 1.70(0.13)
55.86854 230.9	2.21(.03) 2.12(-0.09)	55.86879 231.1	2.06(.03) 1.94(-0.12)	55.87030 231.2	1.67(.04) 1.77(0.10)
55.89116 230.9	2.06(.04) 2.15(0.09)	55.89236 230.9	1.98(.02) 1.95(-0.03)	55.89357 231.1	1.82(.04) 1.78(-0.04)
55.99501 231.0	2.18(.03) 2.24(0.06)	55.99634 231.1	2.01(.03) 2.00(-0.01)	55.99654 230.9	1.88(.04) 1.80(-0.08)
56.09866 231.1	2.47(.03) 2.39(-0.08)	56.09893 231.1	2.24(.04) 2.12(-0.12)	56.09919 231.2	2.02(.04) 1.89(-0.13)
56.20146 231.0	2.64(.03) 2.61(-0.03)	56.20170 231.2	2.24(.04) 2.33(0.09)	56.20196 231.1	2.05(.03) 2.09(0.04)
56.30411 230.9	2.74(.04) 2.84(0.10)	56.30440 231.1	2.46(.04) 2.55(0.09)	56.30457 231.3	2.37(.04) 2.30(-0.07)
56.40690 231.2	2.87(.04) 2.96(0.09)	56.40740 231.0	2.47(.04) 2.65(0.18)	56.40733 231.2	2.25(.04) 2.39(0.14)
56.50959 230.9	2.78(.03) 2.97(0.19)	56.50978 231.0	2.52(.04) 2.62(0.10)	56.51004 231.3	2.18(.04) 2.33(0.15)
56.62414 230.9	2.96(.03) 2.96(0.00)	56.62536 230.8	2.46(.02) 2.57(0.11)	56.62659 231.1	2.23(.04) 2.26(0.03)
56.72936 231.0	3.05(.04) 3.05(0.00)	56.73071 231.1	2.60(.04) 2.65(0.05)	56.73092 231.3	2.27(.04) 2.31(0.04)
56.83438 231.1	3.24(.03) 3.25(0.01)	56.83465 231.1	2.94(.04) 2.83(-0.11)	56.83492 231.2	2.35(.05) 2.49(0.14)
56.93852 231.0	3.28(.04) 3.44(0.16)	56.93876 231.2	2.87(.04) 3.02(0.15)	56.93903 232.0	2.55(.04) 2.68(0.13)
57.04252 230.9	3.61(.04) 3.52(-0.09)	57.04283 231.1	2.90(.04) 3.07(0.17)	57.04301 231.3	2.66(.04) 2.71(0.05)
57.14668 231.2	3.31(.03) 3.48(0.17)	57.14718 231.0	2.85(.04) 3.00(0.15)	57.14711 231.2	2.52(.04) 2.61(0.09)
57.25071 230.9	3.33(.04) 3.47(0.14)	57.25090 231.1	2.81(.05) 2.96(0.15)	57.25116 231.3	2.32(.03) 2.54(0.22)
57.35713 230.9	3.78(.05) 3.58(-0.20)	57.35381 231.2	3.09(.04) 3.04(-0.05)	57.35961 231.1	2.69(.06) 2.61(-0.08)
57.46372 231.0	3.68(.04) 3.82(0.14)	57.46510 231.1	3.32(.06) 3.27(-0.05)	57.46530 231.0	2.76(.06) 2.82(0.06)

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57010 231.1	3.85(.04) 4.05(0.20)	57.57038 231.1	3.26(.04) 3.48(0.22)	57.57065 231.2	3.12(.05) 3.03(-0.09)
57.67560 231.0	3.97(.05) 4.14(0.17)	57.67585 231.2	3.54(.04) 3.54(0.00)	57.67612 231.6	3.11(.07) 3.07(-0.04)
57.78096 230.9	4.04(.05) 4.09(0.05)	57.78127 231.1	3.37(.07) 3.45(0.08)	57.78145 231.3	2.96(.04) 2.95(-0.01)
57.88646 231.2	4.12(.05) 4.06(-0.06)	57.88698 231.0	3.36(.04) 3.38(0.02)	57.88692 231.2	2.93(.06) 2.85(-0.08)
57.99184 230.9	4.10(.04) 4.18(0.08)	57.99205 231.0	3.60(.04) 3.46(-0.14)	57.99231 231.3	2.72(.06) 2.90(0.18)
58.09565 230.9	4.50(.03) 4.47(-0.03)	58.09140 230.9	3.62(.04) 3.71(0.09)	58.09703 231.0	3.01(.03) 3.14(0.13)
58.18470 231.0	4.63(.03) 4.83(0.20)	58.19948 231.1	3.92(.05) 4.10(0.18)	58.18665 231.1	3.44(.02) 3.44(0.00)
58.29041 230.8	5.00(.04) 5.20(0.20)	58.30611 231.1	4.43(.04) 4.43(0.00)	58.30639 231.3	3.74(.05) 3.80(0.06)
58.37359 231.1	5.12(.04) 5.34(0.22)	58.37450 231.0	4.32(.02) 4.52(0.20)	58.37485 231.2	3.55(.03) 3.87(0.32)
58.41269 231.1	5.05(.04) 5.35(0.30)	58.41293 231.2	4.46(.04) 4.51(0.05)	58.41320 231.5	3.52(.04) 3.86(0.34)
58.46668 231.2	5.16(.04) 5.30(0.14)	58.46729 231.1	4.19(.03) 4.45(0.26)	58.46769 230.9	3.61(.02) 3.78(0.17)
58.51938 230.9	5.09(.06) 5.20(0.11)	58.51969 231.1	4.18(.03) 4.34(0.16)	58.51987 231.4	3.47(.04) 3.67(0.20)
58.55933 230.9	4.97(.02) 5.11(0.14)	58.55982 230.9	4.12(.02) 4.24(0.12)	58.56040 231.0	3.40(.02) 3.56(0.16)
58.62622 231.1	4.78(.03) 4.95(0.17)	58.62675 231.0	4.08(.03) 4.07(-0.01)	58.62667 231.2	3.20(.04) 3.39(0.19)
58.73295 230.9	4.60(.04) 4.75(0.15)	58.73316 231.1	3.70(.03) 3.87(0.17)	58.73341 231.3	3.14(.03) 3.20(0.06)
58.83834 231.0	4.57(.02) 4.71(0.14)	58.83871 231.2	3.70(.03) 3.83(0.13)	58.82566 231.1	3.10(.03) 3.15(0.05)
58.91888 230.9	4.63(.02) 4.79(0.16)	58.92093 231.0	4.00(.02) 3.91(-0.09)		
59.02593 230.8	4.76(.02) 4.98(0.22)	59.02634 231.1	4.02(.01) 4.09(0.07)	59.04208 231.2	3.41(.04) 3.44(0.03)
59.11016 231.1	4.91(.02) 5.13(0.22)	59.14998 231.2	4.11(.03) 4.28(0.17)	59.15025 232.0	3.67(.03) 3.59(-0.08)

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20443 231.2	5.12(.02) 5.21(0.09)	59.20504 231.0	4.23(.02) 4.30(0.07)	59.20546 231.0	3.51(.02) 3.61(0.10)
59.25776 230.9	5.12(.03) 5.21(0.09)	59.25808 231.1	4.21(.02) 4.30(0.09)	59.25826 231.3	3.63(.04) 3.60(-0.03)
59.29824 230.9	5.21(.02) 5.21(0.00)	59.29874 230.9	4.19(.01) 4.28(0.09)	59.29934 231.1	3.46(.01) 3.58(0.12)
59.36596 231.1	5.08(.02) 5.19(0.11)	59.36649 231.0	4.13(.02) 4.26(0.13)	59.36641 231.2	3.32(.03) 3.54(0.22)
59.39394 231.0	5.07(.02) 5.19(0.12)	59.39423 231.0	4.14(.01) 4.25(0.11)	59.39511 231.0	3.38(.01) 3.54(0.16)
59.47403 230.9	5.15(.02) 5.20(0.05)	59.47424 231.1	4.16(.03) 4.26(0.10)	59.47450 231.3	3.28(.03) 3.55(0.27)
59.56174 230.9	5.08(.01) 5.23(0.15)	59.56275 231.0	4.25(.01) 4.29(0.04)	59.56317 231.0	3.32(.01) 3.57(0.25)
59.58075 230.9	5.11(.03) 5.23(0.12)	59.58101 231.0	4.13(.03) 4.29(0.16)	59.58263 231.2	3.37(.03) 3.57(0.20)
59.65305 230.9	5.08(.02) 5.23(0.15)	59.66815 231.1	4.14(.03) 4.26(0.12)	59.66836 231.2	3.52(.04) 3.54(0.02)
59.76144 230.8	5.08(.01) 5.17(0.09)	59.76186 231.1	4.06(.01) 4.20(0.14)	59.76231 231.1	3.32(.01) 3.47(0.15)
59.84673 231.1	4.96(.01) 5.15(0.19)	59.84767 231.0	4.09(.01) 4.16(0.07)	59.84803 231.2	3.36(.01) 3.42(0.06)
59.94217 231.2	5.10(.01) 5.23(0.13)	59.94280 231.1	4.08(.01) 4.22(0.14)	59.94323 230.9	3.31(.01) 3.46(0.15)
60.03716 230.9	5.29(.01) 5.43(0.14)	60.03766 230.9	4.33(.01) 4.41(0.08)	60.03827 231.0	3.54(.01) 3.63(0.09)
60.13406 231.0	5.82(.02) 5.77(-0.05)	60.13435 230.9	4.57(.01) 4.72(0.15)	60.13524 231.0	3.78(.01) 3.93(0.15)
60.21511 230.9	6.01(.10) 6.08(0.07)			60.21560 231.3	3.95(.09) 4.22(0.27)
60.29482 230.9	6.14(.01) 6.33(0.19)	60.29583 231.0	5.07(.01) 5.28(0.21)	60.29626 231.0	4.23(.01) 4.46(0.23)
60.32320 230.9	6.08(.07) 6.39(0.31)	60.32357 231.2	5.25(.07) 5.34(0.09)	60.32510 231.2	4.26(.09) 4.52(0.26)
60.38725 230.9	6.25(.01) 6.45(0.20)	60.38935 230.9	5.20(.01) 5.39(0.19)	60.38928 231.2	4.32(.01) 4.58(0.26)
60.49697 230.8	5.99(.01) 6.26(0.27)	60.49740 231.1	4.96(.01) 5.22(0.26)	60.49786 231.0	4.21(.01) 4.41(0.20)

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] / P [torr]	$\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58331	5.80(.01)	60.58427	4.70(.01)	60.58463	3.97(.01)
231.1	5.94(0.14)	231.0	4.91(0.21)	231.2	4.11(0.14)
60.67994	5.39(.01)	60.68056	4.47(.01)	60.68100	3.60(.01)
231.2	5.56(0.17)	231.0	4.55(0.08)	230.9	3.78(0.18)
60.77609	5.14(.01)	60.77660	4.22(.01)	60.77721	3.38(.01)
230.9	5.29(0.15)	230.9	4.31(0.09)	231.1	3.56(0.18)
60.87418	5.06(.01)	60.87447	4.17(.01)	60.87537	3.32(.01)
231.0	5.20(0.14)	230.9	4.25(0.08)	231.0	3.53(0.21)
61.02788	5.08(.01)	61.02890	4.29(.01)	61.02934	3.58(.01)
230.8	5.33(0.25)	231.0	4.44(0.15)	231.0	3.74(0.16)
61.12141	5.25(.02)	61.12356	4.34(.01)	61.12362	3.64(.01)
230.8	5.40(0.15)	230.8	4.53(0.19)	231.0	3.86(0.22)
61.23263	5.29(.02)	61.23296	4.25(.01)	61.23339	3.59(.01)
230.8	5.30(0.01)	231.1	4.45(0.20)	231.1	3.78(0.19)
61.31985	5.08(.02)	61.32085	4.16(.01)	61.32121	3.42(.01)
231.2	5.12(0.04)	231.0	4.26(0.10)	231.0	3.60(0.18)
61.41772	4.91(.01)	61.41844	3.96(.01)	61.41874	3.37(.01)
230.9	4.94(0.03)	231.1	4.09(0.13)	231.1	3.44(0.07)
61.51500	4.87(.02)	61.51551	4.03(.01)	61.51612	3.38(.01)
230.8	4.89(0.02)	231.0	4.07(0.04)	230.9	3.42(0.04)
61.61430	4.97(.01)	61.61462	4.05(.01)	61.61549	3.50(.01)
230.9	5.01(0.04)	230.9	4.20(0.15)	231.1	3.57(0.07)
61.76092	5.17(.01)	61.76225	4.40(.01)	61.76238	3.75(.01)
231.0	5.24(0.07)	231.1	4.47(0.07)	231.1	3.86(0.11)
61.85559	5.16(.01)	61.85778	4.39(.01)	61.85783	3.73(.01)
230.8	5.25(0.09)	230.8	4.48(0.09)	230.9	3.87(0.14)
61.96814	5.04(.01)	61.96849	4.26(.01)	61.96892	3.58(.01)
230.7	5.12(0.08)	231.0	4.34(0.08)	231.0	3.72(0.14)
62.05642	5.11(.01)	62.05743	4.29(.01)	62.05781	3.59(.01)
231.2	5.05(-0.06)	231.0	4.26(-0.03)	231.0	3.63(0.04)
62.15547	5.08(.01)	62.15619	4.25(.01)	62.15651	3.59(.01)
230.8	5.10(0.02)	231.1	4.32(0.07)	231.1	3.70(0.11)
62.25393	5.16(.01)	62.25443	4.50(.01)	62.25507	3.75(.01)
230.8	5.27(0.11)	231.0	4.53(0.03)	230.9	3.92(0.17)
62.35450	5.27(.01)	62.35474	4.67(.01)	62.35562	4.01(.01)
230.8	5.43(0.16)	230.8	4.72(0.05)	231.1	4.15(0.14)
62.49398	5.13(.01)	62.49533	4.57(.01)	62.49546	4.07(.01)
231.0	5.28(0.15)	231.1	4.61(0.04)	231.1	4.05(-0.02)

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.58978 230.8	4.88(.01) 4.93(0.05)	62.59199 230.8	4.24(.01) 4.27(0.03)	62.59205 230.9	3.53(.01) 3.73(0.20)
62.70367 230.7	4.49(.01) 4.48(-0.01)	62.70402 231.0	3.72(.01) 3.87(0.15)	62.70446 231.0	3.27(.01) 3.37(0.10)
62.79300 231.1	4.15(.01) 4.22(0.07)	62.79402 231.0	3.57(.01) 3.66(0.09)	62.79440 231.0	3.11(.01) 3.20(0.09)
62.89323 230.8	3.98(.01) 4.02(0.04)	62.89396 231.0	3.49(.01) 3.53(0.04)	62.89427 231.1	3.07(.01) 3.13(0.06)
62.99286 230.8	3.78(.01) 3.80(0.02)	62.99337 231.0	3.32(.01) 3.37(0.05)	62.99401 230.9	2.95(.01) 3.02(0.07)
63.09462 230.8	3.52(.01) 3.47(-0.05)	63.09487 230.8	3.11(.01) 3.08(-0.03)	63.09576 231.1	2.81(.01) 2.76(-0.05)
63.22704 231.0	3.02(.01) 3.03(0.01)	63.22840 231.0	2.76(.00) 2.67(-0.09)	63.22853 231.1	2.51(.01) 2.38(-0.13)
63.32397 230.8	2.83(.01) 2.81(-0.02)	63.32620 230.8	2.45(.01) 2.50(0.05)	63.32626 231.0	2.23(.01) 2.23(0.00)
63.43919 230.7	2.61(.01) 2.69(0.08)	63.43955 231.0	2.46(.01) 2.43(-0.03)	63.43999 231.1	2.20(.01) 2.21(0.01)
63.52957 231.1	2.61(.01) 2.61(0.00)	63.53061 231.0	2.40(.01) 2.39(-0.01)	63.53099 231.0	2.14(.01) 2.20(0.06)
63.63098 230.8	2.48(.01) 2.44(-0.04)	63.63171 231.1	2.18(.01) 2.24(0.06)	63.63203 231.0	2.00(.01) 2.07(0.07)
63.73177 230.8	2.12(.01) 2.20(0.08)	63.73229 230.9	2.02(.01) 2.02(0.00)	63.73294 230.9	1.79(.01) 1.85(0.06)
63.83474 230.8	2.00(.01) 2.00(0.00)	63.83499 230.8	1.76(.01) 1.82(0.06)	63.83589 231.1	1.68(.01) 1.67(-0.01)
63.96009 231.0	1.77(.01) 1.86(0.09)	63.96148 231.1	1.70(.01) 1.72(0.02)	63.96161 231.1	1.71(.01) 1.60(-0.11)
64.05814 230.8	1.72(.01) 1.80(0.08)	64.06041 230.8	1.73(.01) 1.70(-0.03)	64.06047 230.9	1.70(.01) 1.60(-0.10)
64.17471 230.7	1.67(.01) 1.68(0.01)	64.17508 231.0	1.49(.01) 1.59(0.10)	64.17548 231.0	1.44(.01) 1.52(0.08)
64.26614 231.1	1.53(.00) 1.53(0.00)	64.26719 231.0	1.34(.01) 1.44(0.10)	64.26755 231.3	1.37(.01) 1.36(-0.01)
64.36871 230.9	1.44(.00) 1.37(-0.07)	64.36942 231.0	1.43(.01) 1.29(-0.14)	64.36976 231.1	1.24(.01) 1.21(-0.03)
64.47052 230.9	1.29(.01) 1.27(-0.02)	64.47113 231.0	1.30(.01) 1.20(-0.10)	64.47186 230.9	1.19(.01) 1.13(-0.06)

H = 9.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.57483 230.9	1.25(.01) 1.21(-0.04)	64.57507 230.9	1.23(.01) 1.16(-0.07)	64.57602 231.1	1.08(.01) 1.12(0.04)
64.69321 230.8	1.23(.01) 1.13(-0.10)	64.69453 230.8	1.10(.01) 1.10(0.00)	64.69466 231.1	1.06(.01) 1.08(0.02)
64.79185 230.9	0.96(.01) 1.03(0.07)	64.79426 230.8	0.98(.00) 0.99(0.01)	64.79465 231.1	1.05(.01) 0.97(-0.08)
64.91023 230.9	0.88(.01) 0.89(0.01)	64.91056 231.1	0.84(.00) 0.86(0.02)	64.91101 231.0	0.88(.01) 0.83(-0.05)
65.00270 230.8	0.81(.01) 0.82(0.01)	65.00372 231.1	0.83(.00) 0.79(-0.04)	65.00414 231.3	0.84(.01) 0.77(-0.07)
65.10646 230.9	0.79(.00) 0.78(-0.01)	65.10717 231.0	0.85(.00) 0.76(-0.09)	65.10752 231.0	0.81(.01) 0.75(-0.06)
65.20943 230.8	0.82(.01) 0.73(-0.09)	65.21007 231.0	0.70(.01) 0.73(0.03)	65.21079 230.9	0.67(.01) 0.73(0.06)
65.31494 230.9	0.67(.00) 0.66(-0.01)	65.31519 230.9	0.70(.01) 0.66(-0.04)	65.31612 231.0	0.60(.01) 0.66(0.06)
65.42625 230.7	0.56(.01) 0.58(0.02)	65.42760 230.8	0.56(.00) 0.57(0.01)	65.42772 231.2	0.63(.01) 0.56(-0.07)
65.52602 230.9	0.55(.01) 0.52(-0.03)	65.52847 230.8	0.45(.01) 0.51(0.06)	65.52885 231.1	0.56(.01) 0.50(-0.06)
65.64574 230.9	0.57(.01) 0.48(-0.09)	65.64608 231.1	0.47(.01) 0.48(0.01)	65.64654 231.0	0.51(.01) 0.48(-0.03)
65.73927 230.8	0.42(.01) 0.45(0.03)	65.74030 231.1	0.38(.01) 0.46(0.08)	65.74072 231.3	0.40(.01) 0.47(0.07)
65.84421 230.9	0.37(.01) 0.41(0.04)	65.84494 231.0	0.37(.01) 0.41(0.04)	65.84529 231.1	0.41(.01) 0.42(0.01)
65.94836 230.8	0.37(.00) 0.36(-0.01)	65.94899 231.0	0.26(.01) 0.36(0.10)	65.94973 230.9	0.21(.01) 0.36(0.15)
66.05505 230.8	0.21(.00) 0.32(0.11)	66.05531 230.9	0.24(.01) 0.32(0.08)	66.05625 231.0	0.23(.01) 0.32(0.09)
66.15931 230.7	0.30(.01) 0.30(0.00)	66.16066 230.8	0.34(.01) 0.30(-0.04)	66.16080 231.2	0.23(.01) 0.30(0.07)
66.26020 230.9	0.28(.01) 0.28(0.00)	66.26267 230.8	0.10(.01) 0.28(0.18)	66.26306 231.1	0.22(.01) 0.29(0.07)

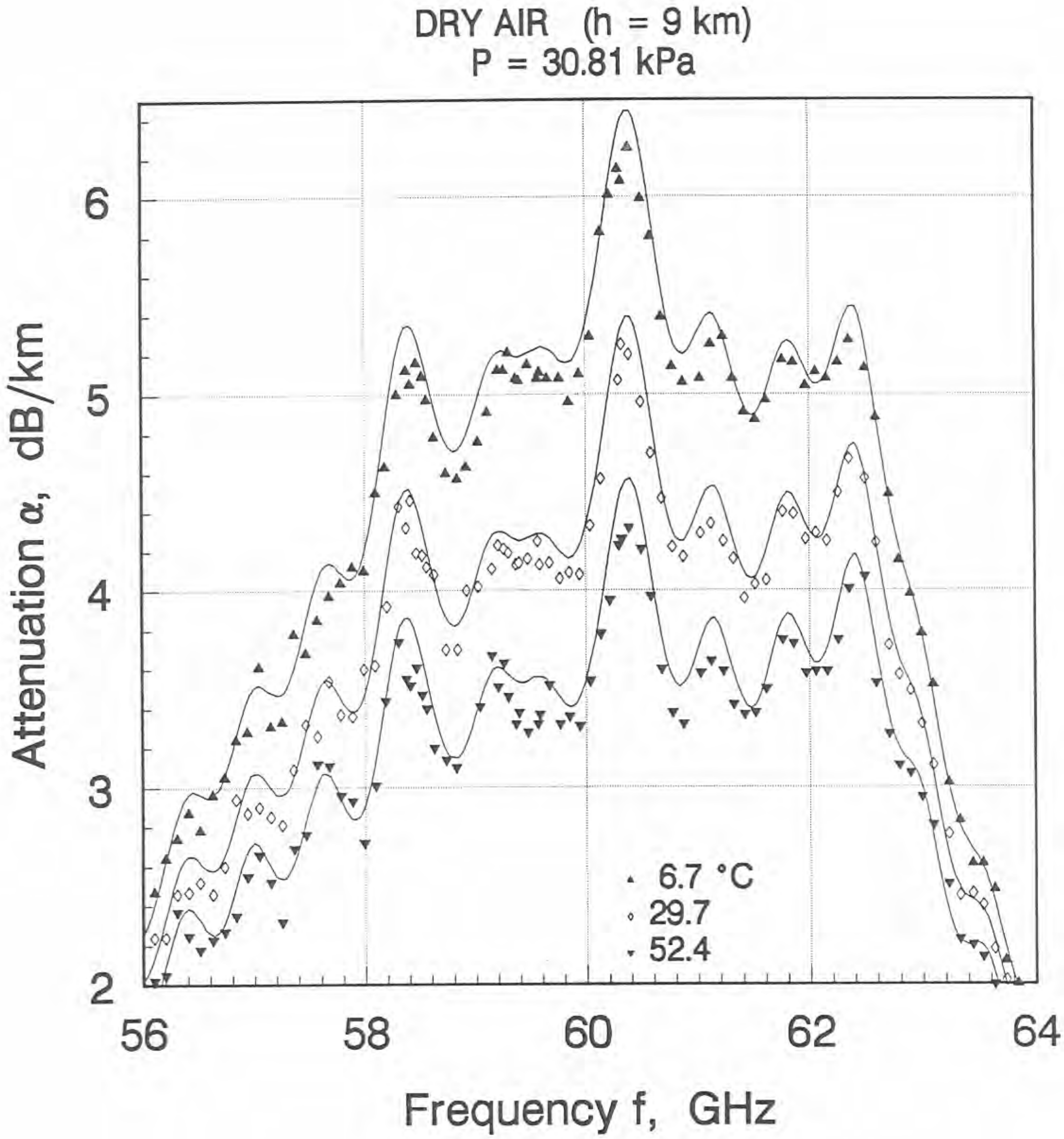

Figure A-8a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 9 km (see **H.**) for frequencies between 56 and 64 GHz.

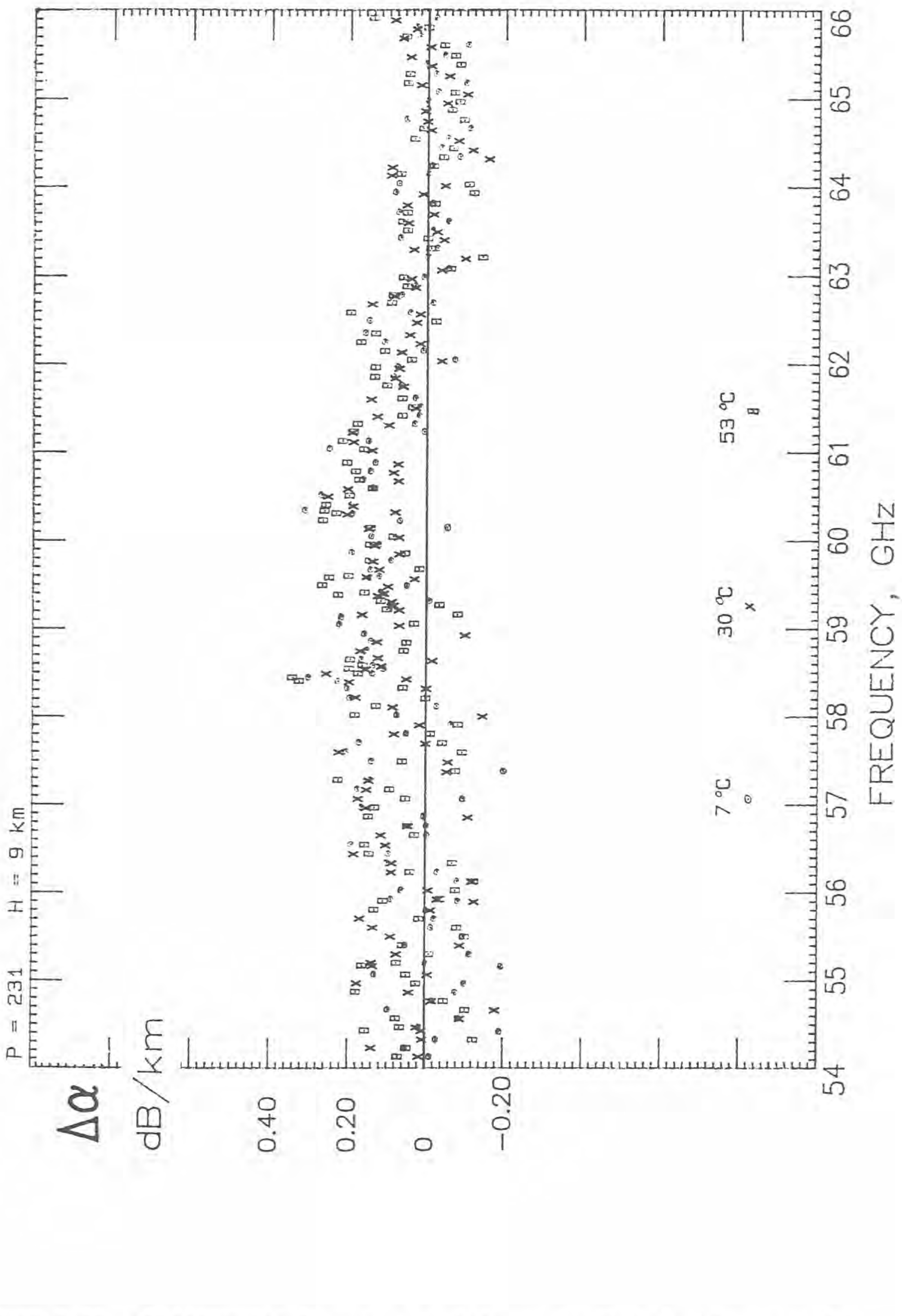

Figure A-8b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **H**.

I.

H = 6 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(34)	52.40(08)
P	[torr] [kPa]	**353.90(23)**	**354.00(14)** 47.187	353.90(31)
$\sigma_x(\Delta\alpha)$	[dB/km]	0.147	0.144	0.141

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.88908 354.2	0.56(.03) 0.70(0.14)	53.88953 353.9	0.64(.02) 0.66(0.02)	53.88994 354.1	0.65(.03) 0.64(-0.01)
53.98781 354.4	0.74(.02) 0.76(0.02)	53.98825 353.7	0.65(.02) 0.73(0.08)	53.98867 353.2	0.83(.02) 0.70(-0.13)
54.08641 353.8	0.74(.02) 0.83(0.09)	54.08689 353.9	0.69(.03) 0.79(0.10)	54.08722 354.0	0.81(.03) 0.77(-0.04)
54.18515 353.9	1.04(.03) 0.90(-0.14)	54.18582 353.9	0.79(.02) 0.86(0.07)	54.18592 353.8	0.79(.03) 0.83(0.04)
54.28377 353.8	0.79(.02) 0.97(0.18)	54.28416 353.9	0.87(.02) 0.92(0.05)	54.28456 353.9	1.05(.04) 0.89(-0.16)
54.38117 353.7	1.19(.02) 1.05(-0.14)	54.38160 353.9	1.02(.03) 1.00(-0.02)	54.38324 354.0	0.98(.03) 0.95(-0.03)
54.42270 354.0	1.21(.02) 1.09(-0.12)	54.42406 354.2	1.04(.02) 1.03(-0.01)	54.42542 353.9	0.86(.03) 0.98(0.12)
54.52383 353.7	1.45(.03) 1.18(-0.27)	54.52532 353.7	1.24(.02) 1.12(-0.12)	54.52568 353.9	1.10(.04) 1.07(-0.03)
54.62475 354.2	1.08(.02) 1.29(0.21)	54.62521 353.9	1.30(.03) 1.22(-0.08)	54.62563 354.1	1.24(.03) 1.16(-0.08)
54.72483 354.4	1.41(.03) 1.39(-0.02)	54.72527 353.7	1.18(.03) 1.31(0.13)	54.72570 353.2	1.27(.02) 1.25(-0.02)
54.82478 353.8	1.48(.03) 1.50(0.02)	54.82527 353.8	1.49(.03) 1.41(-0.08)	54.82561 354.0	1.25(.04) 1.33(0.08)
54.92487 354.0	1.67(.03) 1.61(-0.06)	54.92555 353.9	1.39(.03) 1.51(0.12)	54.92567 353.8	1.33(.04) 1.41(0.08)
55.02485 353.8	1.81(.04) 1.74(-0.07)	55.02524 353.9	1.82(.03) 1.62(-0.20)	55.02565 353.9	1.41(.06) 1.52(0.11)
55.12358 353.8	2.05(.03) 1.88(-0.17)	55.12413 353.8	1.71(.04) 1.75(0.04)	55.12568 354.1	1.48(.04) 1.64(0.16)
55.15565 354.1	1.95(.03) 1.93(-0.02)	55.15703 354.2	1.96(.03) 1.80(-0.16)	55.15840 353.9	1.84(.04) 1.68(-0.16)
55.25814 353.7	2.15(.04) 2.08(-0.07)	55.25965 353.7	1.77(.04) 1.93(0.16)	55.26003 353.9	1.99(.04) 1.80(-0.19)
55.36042 354.2	2.13(.03) 2.23(0.10)	55.36089 353.9	2.14(.04) 2.06(-0.08)	55.36131 354.1	1.97(.04) 1.90(-0.07)
55.46185 354.3	2.66(.03) 2.39(-0.27)	55.46231 353.7	2.33(.03) 2.19(-0.14)	55.46275 353.3	2.10(.05) 2.01(-0.09)
55.56316 353.8	2.50(.03) 2.57(0.07)	55.56366 353.9	2.37(.04) 2.34(-0.03)	55.56400 354.0	2.17(.03) 2.14(-0.03)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.66459	3.00(.03)	55.66529	2.36(.04)	55.66541	2.33(.04)
354.0	2.76(-0.24)	353.9	2.51(0.15)	353.8	2.30(-0.03)
55.76592	3.02(.03)	55.76632	2.57(.04)	55.76674	2.37(.04)
353.8	2.97(-0.05)	353.9	2.69(0.12)	353.9	2.46(0.09)
55.86599	3.26(.03)	55.86643	3.01(.03)	55.86813	2.53(.05)
353.8	3.16(-0.10)	353.9	2.85(-0.16)	354.0	2.60(0.07)
55.88860	3.35(.04)	55.89000	3.03(.03)	55.89139	2.71(.03)
354.1	3.20(-0.15)	354.1	2.89(-0.14)	353.9	2.63(-0.08)
55.99245	3.36(.03)	55.99399	3.07(.04)	55.99435	2.65(.04)
353.7	3.39(0.03)	353.7	3.05(-0.02)	355.0	2.75(0.10)
56.09610	3.78(.04)	56.09657	3.32(.04)	56.09700	2.92(.04)
354.2	3.60(-0.18)	353.9	3.22(-0.10)	354.1	2.89(-0.03)
56.19888	3.80(.03)	56.19934	3.34(.05)	56.19979	2.91(.04)
354.3	3.81(0.01)	353.8	3.40(0.06)	353.4	3.06(0.15)
56.30153	4.12(.03)	56.30204	3.55(.03)	56.30238	3.10(.03)
353.8	4.02(-0.10)	353.8	3.59(0.04)	354.0	3.22(0.12)
56.40432	4.01(.03)	56.40503	3.56(.04)	56.40514	3.33(.05)
353.9	4.21(0.20)	353.9	3.74(0.18)	353.8	3.35(0.02)
56.50700	4.36(.04)	56.50740	3.91(.04)	56.50783	3.43(.04)
353.8	4.37(0.01)	353.9	3.87(-0.04)	354.0	3.44(0.01)
56.62155	4.58(.03)	56.62297	3.77(.03)	56.62438	3.52(.04)
354.0	4.54(-0.04)	354.0	3.99(0.22)	353.9	3.52(0.00)
56.72676	4.77(.04)	56.72832	4.19(.04)	56.72871	3.69(.05)
353.7	4.70(-0.07)	353.7	4.12(-0.07)	355.0	3.63(-0.06)
56.83178	4.75(.04)	56.83226	4.42(.05)	56.83271	3.81(.06)
354.3	4.89(0.14)	353.9	4.27(-0.15)	354.1	3.75(-0.06)
56.93591	5.04(.05)	56.93637	4.24(.04)	56.93682	3.69(.05)
354.3	5.06(0.02)	353.8	4.42(0.18)	354.3	3.88(0.19)
57.03991	5.16(.06)	57.04043	4.63(.05)	57.04078	3.87(.05)
353.8	5.22(0.06)	353.8	4.54(-0.09)	354.0	3.97(0.10)
57.14406	5.39(.04)	57.14478	4.46(.05)	57.14490	4.12(.05)
353.8	5.35(-0.04)	353.9	4.62(0.16)	353.8	4.03(-0.09)
57.24809	5.10(.06)	57.24851	4.83(.06)	57.24894	3.94(.05)
353.8	5.48(0.38)	353.9	4.71(-0.12)	354.0	4.08(0.14)
57.35450	5.74(.05)	57.35140	4.93(.04)	57.35738	4.31(.05)
354.0	5.63(-0.11)	353.9	4.82(-0.11)	353.9	4.18(-0.13)
57.46110	5.72(.07)	57.46267	4.95(.06)	57.46305	4.07(.07)
353.7	5.81(0.09)	353.7	4.98(0.03)	354.2	4.30(0.23)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.56747 354.2	6.10(.06) 5.99(-0.11)	57.56796 353.9	5.06(.05) 5.12(0.06)	57.56842 354.1	4.42(.06) 4.42(0.00)
57.67296 354.4	6.15(.05) 6.14(-0.01)	57.67344 353.8	5.10(.04) 5.23(0.13)	57.67390 353.8	4.70(.07) 4.50(-0.20)
57.77832 353.8	6.07(.06) 6.27(0.20)	57.77884 353.9	5.11(.07) 5.31(0.20)	57.77921 354.0	4.51(.05) 4.55(0.04)
57.88382 353.8	6.47(.06) 6.40(-0.07)	57.88455 353.9	5.23(.06) 5.40(0.17)	57.88466 353.8	4.41(.04) 4.60(0.19)
57.98919 353.8	6.36(.04) 6.57(0.21)	57.98961 354.0	5.42(.04) 5.53(0.11)	57.99005 353.9	4.47(.05) 4.70(0.23)
58.09280 354.2	6.87(.03) 6.79(-0.08)	58.08895 354.2	5.67(.04) 5.70(0.03)	58.09457 354.3	4.66(.04) 4.85(0.19)
58.18184 354.1	6.79(.04) 6.99(0.20)	58.19703 353.7	5.84(.06) 5.91(0.07)	58.18427 353.9	4.91(.02) 5.01(0.10)
58.28767 354.1	7.02(.05) 7.21(0.19)	58.30366 353.9	5.85(.04) 6.09(0.24)	58.30412 354.1	5.30(.05) 5.20(-0.10)
58.37088 354.0	6.99(.03) 7.33(0.34)	58.37201 354.1	5.92(.04) 6.17(0.25)	58.37257 354.3	5.02(.03) 5.26(0.24)
58.41001 354.4	7.12(.06) 7.37(0.25)	58.41048 353.7	5.92(.04) 6.19(0.27)	58.41095 353.4	5.12(.05) 5.27(0.15)
58.46400 354.2	7.07(.05) 7.40(0.33)	58.46475 354.1	6.01(.03) 6.21(0.20)	58.46542 353.9	4.98(.02) 5.27(0.29)
58.51670 353.8	7.36(.04) 7.42(0.06)	58.51723 353.9	5.95(.04) 6.21(0.26)	58.51759 354.0	4.90(.05) 5.26(0.36)
58.55657 354.1	7.06(.03) 7.42(0.36)	58.55729 354.1	6.02(.02) 6.19(0.17)	58.55812 353.9	4.90(.03) 5.24(0.34)
58.62355 353.8	7.34(.04) 7.41(0.07)	58.62428 353.9	5.91(.05) 6.17(0.26)	58.62440 353.9	4.84(.04) 5.19(0.35)
58.73027 353.8	7.29(.06) 7.40(0.11)	58.73069 354.0	5.99(.04) 6.13(0.14)	58.73113 354.0	4.84(.04) 5.13(0.29)
58.83566 353.7	7.22(.03) 7.42(0.20)	58.83625 353.9	5.98(.03) 6.13(0.15)	58.82337 354.0	5.07(.05) 5.12(0.05)
58.91599 354.1	7.20(.03) 7.46(0.26)	58.91827 354.0	6.17(.02) 6.16(-0.01)		
59.02316 354.1	7.04(.03) 7.53(0.49)	59.02385 354.2	6.23(.02) 6.22(-0.01)	59.03978 354.1	5.07(.03) 5.22(0.15)
59.10742 354.0	7.08(.02) 7.60(0.52)	59.14750 353.7	6.06(.04) 6.30(0.24)	59.14796 353.3	5.19(.03) 5.28(0.09)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20173 354.2	7.41(.02) 7.66(0.25)	59.20248 354.0	6.16(.02) 6.33(0.17)	59.20316 353.9	5.21(.02) 5.30(0.09)
59.25505 353.8	7.58(.04) 7.69(0.11)	59.25560 353.8	6.12(.03) 6.35(0.23)	59.25595 354.0	5.05(.05) 5.32(0.27)
59.29546 354.1	7.65(.03) 7.71(0.06)	59.29618 354.0	6.22(.02) 6.36(0.14)	59.29703 353.9	5.00(.01) 5.33(0.33)
59.36324 353.8	7.77(.04) 7.74(-0.03)	59.36399 353.9	6.08(.03) 6.39(0.31)	59.36411 353.9	5.12(.04) 5.34(0.22)
59.39122 353.9	7.58(.02) 7.76(0.18)	59.39173 354.1	6.25(.01) 6.39(0.14)	59.39279 354.3	5.22(.01) 5.34(0.12)
59.47131 353.8	7.68(.03) 7.80(0.12)	59.47174 354.0	6.29(.03) 6.42(0.13)	59.47219 354.0	5.14(.03) 5.36(0.22)
59.55882 354.1	7.60(.02) 7.85(0.25)	59.56018 353.8	6.23(.01) 6.46(0.23)	59.56065 354.3	5.16(.01) 5.38(0.22)
59.57803 353.7	7.58(.03) 7.86(0.28)	59.57851 353.9	6.13(.03) 6.47(0.34)	59.58031 354.0	5.18(.04) 5.39(0.21)
59.65012 354.0	7.66(.02) 7.91(0.25)	59.66564 353.7	6.33(.04) 6.51(0.18)	59.66604 353.9	5.23(.05) 5.42(0.19)
59.75865 354.1	7.84(.02) 7.99(0.15)	59.75933 354.1	6.33(.02) 6.56(0.23)	59.75996 354.3	5.24(.01) 5.45(0.21)
59.84395 354.0	7.80(.02) 8.07(0.27)	59.84512 354.1	6.42(.02) 6.62(0.20)	59.84569 354.3	5.33(.01) 5.50(0.17)
59.93944 354.1	8.05(.02) 8.19(0.14)	59.94020 354.0	6.37(.01) 6.73(0.36)	59.94089 353.9	5.34(.01) 5.59(0.25)
60.03434 354.0	8.09(.02) 8.34(0.25)	60.03508 354.0	6.55(.01) 6.87(0.32)	60.03594 353.9	5.42(.01) 5.73(0.31)
60.13130 353.9	8.58(.02) 8.52(-0.06)	60.13182 354.1	6.72(.01) 7.04(0.32)	60.13289 354.3	5.56(.01) 5.89(0.33)
60.21236 353.8	8.37(.11) 8.65(0.28)	60.29323 353.8	6.95(.01) 7.28(0.33)	60.21326 353.9	5.67(.11) 6.03(0.36)
60.29186 354.2	8.51(.02) 8.75(0.24)			60.29371 354.3	5.81(.01) 6.13(0.32)
60.32044 353.7	8.78(.11) 8.77(-0.01)	60.32105 353.8	6.95(.09) 7.30(0.35)	60.32277 354.0	6.24(.09) 6.16(-0.08)
60.38428 354.0	8.59(.02) 8.80(0.21)	60.38662 354.0	7.01(.01) 7.33(0.32)	60.38682 353.9	5.93(.01) 6.19(0.26)
60.49414 354.1	8.39(.02) 8.75(0.36)	60.49484 354.2	6.92(.01) 7.28(0.36)	60.49549 354.2	5.75(.01) 6.14(0.39)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58051 354.0	8.49(.02) 8.64(0.15)	60.58168 354.1	6.85(.01) 7.18(0.33)	60.58226 354.3	5.60(.01) 6.04(0.44)
60.67716 354.2	8.29(.02) 8.49(0.20)	60.67794 354.0	6.87(.01) 7.04(0.17)	60.67863 353.9	5.62(.01) 5.91(0.29)
60.77324 354.1	8.09(.01) 8.35(0.26)	60.77399 353.9	6.75(.01) 6.92(0.17)	60.77485 353.9	5.59(.01) 5.80(0.21)
60.87139 353.9	8.00(.01) 8.25(0.25)	60.87191 354.1	6.67(.01) 6.84(0.17)	60.87299 354.4	5.59(.01) 5.74(0.15)
61.02489 354.1	7.99(.01) 8.16(0.17)	61.02628 353.8	6.62(.01) 6.80(0.18)	61.02676 354.3	5.46(.01) 5.73(0.27)
61.11842 354.0	7.83(.03) 8.11(0.28)	61.12080 354.1	6.67(.02) 6.78(0.11)	61.12106 354.3	5.38(.02) 5.73(0.35)
61.22967 353.9	8.03(.02) 8.03(0.00)	61.23035 354.1	6.49(.01) 6.72(0.23)	61.23099 354.2	5.42(.02) 5.69(0.27)
61.31702 353.9	7.89(.02) 7.95(0.06)	61.31824 354.1	6.45(.01) 6.66(0.21)	61.31881 354.1	5.42(.01) 5.64(0.22)
61.41490 354.1	7.83(.02) 7.87(0.04)	61.41571 354.2	6.35(.01) 6.59(0.24)	61.41635 353.9	5.33(.01) 5.59(0.26)
61.51212 354.0	7.67(.01) 7.82(0.15)	61.51287 354.1	6.47(.02) 6.57(0.10)	61.51373 353.9	5.31(.01) 5.58(0.27)
61.61148 353.9	7.76(.01) 7.81(0.05)	61.61200 354.1	6.40(.02) 6.59(0.19)	61.61309 354.2	5.46(.01) 5.62(0.16)
61.75791 354.2	7.76(.01) 7.82(0.06)	61.75948 353.8	6.58(.01) 6.63(0.05)	61.75978 354.1	5.53(.01) 5.69(0.16)
61.85256 354.0	7.75(.01) 7.79(0.04)	61.85498 354.1	6.50(.01) 6.63(0.13)	61.85524 354.2	5.54(.01) 5.71(0.17)
61.96516 353.9	7.70(.01) 7.73(0.03)	61.96584 354.1	6.58(.01) 6.60(0.02)	61.96650 354.2	5.44(.01) 5.68(0.24)
62.05357 353.9	7.72(.01) 7.68(−0.04)	62.05479 353.8	6.58(.01) 6.56(−0.02)	62.05538 354.1	5.57(.01) 5.66(0.09)
62.15263 354.0	7.55(.01) 7.63(0.08)	62.15344 354.1	6.45(.00) 6.54(0.09)	62.15409 353.9	5.54(.01) 5.66(0.12)
62.25101 354.1	7.54(.01) 7.57(0.03)	62.25177 354.0	6.49(.02) 6.53(0.04)	62.25264 353.9	5.44(.01) 5.68(0.24)
62.35160 354.0	7.25(.01) 7.47(0.22)	62.35210 354.0	6.43(.01) 6.47(0.04)	62.35320 354.2	5.55(.01) 5.66(0.11)
62.49094 354.2	7.05(.01) 7.20(0.15)	62.49252 353.8	6.28(.01) 6.26(−0.02)	62.49283 354.1	5.36(.01) 5.50(0.14)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.58672 353.9	6.88(.01) 6.93(0.05)	62.58916 354.1	5.96(.01) 6.03(0.07)	62.58943 354.2	5.00(.01) 5.29(0.29)
62.70065 353.9	6.58(.01) 6.56(-0.02)	62.70135 354.0	5.45(.01) 5.72(0.27)	62.70201 354.1	4.90(.01) 5.02(0.12)
62.79011 353.9	6.21(.01) 6.27(0.06)	62.79136 353.8	5.31(.01) 5.47(0.16)	62.79195 354.1	4.75(.01) 4.82(0.07)
62.89035 354.0	5.92(.01) 5.94(0.02)	62.89117 354.1	5.15(.01) 5.21(0.06)	62.89183 353.9	4.64(.01) 4.61(-0.03)
62.98990 354.0	5.64(.01) 5.61(-0.03)	62.99067 354.0	4.95(.01) 4.94(-0.01)	62.99155 353.9	4.35(.01) 4.39(0.04)
63.09169 354.0	5.37(.01) 5.26(-0.11)	63.09220 354.0	4.66(.01) 4.65(-0.01)	63.09331 354.2	4.18(.01) 4.13(-0.05)
63.22396 354.2	4.80(.01) 4.82(0.02)	63.22557 353.8	4.36(.01) 4.26(-0.10)	63.22588 354.2	3.82(.01) 3.80(-0.02)
63.32086 353.9	4.50(.01) 4.53(0.03)	63.32335 354.1	3.95(.01) 4.02(0.07)	63.32361 354.2	3.67(.01) 3.60(-0.07)
63.43615 353.9	4.10(.01) 4.23(0.13)	63.43685 354.0	3.77(.01) 3.78(0.01)	63.43752 354.2	3.33(.01) 3.41(0.08)
63.52665 353.9	4.04(.01) 4.01(-0.03)	63.52791 353.8	3.65(.01) 3.60(-0.05)	63.52851 354.1	3.20(.01) 3.27(0.07)
63.62806 354.0	3.81(.01) 3.76(-0.05)	63.62890 354.1	3.28(.01) 3.40(0.12)	63.62957 353.9	3.10(.01) 3.09(-0.01)
63.72879 354.0	3.42(.01) 3.51(0.09)	63.72957 354.0	3.19(.01) 3.18(-0.01)	63.73046 353.9	2.84(.01) 2.90(0.06)
63.83176 354.0	3.19(.00) 3.27(0.08)	63.83229 354.0	2.88(.01) 2.98(0.10)	63.83342 354.2	2.79(.01) 2.72(-0.07)
63.95698 354.2	2.83(.01) 3.02(0.19)	63.95860 353.8	2.70(.01) 2.76(0.06)	63.95893 354.2	2.60(.01) 2.54(-0.06)
64.05500 353.9	2.72(.01) 2.84(0.12)	64.05751 354.1	2.65(.01) 2.61(-0.04)	64.05779 354.2	2.56(.01) 2.42(-0.14)
64.17162 353.8	2.58(.01) 2.63(0.05)	64.17234 354.1	2.32(.01) 2.44(0.12)	64.17298 354.2	2.21(.02) 2.27(0.06)
64.26318 353.9	2.43(.00) 2.46(0.03)	64.26447 353.8	2.19(.01) 2.28(0.09)	64.26505 354.2	2.17(.01) 2.13(-0.04)
64.36576 354.0	2.40(.01) 2.28(-0.12)	64.36658 354.1	2.28(.01) 2.12(-0.16)	64.36728 353.9	2.02(.01) 1.98(-0.04)
64.46759 354.1	2.16(.01) 2.12(-0.04)	64.46843 354.1	2.13(.01) 1.98(-0.15)	64.46935 353.9	1.91(.01) 1.86(-0.05)

H = 6.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.57183	2.02(.01)	64.57234	2.02(.01)	64.57351	1.61(.01)
354.0	1.97(-0.05)	354.1	1.85(-0.17)	354.2	1.75(0.14)
64.69014	1.85(.01)	64.69161	1.74(.01)	64.69193	1.67(.01)
354.0	1.82(-0.03)	353.8	1.71(-0.03)	354.2	1.63(-0.04)
64.78876	1.62(.01)	64.79143	1.62(.00)	64.79192	1.65(.01)
354.1	1.68(0.06)	354.1	1.59(-0.03)	354.2	1.51(-0.14)
64.90710	1.54(.01)	64.90780	1.47(.00)	64.90849	1.42(.01)
354.0	1.53(-0.01)	354.1	1.45(-0.02)	354.3	1.38(-0.04)
64.99973	1.42(.01)	65.00098	1.37(.00)	65.00160	1.39(.01)
354.1	1.42(0.00)	354.1	1.35(-0.02)	354.2	1.29(-0.10)
65.10348	1.27(.00)	65.10432	1.27(.01)	65.10500	1.31(.01)
354.0	1.32(0.05)	354.1	1.25(-0.02)	353.9	1.21(-0.10)
65.20647	1.32(.01)	65.20732	1.12(.00)	65.20825	1.09(.01)
354.0	1.22(-0.10)	354.1	1.17(0.05)	353.9	1.13(0.04)
65.31190	1.08(.01)	65.31242	1.07(.01)	65.31358	0.95(.01)
354.0	1.12(0.04)	354.1	1.07(0.00)	354.3	1.04(0.09)
65.42316	1.01(.01)	65.42464	1.02(.01)	65.42496	1.07(.01)
354.0	1.02(0.01)	353.8	0.97(-0.05)	354.2	0.94(-0.13)
65.52289	0.97(.01)	65.52560	0.80(.01)	65.52610	0.98(.01)
354.1	0.94(-0.03)	354.1	0.89(0.09)	354.3	0.86(-0.12)
65.64259	0.90(.01)	65.64329	0.79(.01)	65.64398	0.85(.01)
354.0	0.85(-0.05)	354.1	0.82(0.03)	354.2	0.79(-0.06)
65.73626	0.77(.00)	65.73755	0.65(.00)	65.73817	0.63(.01)
354.0	0.79(0.02)	354.1	0.76(0.11)	354.2	0.74(0.11)
65.84119	0.62(.01)	65.84203	0.64(.01)	65.84274	0.67(.01)
353.9	0.73(0.11)	354.1	0.70(0.06)	353.9	0.68(0.01)
65.94535	0.62(.01)	65.94622	0.50(.00)	65.94716	0.43(.01)
354.0	0.67(0.05)	354.1	0.64(0.14)	353.9	0.62(0.19)
66.05199	0.37(.01)	66.05252	0.49(.01)	66.05368	0.40(.01)
353.9	0.61(0.24)	354.1	0.58(0.09)	354.2	0.56(0.16)
66.15617	0.52(.00)	66.15768	0.58(.01)	66.15801	0.41(.01)
354.0	0.56(0.04)	353.8	0.53(-0.05)	354.2	0.52(0.11)
66.25703	0.49(.00)	66.25977	0.44(.01)	66.26028	0.41(.01)
354.1	0.52(0.03)	354.1	0.49(0.05)	354.2	0.48(0.07)

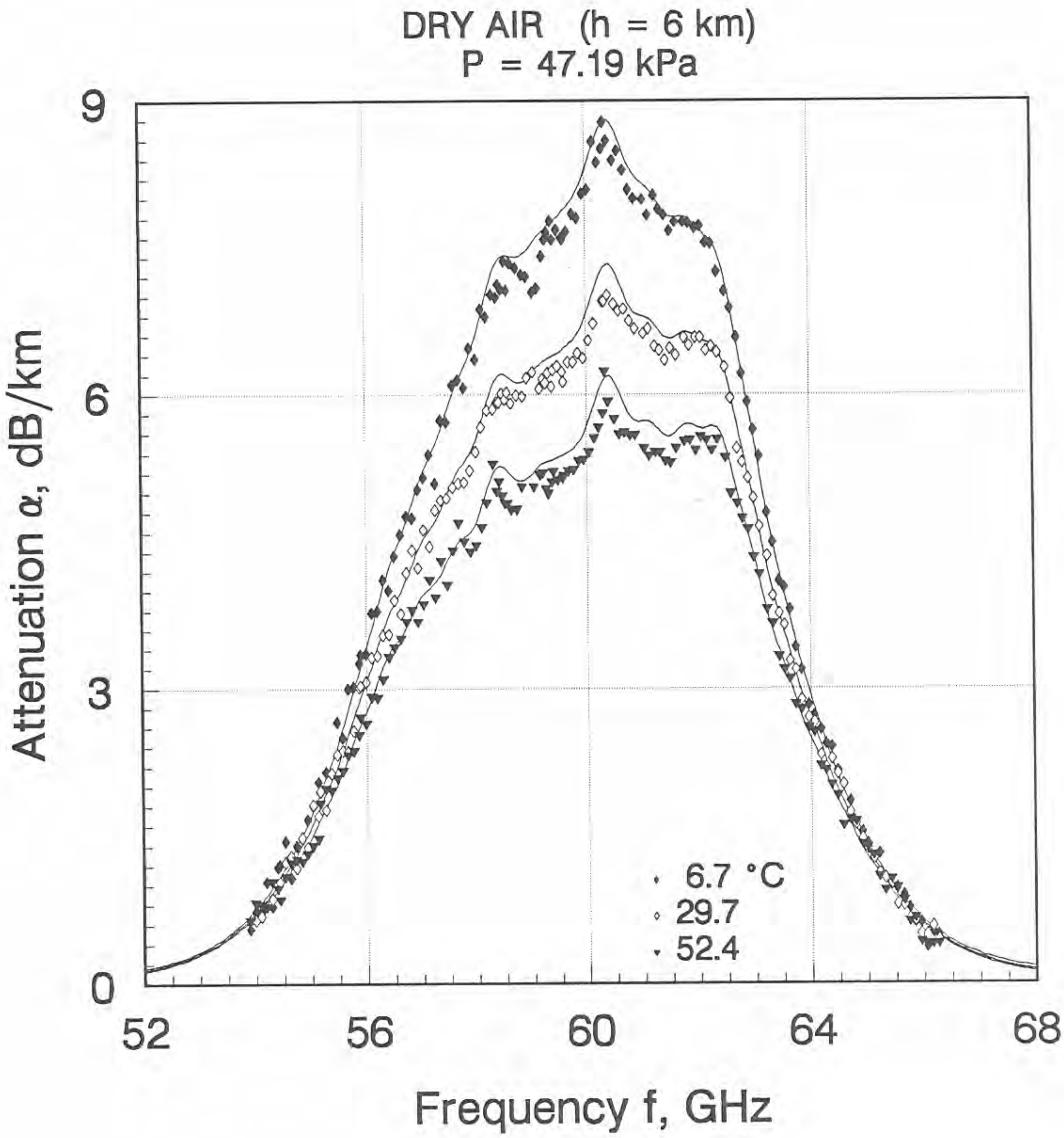

Figure A-9a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 6 km (see I.) for frequencies between 52 and 68 GHz.

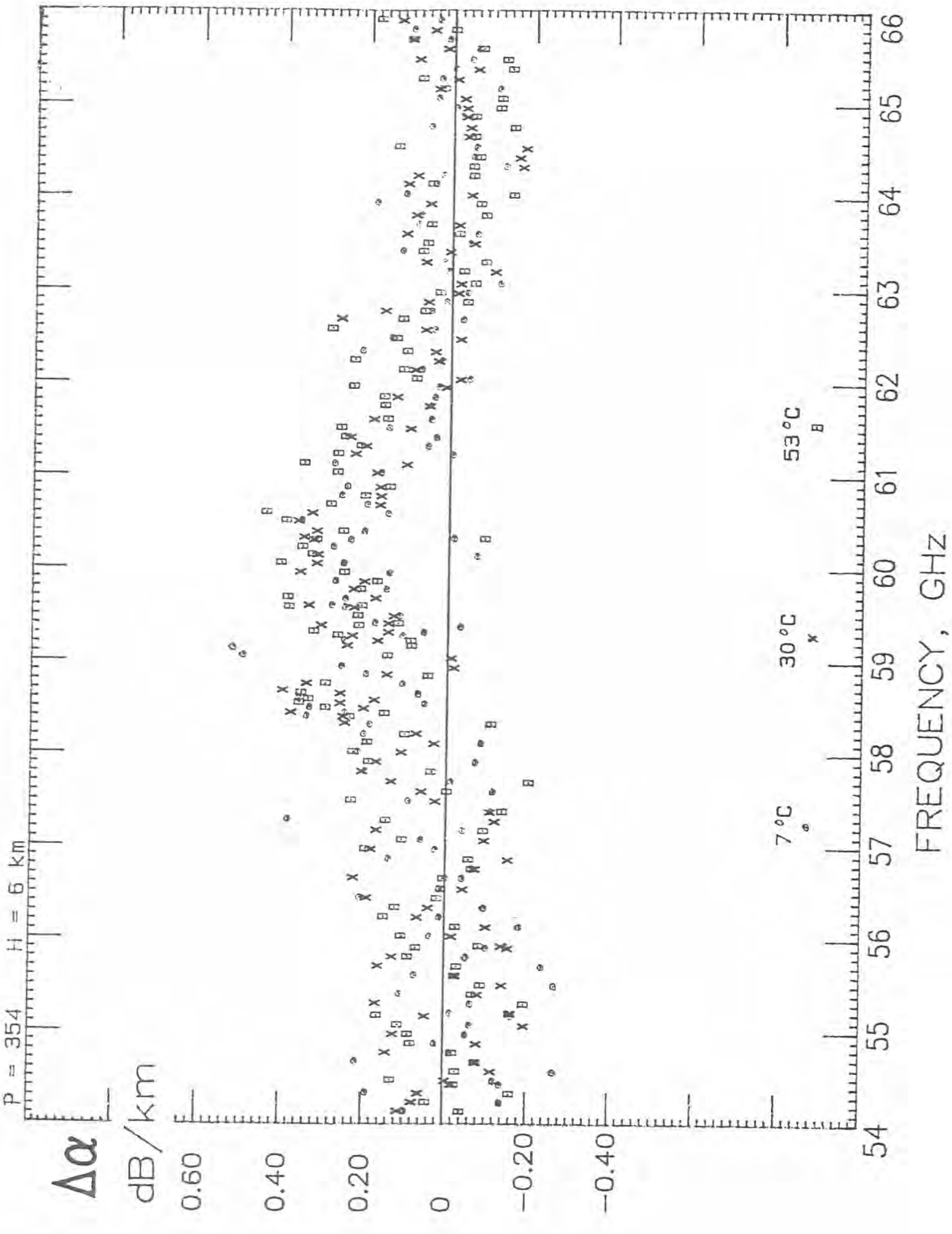

Figure A-9b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under I.

K.

$H = 3$ km

Statistics Summary:

T	[°C]	6.70(24)	29.70(34)	52.40(08)
P	[torr] [kPa]	**525.80(29)**	**525.90(19)** 70.110	**525.90(34)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.237	0.254	0.286

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.88563 526.0	1.05(.03) 1.21(0.16)	53.88635 525.6	1.06(.03) 1.12(0.06)	53.88699 526.2	0.95(.03) 1.05(0.10)
53.98437 525.3	1.32(.02) 1.30(-0.02)	53.98505 526.2	1.13(.03) 1.20(0.07)	53.98571 525.3	1.28(.03) 1.13(-0.15)
54.08293 526.1	1.44(.02) 1.40(-0.04)	54.08369 526.2	1.29(.02) 1.30(0.01)	54.08427 525.8	1.30(.03) 1.22(-0.08)
54.18166 526.0	1.64(.02) 1.51(-0.13)	54.18262 525.5	1.46(.02) 1.40(-0.06)	54.18296 526.2	1.14(.04) 1.31(0.17)
54.28028 526.1	1.69(.02) 1.62(-0.07)	54.28096 526.1	1.51(.02) 1.50(-0.01)	54.28160 525.8	1.55(.04) 1.41(-0.14)
54.37769 525.6	1.78(.02) 1.74(-0.04)	54.37840 525.7	1.57(.03) 1.61(0.04)	54.38028 525.7	1.65(.03) 1.51(-0.14)
54.41922 525.8	1.96(.03) 1.79(-0.17)	54.42085 526.1	1.56(.03) 1.66(0.10)	54.42244 526.1	1.37(.03) 1.56(0.19)
54.52033 525.5	2.23(.02) 1.93(-0.30)	54.52209 526.1	1.93(.03) 1.79(-0.14)	54.52271 526.5	1.80(.03) 1.67(-0.13)
54.62125 526.0	2.01(.02) 2.07(0.06)	54.62199 525.6	2.07(.03) 1.92(-0.15)	54.62263 526.2	1.83(.03) 1.79(-0.04)
54.72134 525.3	2.25(.02) 2.23(-0.02)	54.72203 526.2	1.99(.03) 2.05(0.06)	54.72271 525.4	2.04(.03) 1.91(-0.13)
54.82126 526.1	2.44(.03) 2.39(-0.05)	54.82203 526.2	2.20(.03) 2.20(0.00)	54.82262 525.8	1.84(.05) 2.04(0.20)
54.92134 526.0	2.50(.03) 2.56(0.06)	54.92232 525.5	2.25(.04) 2.35(0.10)	54.92266 526.3	2.32(.04) 2.18(-0.14)
55.02130 526.1	2.67(.04) 2.74(0.07)	55.02199 526.0	2.60(.03) 2.51(-0.09)	55.02264 525.9	2.40(.05) 2.32(-0.08)
55.12004 525.6	3.18(.02) 2.93(-0.25)	55.12088 525.5	2.56(.04) 2.68(0.12)	55.12268 525.7	2.34(.05) 2.47(0.13)
55.15213 525.9	3.12(.05) 2.99(-0.13)	55.15377 526.0	2.56(.03) 2.74(0.18)	55.15539 526.1	2.66(.04) 2.53(-0.13)
55.25460 525.5	3.65(.05) 3.20(-0.45)	55.25638 526.0	2.85(.04) 2.92(0.07)	55.25700 526.4	2.96(.06) 2.69(-0.27)
55.35688 526.0	3.35(.04) 3.42(0.07)	55.35763 525.6	3.39(.04) 3.11(-0.28)	55.35829 526.2	2.80(.05) 2.85(0.05)
55.45832 525.3	3.87(.03) 3.64(-0.23)	55.45903 526.2	3.31(.04) 3.30(-0.01)	55.45971 525.4	3.33(.06) 3.02(-0.31)
55.55958 526.1	4.04(.04) 3.87(-0.17)	55.56037 526.1	3.42(.04) 3.51(0.09)	55.56096 525.8	3.31(.04) 3.20(-0.11)

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.66101 526.0	4.26(.04) 4.12(-0.14)	55.66201 525.6	3.70(.04) 3.72(0.02)	55.66236 526.3	3.51(.04) 3.38(-0.13)
55.76233 526.1	4.48(.04) 4.37(-0.11)	55.76303 526.2	4.04(.05) 3.93(-0.11)	55.76370 525.8	3.39(.04) 3.57(0.18)
55.86240 525.6	4.77(.04) 4.62(-0.15)	55.86314 525.7	4.15(.03) 4.15(0.00)	55.86508 525.7	3.82(.04) 3.76(-0.06)
55.88503 525.8	4.92(.04) 4.68(-0.24)	55.88670 526.0	4.31(.04) 4.20(-0.11)	55.88834 526.0	3.97(.05) 3.80(-0.17)
55.98886 525.5	5.05(.04) 4.94(-0.11)	55.99067 526.0	4.61(.03) 4.43(-0.18)	55.99131 525.6	4.05(.05) 3.99(-0.06)
56.09250 526.1	5.24(.05) 5.21(-0.03)	56.09327 525.6	4.84(.05) 4.65(-0.19)	56.09394 526.2	4.28(.04) 4.18(-0.10)
56.19529 525.3	5.92(.04) 5.48(-0.44)	56.19601 526.2	5.03(.04) 4.88(-0.15)	56.19671 526.0	4.34(.04) 4.38(0.04)
56.29791 526.1	5.83(.05) 5.75(-0.08)	56.29870 526.1	5.14(.04) 5.11(-0.03)	56.29930 525.8	4.62(.05) 4.57(-0.05)
56.40070 526.0	6.50(.05) 6.01(-0.49)	56.40171 525.6	5.14(.06) 5.33(0.19)	56.40206 526.3	4.44(.05) 4.75(0.31)
56.50337 526.1	6.36(.05) 6.27(-0.09)	56.50407 525.9	5.68(.06) 5.54(-0.14)	56.50475 525.8	4.80(.05) 4.93(0.13)
56.61793 525.8	6.61(.03) 6.56(-0.05)	56.61962 526.1	5.80(.02) 5.77(-0.03)	56.62128 526.0	5.17(.04) 5.12(-0.05)
56.72313 525.5	7.15(.05) 6.81(-0.34)	56.72497 526.0	6.01(.04) 5.98(-0.03)	56.72562 525.6	5.24(.06) 5.29(0.05)
56.82814 525.9	6.95(.06) 7.07(0.12)	56.82891 525.6	6.34(.05) 6.18(-0.16)	56.82959 526.3	5.33(.08) 5.45(0.12)
56.93229 525.3	7.39(.07) 7.31(-0.08)	56.93301 526.2	6.16(.05) 6.38(0.22)	56.93372 526.0	5.52(.06) 5.61(0.09)
57.03625 526.1	7.54(.07) 7.55(0.01)	57.03706 526.1	6.38(.05) 6.57(0.19)	57.03767 525.8	5.77(.05) 5.76(-0.01)
57.14038 526.0	7.73(.05) 7.79(0.06)	57.14140 525.6	6.67(.06) 6.75(0.08)	57.14177 526.3	6.08(.07) 5.91(-0.17)
57.24440 526.1	7.87(.06) 8.01(0.14)	57.24512 526.0	6.76(.05) 6.93(0.17)	57.24581 525.7	5.57(.05) 6.04(0.47)
57.35085 525.8	8.55(.08) 8.24(-0.31)	57.34802 525.6	7.13(.06) 7.10(-0.03)	57.35424 526.0	6.11(.08) 6.18(0.07)
57.45742 525.5	8.35(.07) 8.47(0.12)	57.45927 526.1	7.03(.06) 7.28(0.25)	57.45994 526.8	6.49(.09) 6.32(-0.17)

H = 3.0 km

6.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$ dB/km
57.56379 526.0	9.09(.07) 8.69(-0.40)	57.56458 525.6	7.38(.07) 7.45(0.07)	57.56526 526.3	6.83(.08) 6.45(-0.38)
57.66929 525.3	8.95(.08) 8.90(-0.05)	57.67003 526.1	7.35(.07) 7.61(0.26)	57.67075 525.3	6.13(.08) 6.57(0.44)
57.77461 526.1	9.12(.10) 9.11(-0.01)	57.77542 526.2	7.56(.08) 7.77(0.21)	57.77605 525.8	6.60(.07) 6.69(0.09)
57.88010 526.0	9.19(.08) 9.32(0.13)	57.88113 525.6	7.69(.05) 7.93(0.24)	57.88151 526.3	6.35(.04) 6.81(0.46)
57.98547 526.1	9.42(.06) 9.53(0.11)	57.98620 526.0	8.12(.05) 8.09(-0.03)	57.98690 525.7	6.53(.08) 6.94(0.41)
58.08885 526.0	9.81(.05) 9.73(-0.08)	58.08553 526.1	8.27(.05) 8.24(-0.03)	58.09118 526.1	6.81(.04) 7.06(0.25)
58.17787 526.0	9.68(.06) 9.90(0.22)	58.19360 526.0	8.29(.07) 8.41(0.12)	58.18106 526.2	6.83(.02) 7.17(0.34)
58.28396 525.9	9.80(.05) 10.09(0.29)	58.30023 525.6	8.29(.06) 8.55(0.26)	58.30092 526.3	6.76(.07) 7.31(0.55)
58.36714 525.9	10.12(.05) 10.22(0.10)	58.36858 526.2	8.32(.03) 8.63(0.31)	58.36940 526.2	7.09(.04) 7.37(0.28)
58.40628 525.3	9.71(.06) 10.28(0.57)	58.40704 526.2	8.47(.05) 8.68(0.21)	58.40777 525.2	6.90(.07) 7.40(0.50)
58.46028 526.0	10.25(.05) 10.36(0.11)	58.46132 525.9	8.49(.04) 8.73(0.24)	58.46223 526.2	7.20(.04) 7.44(0.24)
58.51294 526.1	10.04(.06) 10.42(0.38)	58.51379 526.2	8.62(.06) 8.77(0.15)	58.51440 525.8	6.98(.05) 7.47(0.49)
58.55280 525.9	10.10(.04) 10.47(0.37)	58.55382 526.0	8.60(.03) 8.80(0.20)	58.55494 526.2	6.92(.03) 7.49(0.57)
58.61979 526.0	10.50(.05) 10.54(0.04)	58.62083 525.5	8.55(.05) 8.85(0.30)	58.62120 526.4	7.06(.06) 7.51(0.45)
58.72650 526.1	10.41(.07) 10.64(0.23)	58.72724 525.9	8.64(.04) 8.91(0.27)	58.72794 525.8	6.90(.05) 7.55(0.65)
58.83189 525.8	10.54(.04) 10.73(0.19)	58.83279 525.6	8.67(.04) 8.97(0.30)	58.82016 526.0	7.07(.04) 7.58(0.51)
58.91196 526.0	10.58(.03) 10.80(0.22)	58.91458 525.9	9.00(.03) 9.02(0.02)		
59.01941 525.9	10.28(.05) 10.89(0.61)	59.02037 526.1	8.94(.02) 9.08(0.14)	59.03655 526.3	7.59(.06) 7.67(0.08)
59.10364 525.9	10.07(.03) 10.96(0.89)	59.14400 526.2	8.79(.05) 9.16(0.37)	59.14473 525.2	7.27(.05) 7.72(0.45)

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.19795 525.9	10.59(.03) 11.05(0.46)	59.19901 525.9	8.96(.03) 9.20(0.24)	59.19992 526.2	7.50(.03) 7.75(0.25)
59.25125 526.1	10.87(.05) 11.09(0.22)	59.25209 526.1	8.73(.03) 9.23(0.50)	59.25273 525.8	7.26(.05) 7.77(0.51)
59.29165 525.9	11.03(.03) 11.13(0.10)	59.29269 526.0	8.85(.02) 9.26(0.41)	59.29380 526.2	7.13(.02) 7.79(0.66)
59.35943 526.0	10.99(.04) 11.19(0.20)	59.36049 525.5	8.80(.03) 9.30(0.50)	59.36087 526.3	7.17(.04) 7.83(0.66)
59.38744 526.0	10.87(.02) 11.22(0.35)	59.38824 526.0	8.92(.02) 9.32(0.40)	59.38955 526.2	7.20(.01) 7.84(0.64)
59.46749 526.1	10.87(.04) 11.29(0.42)	59.46824 525.9	9.02(.03) 9.38(0.36)	59.46896 525.8	7.40(.05) 7.89(0.49)
59.55478 525.8	10.95(.03) 11.38(0.43)	59.55669 526.1	8.94(.01) 9.45(0.51)	59.55717 526.1	7.34(.02) 7.94(0.60)
59.57422 525.8	11.28(.06) 11.40(0.12)	59.57501 525.6	9.14(.03) 9.47(0.33)	59.57707 525.7	7.33(.04) 7.96(0.63)
59.64605 525.9	10.87(.03) 11.48(0.61)	59.66213 526.0	9.28(.05) 9.55(0.27)	59.66278 525.5	7.33(.07) 8.02(0.69)
59.75484 525.8	11.36(.02) 11.60(0.24)	59.75581 526.2	9.37(.02) 9.64(0.27)	59.75671 526.1	7.68(.02) 8.10(0.42)
59.84013 525.9	11.26(.02) 11.71(0.45)	59.84159 526.2	9.42(.02) 9.73(0.31)	59.84245 526.2	7.68(.02) 8.17(0.49)
59.93562 525.9	11.65(.02) 11.82(0.17)	59.93670 525.8	9.40(.02) 9.83(0.43)	59.93762 526.1	7.83(.01) 8.27(0.44)
60.03049 525.9	11.51(.03) 11.93(0.42)	60.03154 525.9	9.47(.01) 9.93(0.46)	60.03267 526.1	7.62(.01) 8.37(0.75)
60.12748 526.0	12.19(.03) 12.04(-0.15)	60.12829 526.0	9.54(.02) 10.03(0.49)	60.12962 526.2	8.01(.02) 8.46(0.45)
60.20853 526.1	11.53(.12) 12.11(0.58)			60.20999 525.8	7.67(.12) 8.53(0.86)
60.28778 525.8	11.81(.02) 12.16(0.35)	60.28971 526.1	9.72(.02) 10.16(0.44)	60.29018 526.1	8.13(.02) 8.59(0.46)
60.31657 525.8	11.41(.13) 12.18(0.77)	60.31750 525.6	9.68(.09) 10.18(0.50)	60.31945 525.7	8.19(.13) 8.61(0.42)
60.38017 525.9	11.95(.03) 12.20(0.25)	60.38286 526.0	9.75(.01) 10.21(0.46)	60.38350 526.1	7.75(.01) 8.64(0.89)
60.49029 525.8	11.69(.02) 12.21(0.52)	60.49128 526.1	9.74(.01) 10.22(0.48)	60.49219 526.1	7.96(.01) 8.65(0.69)

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.57664	12.06(.02)	60.57812	9.77(.01)	60.57897	7.83(.01)
525.9	12.20(0.14)	526.2	10.21(0.44)	526.2	8.64(0.81)
60.67330	11.85(.02)	60.67439	9.83(.01)	60.67531	8.17(.01)
525.9	12.15(0.30)	525.8	10.17(0.34)	526.1	8.61(0.44)
60.76934	11.76(.02)	60.77040	9.68(.01)	60.77154	7.85(.01)
525.8	12.10(0.34)	525.9	10.13(0.45)	526.1	8.58(0.73)
60.86752	11.74(.01)	60.86834	9.71(.01)	60.86968	7.99(.01)
526.0	12.03(0.29)	526.0	10.08(0.37)	526.2	8.55(0.56)
61.02076	11.51(.01)	61.02271	9.76(.01)	61.02320	8.06(.01)
525.7	11.92(0.41)	526.1	10.01(0.25)	526.1	8.50(0.44)
61.11425	11.68(.03)	61.11699	9.61(.03)	61.11761	8.12(.03)
526.1	11.85(0.17)	525.9	9.96(0.35)	526.3	8.47(0.35)
61.22574	11.64(.02)	61.22673	9.63(.02)	61.22765	8.08(.01)
525.8	11.76(0.12)	526.1	9.91(0.28)	526.1	8.43(0.35)
61.31313	11.53(.01)	61.31463	9.47(.01)	61.31548	8.15(.02)
525.9	11.69(0.16)	526.1	9.86(0.39)	526.2	8.40(0.25)
61.41096	11.46(.01)	61.41208	9.45(.02)	61.41300	8.04(.01)
525.9	11.60(0.14)	526.0	9.80(0.35)	526.2	8.37(0.33)
61.50817	11.38(.02)	61.50925	9.45(.02)	61.51037	7.95(.01)
525.8	11.52(0.14)	526.0	9.75(0.30)	526.2	8.35(0.40)
61.60757	11.32(.01)	61.60839	9.35(.03)	61.60974	7.93(.02)
525.9	11.43(0.11)	526.1	9.70(0.35)	526.2	8.32(0.39)
61.75374	11.33(.01)	61.75569	9.60(.02)	61.75618	8.11(.02)
526.1	11.29(-0.04)	526.1	9.62(0.02)	526.3	8.29(0.18)
61.84835	11.33(.01)	61.85114	9.33(.01)	61.85176	8.01(.01)
526.0	11.18(-0.15)	525.9	9.56(0.23)	526.3	8.25(0.24)
61.96115	11.04(.02)	61.96220	9.48(.01)	61.96312	7.93(.01)
525.9	11.03(-0.01)	526.0	9.46(-0.02)	526.1	8.19(0.26)
62.04960	11.09(.02)	62.05116	9.37(.01)	62.05201	7.88(.01)
526.2	10.90(-0.19)	525.9	9.37(0.00)	526.2	8.13(0.25)
62.14866	10.78(.01)	62.14977	9.12(.01)	62.15071	7.83(.01)
525.9	10.72(-0.06)	525.9	9.25(0.13)	526.1	8.05(0.22)
62.24703	10.52(.02)	62.24811	9.33(.02)	62.24925	7.67(.01)
525.8	10.52(0.00)	525.9	9.10(-0.23)	526.2	7.94(0.27)
62.34762	10.10(.01)	62.34844	8.84(.01)	62.34982	7.58(.01)
525.9	10.28(0.18)	526.0	8.92(0.08)	526.1	7.81(0.23)
62.48672	9.67(.01)	62.48870	8.74(.02)	62.48919	7.58(.01)
526.1	9.89(0.22)	526.2	8.61(-0.13)	526.3	7.56(-0.02)

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.58245 526.0	9.60(.01) 9.59(-0.01)	62.58527 525.9	8.35(.01) 8.36(0.01)	62.58591 526.3	6.99(.01) 7.35(0.36)
62.69660 525.9	9.24(.02) 9.19(-0.05)	62.69766 526.0	7.66(.01) 8.03(0.37)	62.69860 526.1	6.95(.01) 7.08(0.13)
62.78610 526.2	8.85(.01) 8.86(0.01)	62.78767 525.9	7.52(.01) 7.75(0.23)	62.78854 526.1	6.75(.01) 6.85(0.10)
62.88633 525.9	8.47(.01) 8.48(0.01)	62.88747 525.9	7.40(.01) 7.44(0.04)	62.88840 526.1	6.70(.01) 6.58(-0.12)
62.98588 525.8	8.17(.01) 8.09(-0.08)	62.98698 525.9	7.08(.01) 7.11(0.03)	62.98812 526.1	6.25(.01) 6.30(0.05)
63.08766 525.9	7.84(.01) 7.69(-0.15)	63.08849 526.0	6.84(.01) 6.77(-0.07)	63.08989 526.1	6.08(.01) 6.02(-0.06)
63.21970 526.1	7.07(.01) 7.18(0.11)	63.22170 526.2	6.46(.01) 6.34(-0.12)	63.22220 526.3	5.65(.01) 5.65(0.00)
63.31655 526.1	6.66(.01) 6.81(0.15)	63.31940 525.9	6.03(.01) 6.03(0.00)	63.32005 526.3	5.49(.01) 5.39(-0.10)
63.43204 525.9	6.15(.01) 6.39(0.24)	63.43312 526.0	5.69(.01) 5.68(-0.01)	63.43407 526.1	5.04(.01) 5.09(0.05)
63.52259 526.3	6.10(.01) 6.08(-0.02)	63.52419 525.9	5.49(.01) 5.41(-0.08)	63.52506 526.2	4.74(.01) 4.87(0.13)
63.62400 525.9	5.75(.01) 5.73(-0.02)	63.62515 525.9	5.00(.01) 5.12(0.12)	63.62610 526.1	4.62(.01) 4.62(0.00)
63.72472 525.8	5.25(.01) 5.41(0.16)	63.72583 525.9	4.83(.01) 4.85(0.02)	63.72699 526.2	4.33(.01) 4.38(0.05)
63.82770 525.9	4.87(.01) 5.09(0.22)	63.82854 526.0	4.37(.01) 4.57(0.20)	63.82995 526.1	4.21(.01) 4.15(-0.06)
63.95267 526.1	4.42(.01) 4.72(0.30)	63.95470 526.2	4.21(.01) 4.25(0.04)	63.95520 526.3	3.95(.01) 3.88(-0.07)
64.05064 526.1	4.20(.01) 4.45(0.25)	64.05354 525.9	4.14(.01) 4.02(-0.12)	64.05419 526.3	3.77(.01) 3.67(-0.10)
64.16747 525.9	3.96(.01) 4.13(0.17)	64.16857 526.1	3.59(.01) 3.75(0.16)	64.16949 526.3	3.52(.02) 3.44(-0.08)
64.25908 526.3	3.84(.01) 3.90(0.06)	64.26069 525.9	3.32(.01) 3.55(0.23)	64.26157 526.1	3.35(.01) 3.26(-0.09)
64.36166 526.0	3.73(.01) 3.65(-0.08)	64.36279 526.0	3.48(.01) 3.33(-0.15)	64.36378 526.2	3.19(.01) 3.07(-0.12)
64.46350 525.9	3.45(.02) 3.42(-0.03)	64.46465 526.0	3.32(.01) 3.12(-0.20)	64.46584 526.1	3.04(.01) 2.89(-0.15)

H = 3.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.56770 526.1	3.16(.01) 3.19(0.03)	64.56856 526.0	3.23(.01) 2.92(-0.31)	64.57001 526.1	2.64(.01) 2.71(0.07)
64.68603 525.8	2.97(.01) 2.95(-0.02)	64.68767 525.8	2.75(.01) 2.71(-0.04)	64.68816 526.0	2.62(.01) 2.52(-0.10)
64.78455 525.8	2.70(.01) 2.76(0.06)	64.78763 526.1	2.62(.01) 2.53(-0.09)	64.78827 526.3	2.57(.01) 2.36(-0.21)
64.90290 526.0	2.42(.01) 2.54(0.12)	64.90398 526.0	2.39(.01) 2.34(-0.05)	64.90495 526.2	2.31(.01) 2.19(-0.12)
64.99561 525.9	2.37(.01) 2.38(0.01)	64.99718 526.0	2.19(.01) 2.20(0.01)	64.99808 526.1	2.16(.01) 2.05(-0.11)
65.09933 526.0	2.07(.00) 2.22(0.15)	65.10046 525.9	1.94(.01) 2.05(0.11)	65.10146 526.2	2.03(.01) 1.92(-0.11)
65.20234 525.9	2.25(.01) 2.06(-0.19)	65.20351 525.9	1.75(.01) 1.90(0.15)	65.20470 526.1	1.76(.01) 1.79(0.03)
65.30773 526.0	1.75(.01) 1.91(0.16)	65.30860 526.0	1.72(.00) 1.77(0.05)	65.31003 526.2	1.54(.01) 1.66(0.12)
65.41899 525.8	1.72(.01) 1.77(0.05)	65.42066 525.8	1.75(.01) 1.63(-0.12)	65.42115 526.0	1.77(.01) 1.53(-0.24)
65.51863 525.8	1.70(.01) 1.64(-0.06)	65.52177 526.0	1.36(.01) 1.51(0.15)	65.52240 526.3	1.53(.01) 1.42(-0.11)
65.63834 526.0	1.47(.01) 1.51(0.04)	65.63943 526.0	1.35(.01) 1.39(0.04)	65.64041 526.1	1.41(.01) 1.30(-0.11)
65.73209 525.8	1.33(.01) 1.41(0.08)	65.73369 526.0	1.14(.01) 1.29(0.15)	65.73460 526.1	0.96(.01) 1.22(0.26)
65.83699 525.9	1.02(.01) 1.31(0.29)	65.83816 525.9	1.08(.01) 1.20(0.12)	65.83916 526.2	1.03(.01) 1.13(0.10)
65.94117 525.8	1.07(.01) 1.21(0.14)	65.94236 525.9	1.00(.00) 1.11(0.11)	65.94356 526.1	0.72(.01) 1.04(0.32)
66.04777 525.9	0.75(.00) 1.12(0.37)	66.04865 525.9	0.93(.01) 1.02(0.09)	66.05009 526.3	0.73(.01) 0.96(0.23)
66.15196 525.8	0.94(.01) 1.05(0.11)	66.15365 525.8	0.98(.01) 0.95(-0.03)	66.15415 526.0	0.65(.01) 0.89(0.24)
66.25272 525.8	0.88(.01) 0.97(0.09)	66.25589 526.0	0.65(.01) 0.88(0.23)	66.25654 526.3	0.75(.01) 0.82(0.07)

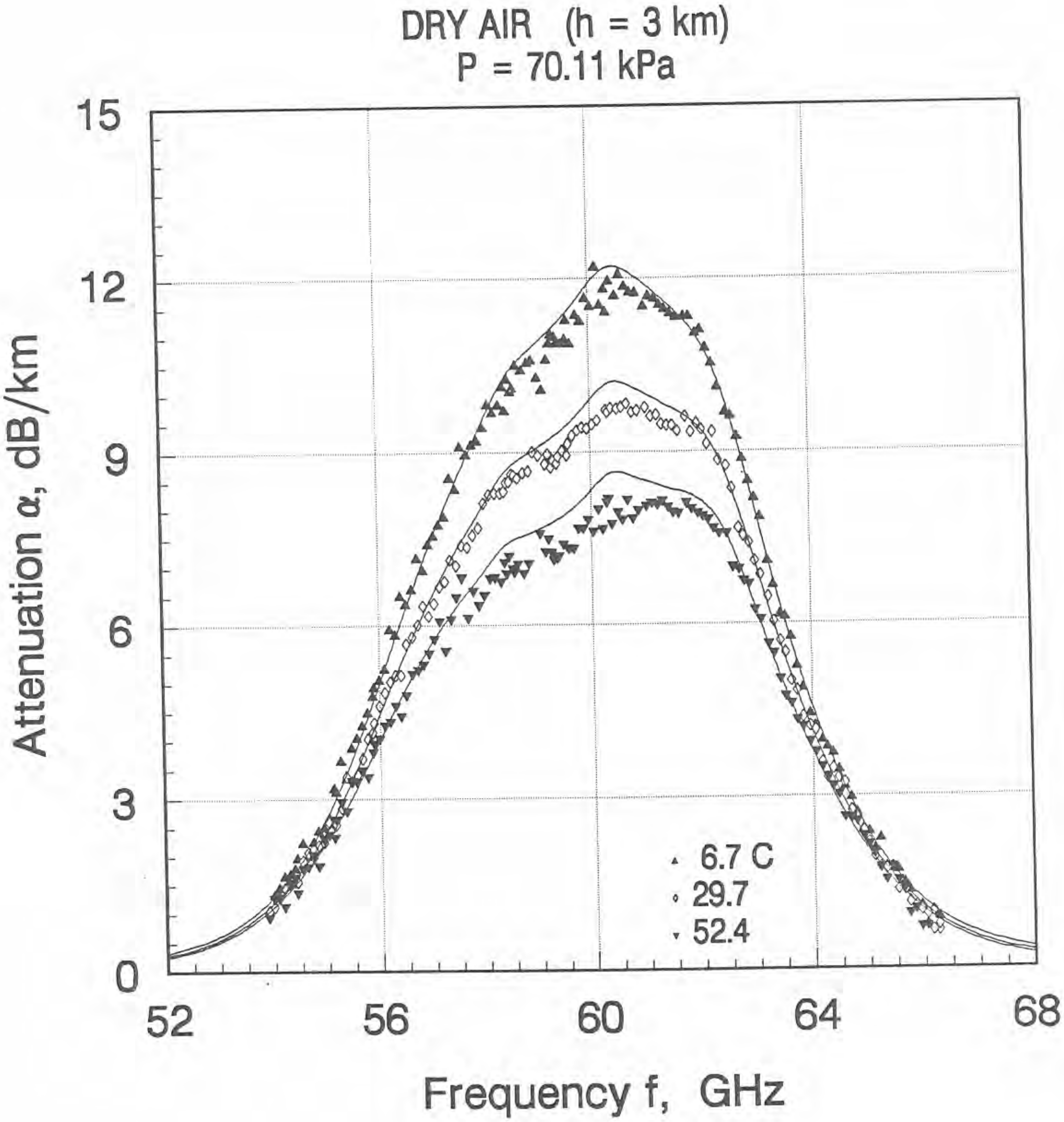

Figure A-10a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 3 km (see K.) for frequencies between 52 and 68 GHz.

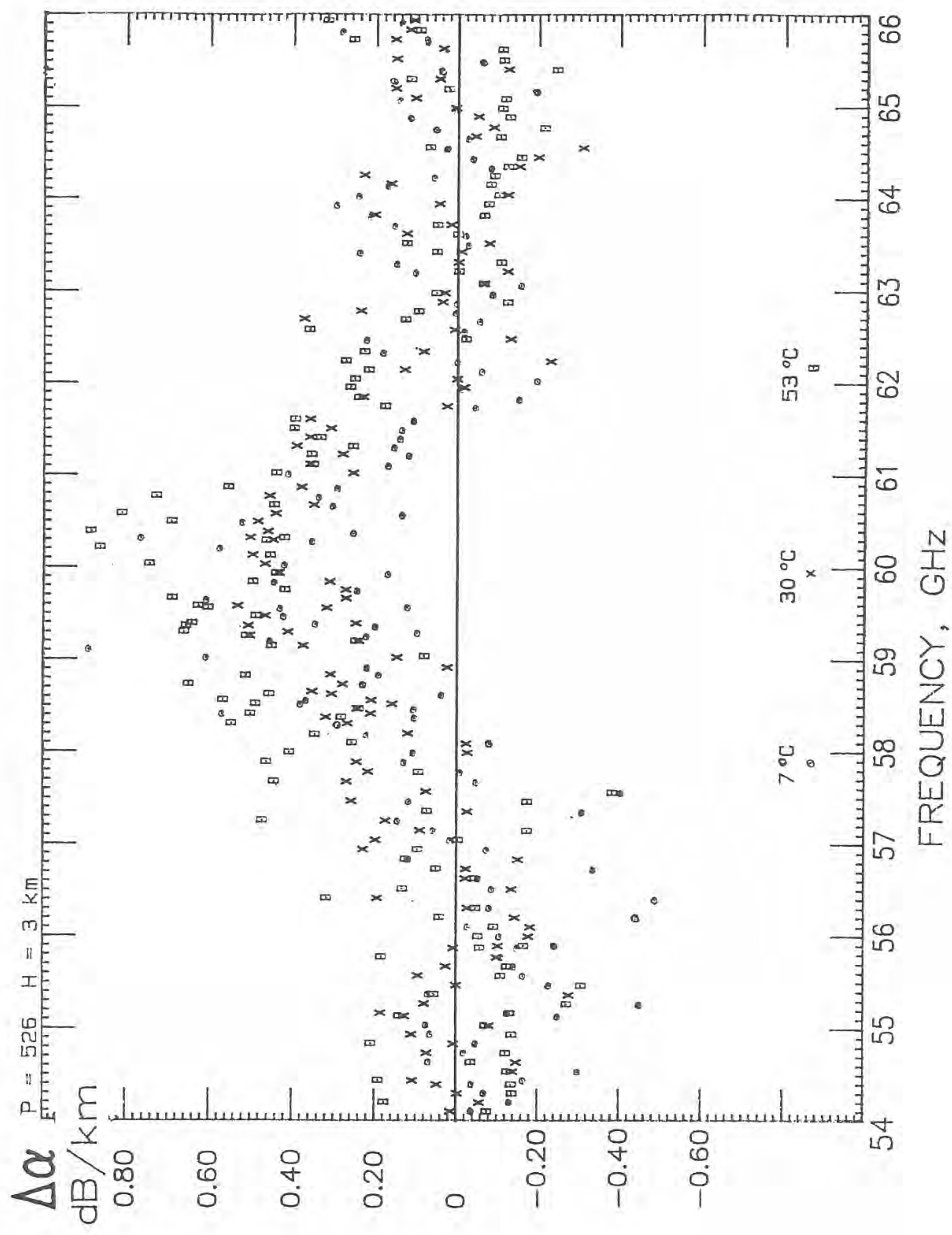

Figure A-10b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **K**.

L.

H = 0 km

Statistics Summary:

T	[°C]	6.70(24)	29.70(35)	52.40(08)
P	[torr] [kPa]	**759.80(19)**	**759.90(21)** 101.30	**759.70(35)**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.314	0.381	0.434

H = 0.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.88093 759.9	1.94(.03) 2.05(0.11)	53.88202 760.0	1.71(.03) 1.84(0.13)	53.88298 759.8	1.57(.03) 1.69(0.12)
53.97964 759.8	2.21(.02) 2.18(-0.03)	53.98071 759.8	1.73(.02) 1.97(0.24)	53.98169 759.3	1.85(.03) 1.80(-0.05)
54.07821 759.9	2.44(.02) 2.33(-0.11)	54.07935 759.8	2.09(.02) 2.10(0.01)	54.08023 760.1	2.11(.03) 1.93(-0.18)
54.17692 759.9	2.56(.03) 2.48(-0.08)	54.17826 759.8	2.12(.03) 2.24(0.12)	54.17894 759.9	1.81(.03) 2.06(0.25)
54.27554 759.6	2.48(.02) 2.64(0.16)	54.27660 759.6	2.39(.03) 2.39(0.00)	54.27756 760.0	2.42(.04) 2.19(-0.23)
54.37293 759.6	2.74(.02) 2.82(0.08)	54.37414 759.6	2.55(.03) 2.55(0.00)	54.37623 759.6	2.50(.03) 2.34(-0.16)
54.41448 759.6	3.43(.03) 2.89(-0.54)	54.41647 759.8	2.77(.03) 2.62(-0.15)	54.41839 759.6	2.13(.04) 2.40(0.27)
54.51556 759.8	3.39(.03) 3.08(-0.31)	54.51771 760.0	3.09(.02) 2.79(-0.30)	54.51865 759.2	2.81(.03) 2.56(-0.25)
54.61648 759.9	3.09(.03) 3.28(0.19)	54.61759 760.0	3.19(.03) 2.97(-0.22)	54.61858 759.8	2.48(.04) 2.72(0.24)
54.71655 759.7	3.48(.02) 3.49(0.01)	54.71764 759.9	2.92(.03) 3.16(0.24)	54.71864 760.4	2.91(.04) 2.90(-0.01)
54.81646 760.0	3.60(.04) 3.72(0.12)	54.81762 759.8	3.47(.03) 3.36(-0.11)	54.81853 760.1	3.06(.04) 3.07(0.01)
54.91653 760.0	3.78(.04) 3.95(0.17)	54.91789 759.8	3.39(.04) 3.57(0.18)	54.91857 759.9	3.67(.05) 3.26(-0.41)
55.01651 759.6	4.00(.04) 4.19(0.19)	55.01757 759.6	3.94(.05) 3.78(-0.16)	55.01855 760.0	3.42(.05) 3.45(0.03)
55.11522 759.5	5.25(.04) 4.44(-0.81)	55.11645 759.6	3.97(.04) 4.01(0.04)	55.11858 759.5	3.49(.04) 3.65(0.16)
55.14732 759.4	4.78(.04) 4.53(-0.25)	55.14934 759.7	3.97(.04) 4.08(0.11)	55.15129 759.6	3.94(.06) 3.72(-0.22)
55.24976 759.8	4.91(.05) 4.80(-0.11)	55.25194 760.0	4.67(.04) 4.32(-0.35)	55.25290 758.9	4.26(.04) 3.94(-0.32)
55.35204 759.9	4.94(.04) 5.08(0.14)	55.35317 760.0	5.15(.04) 4.57(-0.58)	55.35417 759.7	4.23(.06) 4.15(-0.08)
55.45346 760.1	5.49(.04) 5.37(-0.12)	55.45457 759.8	4.74(.04) 4.83(0.09)	55.45559 759.9	4.62(.05) 4.38(-0.24)
55.55473 760.0	6.03(.04) 5.68(-0.35)	55.55591 759.8	5.20(.04) 5.09(-0.11)	55.55682 760.1	4.75(.05) 4.61(-0.14)

H = 0.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.65614 760.0	6.08(.05) 5.99(-0.09)	55.65752 759.7	5.25(.05) 5.36(0.11)	55.65822 759.9	5.27(.05) 4.85(-0.42)
55.75747 759.6	6.36(.05) 6.30(-0.06)	55.75855 759.7	6.17(.05) 5.64(-0.53)	55.75955 760.0	4.97(.04) 5.09(0.12)
55.85752 759.5	7.21(.05) 6.62(-0.59)	55.85865 759.7	6.12(.04) 5.91(-0.21)	55.86092 759.5	5.23(.05) 5.33(0.10)
55.88015 759.5	7.25(.06) 6.70(-0.55)	55.88221 759.8	6.32(.04) 5.98(-0.34)	55.88417 759.6	5.71(.05) 5.39(-0.32)
55.98396 759.8	7.11(.04) 7.04(-0.07)	55.98617 760.0	6.57(.03) 6.27(-0.30)	55.98714 759.0	5.71(.06) 5.64(-0.07)
56.08761 759.9	7.59(.05) 7.38(-0.21)	56.08874 760.1	7.20(.05) 6.56(-0.64)	56.08977 759.8	6.12(.05) 5.89(-0.23)
56.19037 759.8	8.29(.04) 7.72(-0.57)	56.19151 759.9	7.05(.06) 6.86(-0.19)	56.19252 759.0	6.22(.07) 6.14(-0.08)
56.29298 760.0	8.28(.05) 8.07(-0.21)	56.29418 759.8	7.30(.05) 7.15(-0.15)	56.29511 760.0	6.48(.05) 6.39(-0.09)
56.39576 760.0	8.58(.07) 8.42(-0.16)	56.39716 759.8	7.92(.06) 7.45(-0.47)	56.39787 759.9	6.55(.05) 6.64(0.09)
56.49843 759.6	8.74(.07) 8.76(0.02)	56.49954 759.6	8.03(.06) 7.74(-0.29)	56.50054 760.0	6.89(.06) 6.88(-0.01)
56.61300 759.7	9.47(.05) 9.15(-0.32)	56.61507 759.7	8.63(.05) 8.06(-0.57)	56.61707 759.6	7.17(.07) 7.15(-0.02)
56.71817 759.8	9.84(.06) 9.50(-0.34)	56.72041 759.9	8.51(.06) 8.35(-0.16)	56.72140 758.9	7.54(.06) 7.39(-0.15)
56.82318 759.9	9.64(.07) 9.84(0.20)	56.82434 760.0	9.07(.06) 8.63(-0.44)	56.82534 759.8	7.71(.09) 7.62(-0.09)
56.92730 760.1	10.25(.09) 10.18(-0.07)	56.92844 759.9	8.33(.05) 8.90(0.57)	56.92947 759.0	7.76(.08) 7.85(0.09)
57.03127 760.0	10.80(.08) 10.51(-0.29)	57.03248 759.8	9.16(.08) 9.17(0.01)	57.03342 760.1	8.27(.06) 8.07(-0.20)
57.13538 760.0	10.62(.08) 10.83(0.21)	57.13681 759.8	9.59(.06) 9.43(-0.16)	57.13750 759.9	8.22(.06) 8.28(0.06)
57.23942 759.6	11.08(.08) 11.15(0.07)	57.24053 759.6	9.84(.09) 9.69(-0.15)	57.24155 760.0	8.06(.05) 8.48(0.42)
57.34585 759.6	11.85(.09) 11.46(-0.39)	57.34341 759.6	9.79(.06) 9.93(0.14)	57.34998 759.6	8.57(.07) 8.69(0.12)
57.45239 759.8	11.55(.08) 11.77(0.22)	57.45467 760.0	10.13(.08) 10.18(0.05)	57.45567 760.2	8.56(.12) 8.88(0.32)

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.55877 759.9	12.08(.09) 12.06(-0.02)	57.55994 760.0	10.60(.09) 10.41(-0.19)	57.56098 759.7	9.32(.11) 9.06(-0.26)
57.66424 759.8	12.77(.09) 12.35(-0.42)	57.66541 759.9	9.94(.07) 10.63(0.69)	57.66647 759.2	8.83(.10) 9.24(0.41)
57.76955 760.0	13.26(.13) 12.62(-0.64)	57.77079 759.8	10.84(.11) 10.85(0.01)	57.77175 760.1	8.40(.09) 9.41(1.01)
57.87504 760.0	13.16(.10) 12.89(-0.27)	57.87648 759.7	10.97(.08) 11.06(0.09)	57.87725 759.9	9.65(.08) 9.57(-0.08)
57.98043 759.6	13.29(.08) 13.14(-0.15)	57.98155 759.6	11.12(.07) 11.26(0.14)	57.98259 760.0	9.33(.07) 9.72(0.39)
58.08361 760.3	13.49(.05) 13.39(-0.10)	58.08086 759.7	11.49(.06) 11.44(-0.05)	58.08671 760.1	9.32(.06) 9.87(0.55)
58.17257 759.8	13.61(.08) 13.59(-0.02)	58.18893 759.9	11.51(.09) 11.62(0.11)	58.17680 760.0	9.77(.04) 9.99(0.22)
58.27888 759.8	13.63(.08) 13.81(0.18)	58.29556 760.0	11.47(.07) 11.80(0.33)	58.29659 759.8	9.54(.09) 10.15(0.61)
58.36207 760.1	13.95(.06) 13.98(0.03)	58.36390 759.9	11.48(.04) 11.90(0.42)	58.36509 759.8	9.82(.05) 10.23(0.41)
58.40118 759.8	14.17(.07) 14.06(-0.11)	58.40234 759.9	11.47(.07) 11.96(0.49)	58.40340 759.3	9.67(.07) 10.27(0.60)
58.45518 759.9	14.03(.06) 14.16(0.13)	58.45667 759.7	11.44(.06) 12.04(0.60)	58.45789 760.0	9.70(.04) 10.33(0.63)
58.50784 760.0	13.70(.07) 14.26(0.56)	58.50908 759.8	11.88(.06) 12.11(0.23)	58.51006 760.1	9.62(.07) 10.38(0.76)
58.54771 759.6	14.13(.05) 14.33(0.20)	58.54914 759.7	11.80(.03) 12.16(0.36)	58.55060 760.1	9.42(.03) 10.42(1.00)
58.61466 760.0	14.24(.05) 14.45(0.21)	58.61611 759.8	11.76(.06) 12.25(0.49)	58.61686 759.9	9.80(.05) 10.49(0.69)
58.72138 759.6	14.45(.09) 14.62(0.17)	58.72252 759.6	11.19(.06) 12.38(1.19)	58.72356 760.0	9.81(.05) 10.58(0.77)
58.82675 759.6	14.68(.06) 14.79(0.11)	58.82807 759.6	12.09(.04) 12.50(0.41)	58.81578 759.6	9.83(.06) 10.66(0.83)
58.90662 759.7	14.71(.05) 14.90(0.19)	58.90988 760.2	12.25(.03) 12.59(0.34)		
59.01428 759.8	14.32(.05) 15.06(0.74)	59.01564 760.1	12.20(.03) 12.70(0.50)	59.03218 759.8	10.27(.07) 10.83(0.56)
59.09850 760.1	14.09(.04) 15.17(1.08)	59.13926 759.9	12.39(.05) 12.83(0.44)	59.14034 759.6	9.95(.05) 10.91(0.96)

H = 0.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.19279 760.1	14.81(.04) 15.30(0.49)	59.19428 759.6	12.39(.04) 12.88(0.49)	59.19554 759.8	10.64(.03) 10.96(0.32)
59.24607 760.0	15.04(.08) 15.37(0.33)	59.24733 759.8	11.93(.05) 12.94(1.01)	59.24831 760.1	9.98(.06) 11.00(1.02)
59.28649 759.5	15.19(.05) 15.42(0.23)	59.28794 759.6	12.29(.02) 12.98(0.69)	59.28941 760.0	10.05(.03) 11.03(0.98)
59.35426 760.0	15.04(.06) 15.51(0.47)	59.35574 759.8	12.18(.05) 13.05(0.87)	59.35646 759.9	10.29(.06) 11.09(0.80)
59.38229 759.9	15.08(.04) 15.55(0.47)	59.38350 759.7	12.89(.02) 13.08(0.19)	59.38516 759.9	10.12(.02) 11.11(0.99)
59.46232 759.6	15.25(.06) 15.65(0.40)	59.46347 759.6	12.15(.05) 13.16(1.01)	59.46453 760.0	10.42(.06) 11.18(0.76)
59.54941 760.3	15.63(.04) 15.77(0.14)	59.55196 760.2	12.58(.01) 13.26(0.68)	59.55260 760.0	10.33(.02) 11.26(0.93)
59.56902 759.7	15.81(.06) 15.79(-0.02)	59.57023 759.9	12.46(.05) 13.28(0.82)	59.57264 759.5	10.39(.05) 11.27(0.88)
59.64063 759.7	15.01(.04) 15.88(0.87)	59.65734 759.9	12.45(.06) 13.37(0.92)	59.65836 759.3	10.47(.08) 11.35(0.88)
59.74966 759.8	15.99(.04) 16.02(0.03)	59.75102 760.3	13.11(.03) 13.47(0.36)	59.75228 759.9	11.02(.02) 11.44(0.42)
59.83492 760.2	15.60(.03) 16.12(0.52)	59.83680 760.1	13.11(.02) 13.56(0.45)	59.83804 759.8	10.42(.03) 11.52(1.10)
59.93040 760.1	16.03(.03) 16.23(0.20)	59.93192 759.5	12.78(.02) 13.66(0.88)	59.93318 759.8	10.74(.02) 11.61(0.87)
60.02528 759.5	16.08(.03) 16.33(0.25)	60.02674 759.6	13.04(.02) 13.75(0.71)	60.02822 760.1	10.66(.02) 11.69(1.03)
60.12228 759.8	16.32(.04) 16.42(0.10)	60.12349 759.7	12.80(.02) 13.83(1.03)	60.12517 759.9	11.07(.02) 11.77(0.70)
60.20327 759.7	15.46(.17) 16.48(1.02)			60.20550 760.0	10.22(.15) 11.83(1.61)
60.28234 760.2	16.21(.03) 13.95(0.53)	60.28491 760.2	13.42(.02) 16.54(0.33)	60.28556 760.0	11.21(.02) 11.88(0.67)
60.31134 759.5	16.54(.17) 16.55(0.01)	60.31267 759.6	13.44(.15) 13.96(0.52)	60.31501 759.5	10.91(.15) 11.90(0.99)
60.37468 759.7	16.26(.03) 16.59(0.33)	60.37803 760.3	13.16(.02) 14.00(0.84)	60.37907 760.1	10.85(.01) 11.93(1.08)
60.48505 759.8	16.48(.02) 16.62(0.14)	60.48644 760.4	13.41(.02) 14.04(0.63)	60.48771 759.9	11.15(.02) 11.98(0.83)

H = 0.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.57137 760.3	16.53(.03) 16.63(0.10)	60.57326 760.2	13.48(.01) 14.06(0.58)	60.57450 759.7	10.72(.02) 12.00(1.28)
60.66801 760.2	16.31(.03) 16.63(0.32)	60.66955 759.5	13.71(.02) 14.06(0.35)	60.67083 759.8	11.25(.01) 12.01(0.76)
60.76407 759.4	16.36(.03) 16.61(0.25)	60.76554 759.6	13.31(.01) 14.06(0.75)	60.76704 760.0	10.96(.01) 12.02(1.06)
60.86226 759.7	16.30(.02) 16.57(0.27)	60.86348 759.7	13.41(.01) 14.04(0.63)	60.86518 759.9	11.16(.01) 12.01(0.85)
61.01526 760.1	16.09(.02) 16.47(0.38)	61.01787 760.4	13.54(.02) 13.98(0.44)	61.01852 760.0	11.42(.01) 11.98(0.56)
61.10872 759.8	16.46(.05) 16.40(-0.06)	61.11213 759.9	13.64(.03) 13.93(0.29)	61.11312 760.1	11.46(.03) 11.95(0.49)
61.22038 759.9	16.31(.04) 16.29(-0.02)	61.22184 759.9	13.67(.02) 13.86(0.19)	61.22312 760.1	11.42(.02) 11.91(0.49)
61.30779 760.0	16.54(.04) 16.19(-0.35)	61.30973 760.2	13.28(.01) 13.80(0.52)	61.31095 760.0	11.44(.02) 11.86(0.42)
61.40565 759.7	16.20(.03) 16.07(-0.13)	61.40717 759.8	13.16(.02) 13.71(0.55)	61.40846 760.0	11.25(.02) 11.81(0.56)
61.50285 759.4	15.84(.01) 15.93(0.09)	61.50434 759.8	13.16(.03) 13.62(0.46)	61.50582 760.2	11.23(.02) 11.75(0.52)
61.60223 760.0	15.60(.03) 15.77(0.17)	61.60346 759.8	13.20(.03) 13.51(0.31)	61.60519 760.1	11.33(.02) 11.67(0.34)
61.74821 760.1	15.65(.02) 15.51(-0.14)	61.75080 760.1	13.26(.03) 13.32(0.06)	61.75144 760.2	11.04(.02) 11.54(0.50)
61.84276 759.9	15.65(.02) 15.31(-0.34)	61.84620 760.0	12.75(.02) 13.17(0.42)	61.84722 760.1	11.37(.02) 11.44(0.07)
61.95577 759.9	15.16(.03) 15.05(-0.11)	61.95724 760.0	13.16(.01) 12.98(-0.18)	61.95854 760.0	11.20(.01) 11.30(0.10)
62.04422 760.2	15.22(.02) 14.82(-0.40)	62.04619 760.1	13.06(.01) 12.81(-0.25)	62.04743 760.0	10.79(.01) 11.17(0.38)
62.14326 759.8	14.92(.01) 14.55(-0.37)	62.14481 759.7	12.32(.01) 12.60(0.28)	62.14611 760.0	10.76(.02) 11.00(0.24)
62.24163 759.6	14.39(.03) 14.25(-0.14)	62.24316 759.7	12.84(.03) 12.36(-0.48)	62.24465 760.2	10.60(.01) 10.82(0.22)
62.34222 759.9	13.80(.02) 13.91(0.11)	62.34346 759.7	11.95(.02) 12.09(0.14)	62.34521 760.1	10.32(.01) 10.61(0.29)
62.48113 760.1	13.37(.01) 13.41(0.04)	62.48374 760.2	11.74(.02) 11.68(-0.06)	62.48440 760.2	10.18(.01) 10.27(0.09)

H = 0.0 km

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.57680 760.1	13.05(.01) 13.04(-0.01)	62.58029 760.1	11.63(.02) 11.37(-0.26)	62.58132 760.1	9.59(.01) 10.02(0.43)
62.69115 760.1	12.82(.02) 12.57(-0.25)	62.69265 760.1	10.48(.01) 10.99(0.51)	62.69397 760.0	9.54(.01) 9.70(0.16)
62.78065 760.3	12.17(.01) 12.19(0.02)	62.78265 760.1	10.43(.01) 10.67(0.24)	62.78391 759.9	9.12(.01) 9.43(0.31)
62.88087 759.9	11.81(.01) 11.75(-0.06)	62.88244 759.7	10.15(.01) 10.30(0.15)	62.88375 760.0	9.37(.01) 9.12(-0.25)
62.98042 759.6	11.45(.01) 11.31(-0.14)	62.98195 759.7	9.79(.01) 9.93(0.14)	62.98347 760.1	8.73(.01) 8.80(0.07)
63.08220 759.8	11.02(.01) 10.85(-0.17)	63.08346 759.7	9.43(.01) 9.54(0.11)	63.08522 760.1	8.58(.01) 8.47(-0.11)
63.21404 760.1	9.95(.01) 10.25(0.30)	63.21669 760.3	8.90(.01) 9.03(0.13)	63.21735 760.1	8.00(.01) 8.03(0.03)
63.31083 760.0	9.49(.01) 9.82(0.33)	63.31436 760.2	8.52(.01) 8.65(0.13)	63.31541 760.0	7.99(.01) 7.71(-0.28)
63.42653 760.1	9.02(.01) 9.31(0.29)	63.42804 760.2	8.07(.01) 8.22(0.15)	63.42938 760.0	7.21(.01) 7.34(0.13)
63.51708 760.6	8.70(.01) 8.91(0.21)	63.51910 760.2	7.87(.01) 7.88(0.01)	63.52038 759.9	6.98(.01) 7.04(0.06)
63.61848 759.9	8.47(.01) 8.48(0.01)	63.62008 759.7	7.29(.01) 7.51(0.22)	63.62140 759.9	6.58(.01) 6.73(0.15)
63.71920 759.6	7.59(.01) 8.06(0.47)	63.72075 759.7	7.08(.01) 7.15(0.07)	63.72229 760.1	6.26(.01) 6.41(0.15)
63.82217 759.8	7.14(.01) 7.64(0.50)	63.82345 759.7	6.46(.01) 6.79(0.33)	63.82523 760.1	6.04(.01) 6.10(0.06)
63.94695 760.1	6.67(.02) 7.16(0.49)	63.94962 760.5	6.27(.01) 6.37(0.10)	63.95030 760.2	5.65(.01) 5.74(0.09)
64.04486 760.1	6.53(.01) 6.79(0.26)	64.04843 760.3	6.28(.01) 6.04(-0.24)	64.04950 760.1	5.34(.01) 5.46(0.12)
64.16190 760.2	6.11(.01) 6.37(0.26)	64.16344 760.2	5.36(.02) 5.68(0.32)	64.16476 760.1	5.22(.02) 5.14(-0.08)
64.25349 760.8	5.79(.01) 6.05(0.26)	64.25555 760.3	5.16(.01) 5.40(0.24)	64.25682 760.1	5.04(.01) 4.89(-0.15)
64.35608 760.0	5.67(.01) 5.71(0.04)	64.35765 759.8	5.34(.01) 5.11(-0.23)	64.35902 759.9	4.75(.01) 4.63(-0.12)
64.45793 759.7	5.39(.02) 5.38(-0.01)	64.45953 759.9	5.08(.01) 4.82(-0.26)	64.46107 760.1	4.57(.01) 4.38(-0.19)

H = 0.0 km

6.7°C f_x [GHz] / P [torr]	6.7°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	29.7°C f_x [GHz] / P [torr]	29.7°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km	52.4°C f_x [GHz] / P [torr]	52.4°C $\alpha_x(\delta\alpha)$ / $\alpha_M(\pm\Delta\alpha)$ dB/km
64.56211	4.94(.01)	64.56342	4.88(.01)	64.56524	4.01(.01)
759.8	5.07(0.13)	759.7	4.54(-0.34)	760.1	4.13(0.12)
64.68047	4.67(.02)	64.68255	4.36(.01)	64.68319	4.62(.09)
759.6	4.73(0.06)	759.9	4.24(-0.12)	760.0	3.86(-0.76)
64.77893	4.17(.01)	64.78252	3.98(.01)	64.78352	3.75(.01)
759.6	4.46(0.29)	759.8	3.99(0.01)	759.9	3.64(-0.11)
64.89726	3.89(.01)	64.89879	3.70(.00)	64.90016	3.69(.02)
760.0	4.15(0.26)	760.0	3.72(0.02)	760.1	3.40(-0.29)
64.98999	3.81(.01)	64.99200	3.45(.01)	64.99328	3.27(.01)
759.6	3.92(0.11)	759.9	3.51(0.06)	760.0	3.21(-0.06)
65.09367	3.45(.00)	65.09527	2.98(.01)	65.09666	3.16(.01)
759.9	3.68(0.23)	759.8	3.30(0.32)	759.9	3.01(-0.15)
65.19670	3.58(.01)	65.19832	2.83(.01)	65.19987	2.73(.01)
759.6	3.45(-0.13)	759.8	3.09(0.26)	760.0	2.82(0.09)
65.30208	2.86(.01)	65.30340	2.77(.01)	65.30522	2.48(.01)
759.8	3.23(0.37)	759.7	2.89(0.12)	760.1	2.64(0.16)
65.41338	2.77(.01)	65.41547	2.80(.01)	65.41613	2.74(.02)
759.6	3.02(0.25)	759.9	2.69(-0.11)	759.9	2.46(-0.28)
65.51295	2.90(.01)	65.51658	2.20(.01)	65.51760	2.49(.01)
759.5	2.83(-0.07)	759.8	2.52(0.32)	760.0	2.30(-0.19)
65.63262	2.38(.01)	65.63418	2.17(.01)	65.63557	2.17(.01)
760.0	2.63(0.25)	760.0	2.34(0.17)	760.0	2.13(-0.04)
65.72641	2.30(.01)	65.72845	2.00(.01)	65.72974	1.61(.01)
759.6	2.48(0.18)	759.9	2.20(0.20)	760.0	2.00(0.39)
65.83128	1.75(.01)	65.83289	1.77(.01)	65.83430	1.72(.01)
759.9	2.32(0.57)	759.9	2.05(0.28)	759.8	1.87(0.15)
65.93547	1.82(.01)	65.93710	1.64(.01)	65.93869	1.28(.01)
759.6	2.18(0.36)	759.8	1.92(0.28)	760.0	1.74(0.46)
66.04204	1.39(.01)	66.04338	1.33(.01)	66.04523	1.24(.01)
759.8	2.04(0.65)	759.6	1.79(0.46)	760.0	1.62(0.38)
66.14628	1.62(.01)	66.14841	1.53(.01)	66.14907	1.42(.01)
759.5	1.91(0.29)	760.0	1.67(0.14)	760.0	1.51(0.09)
66.24697	1.61(.01)	66.25065	0.97(.01)	66.25169	1.13(.01)
759.5	1.80(0.19)	759.9	1.56(0.59)	760.0	1.41(0.28)

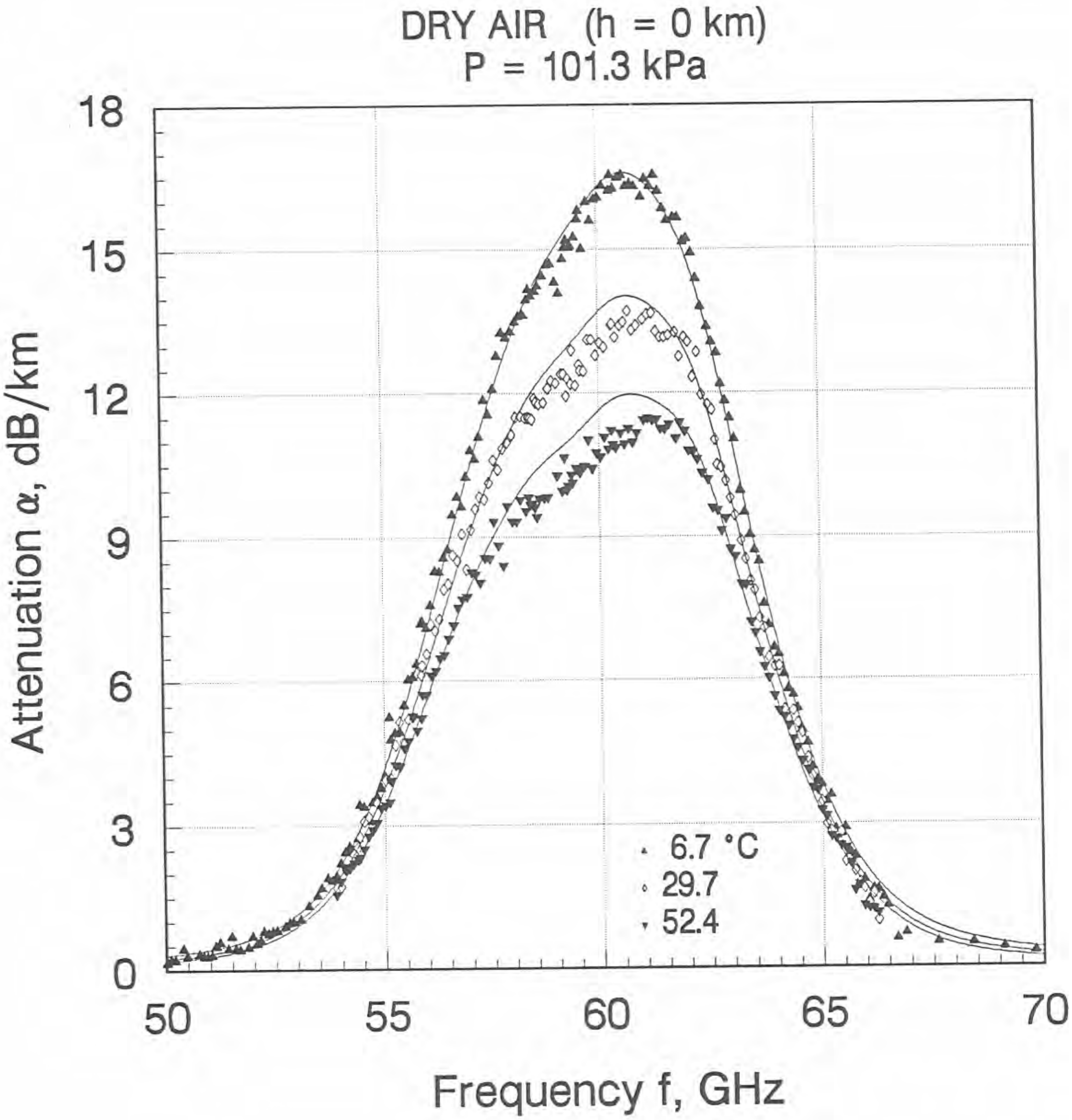

Figure A-11a. Predicted and measured attenuation rates of dry air, α_M and α_x, at H = 0 km (see L.) for frequencies between 50 and 70 GHz.

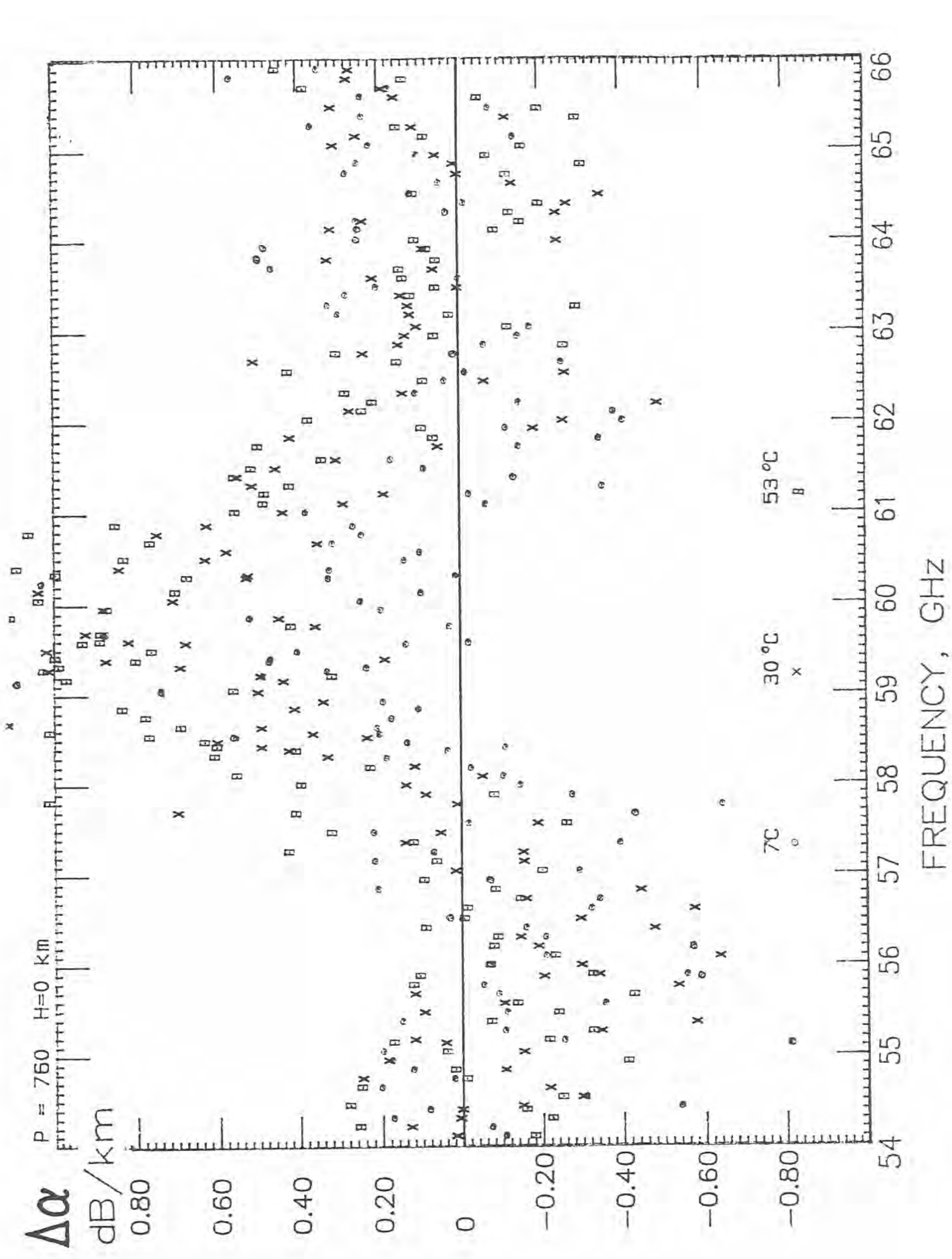

Figure A-11b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under L.

P = 0 torr

Statistics Summary:

T	[°C]	6.70(24)	29.70(34)	52.40(08)
P	[torr] [kPa]	**0.00**	**0.00** 0.00	**0.00**
$\sigma_x(\Delta\alpha)$	[dB/km]	0.037	0.055	0.050

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
53.89632	0.00(.12)	53.89606	0.11(.03)	53.89599	0.01(.02)
0.0	0.00(0.10)	0.0	0.00(-.11)	0.0	0.00(-.01)
53.99500	0.00(.11)	53.99479	0.05(.07)	53.99471	0.03(.02)
0.0	0.00(0.09)	0.0	0.00(0.05)	0.0	0.00(-0.03)
54.09359	0.00(.03)	54.09346	0.06(.02)	54.09329	0.00(.04)
0.0	0.00(0.01)	0.0	0.00(-0.06)	0.0	0.00(0.01)
54.19233	0.00(.02)	54.19239	0.00(.06)	54.19200	0.06(.03)
0.0	0.00(0.00)	0.0	0.00(0.04)	0.0	0.00(-0.06)
54.29100	0.03(.05)	54.29074	0.01(.03)	54.29065	0.00(.05)
0.0	0.00(0.03)	0.0	0.00(-0.01)	0.0	0.00(0.01)
54.38837	0.00(.13)	54.38832	0.09(.03)	54.38934	0.10(.03)
0.0	0.00(0.11)	0.0	0.00(-0.09)	0.0	0.00(-0.10)
54.42987	0.00(.06)	54.43067	0.01(.03)	54.43153	0.00(.13)
0.0	0.00(0.04)	0.0	0.00(-0.01)	0.0	0.00(0.09)
54.53103	0.04(.02)	54.53194	0.00(.04)	54.53180	0.06(.02)
0.0	0.00(-0.04)	0.0	0.00(0.02)	0.0	0.00(-0.06)
54.63209	0.04(.02)	54.63183	0.12(.03)	54.63176	0.06(.04)
0.0	0.00(-0.04)	0.0	0.00(-0.12)	0.0	0.00(-0.06)
54.73212	0.00(.09)	54.73191	0.00(.04)	54.73183	0.00(.07)
0.0	0.00(0.07)	0.0	0.00(0.01)	0.0	0.00(0.04)
54.83207	0.01(.04)	54.83193	0.00(.09)	54.83176	0.00(.04)
0.0	0.00(0.01)	0.0	0.00(0.07)	0.0	0.00(0.01)
54.93216	0.06(.03)	54.93222	0.00(.14)	54.93182	0.00(.10)
0.0	0.00(-0.06)	0.0	0.00(0.14)	0.0	0.00(0.07)
55.03218	0.00(.08)	55.03191	0.00(.09)	55.03182	0.00(.08)
0.0	0.00(0.04)	0.0	0.00(0.06)	0.0	0.00(0.03)
55.13087	0.01(.02)	55.13083	0.07(.04)	55.13187	0.00(.06)
0.0	0.00(-0.01)	0.0	0.00(-0.07)	0.0	0.00(0.03)
55.16293	0.00(.04)	55.16373	0.04(.03)	55.16460	0.00(.08)
0.0	0.00(0.01)	0.0	0.00(-0.04)	0.0	0.00(0.04)
55.26544	0.02(.03)	55.26636	0.03(.03)	55.26622	0.04(.04)
0.0	0.00(-0.02)	0.0	0.00(-0.03)	0.0	0.00(-0.04)
55.36786	0.01(.03)	55.36761	0.15(.04)	55.36752	0.00(.09)
0.0	0.00(-0.01)	0.0	0.00(-0.21)	0.0	0.00(0.06)
55.46925	0.00(.12)	55.46904	0.00(.07)	55.46896	0.01(.03)
0.0	0.00(0.09)	0.0	0.00(0.04)	0.0	0.00(-0.01)
55.57055	0.04(.02)	55.57040	0.03(.03)	55.57023	0.04(.03)
0.0	0.00(-0.04)	0.0	0.00(-0.03)	0.0	0.00(-0.04)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
55.67198	0.03(.03)	55.67204	0.02(.03)	55.67165	0.00(.04)
0.0	0.00(-0.03)	0.0	0.00(-0.02)	0.0	0.00(0.01)
55.77336	0.01(.02)	55.77309	0.04(.03)	55.77299	0.00(.05)
0.0	0.00(-0.01)	0.0	0.00(-0.04)	0.0	0.00(0.01)
55.87339	0.00(.11)	55.87321	0.01(.02)	55.87439	0.11(.04)
0.0	0.00(0.09)	0.0	0.00(-0.01)	0.0	0.00(-0.11)
55.89597	0.00(.07)	55.89679	0.01(.02)	55.89767	0.03(.02)
0.0	0.00(0.04)	0.0	0.00(-0.01)	0.0	0.00(-0.03)
55.99986	0.04(.02)	56.00078	0.14(.03)	56.00064	0.11(.04)
0.0	0.00(-0.04)	0.0	0.00(-0.17)	0.0	0.00(-0.11)
56.10364	0.00(.10)	56.10338	0.08(.04)	56.10329	0.00(.07)
0.0	0.00(0.06)	0.0	0.00(-0.08)	0.0	0.00(0.04)
56.20637	0.06(.02)	56.20616	0.00(.06)	56.20608	0.08(.11)
0.0	0.00(-0.06)	0.0	0.00(0.02)	0.0	0.00(0.08)
56.30902	0.01(.02)	56.30887	0.05(.03)	56.30870	0.02(.03)
0.0	0.00(-0.01)	0.0	0.00(-0.05)	0.0	0.00(-0.02)
56.41181	0.00(.08)	56.41187	0.02(.04)	56.41146	0.00(.08)
0.0	0.00(0.05)	0.0	0.00(-0.02)	0.0	0.00(0.04)
56.51453	0.00(.11)	56.51426	0.00(.09)	56.51416	0.03(.03)
0.0	0.00(0.08)	0.0	0.00(0.06)	0.0	0.00(-0.03)
56.62902	0.03(.03)	56.62984	0.00(.06)	56.63074	0.00(.12)
0.0	0.00(-0.03)	0.0	0.00(0.04)	0.0	0.00(0.09)
56.73427	0.02(.03)	56.73521	0.00(.04)	56.73506	0.00(.10)
0.0	0.00(-0.02)	0.0	0.00(0.01)	0.0	0.00(0.07)
56.83942	0.01(.02)	56.83915	0.12(.03)	56.83907	0.00(.13)
0.0	0.00(-0.01)	0.0	0.00(-0.12)	0.0	0.00(0.10)
56.94350	0.00(.09)	56.94328	0.00(.14)	56.94319	0.04(.03)
0.0	0.00(0.06)	0.0	0.00(0.10)	0.0	0.00(-0.04)
57.04750	0.04(.03)	57.04735	0.04(.03)	57.04717	0.00(.04)
0.0	0.00(-0.04)	0.0	0.00(-0.04)	0.0	0.00(0.00)
57.15164	0.05(.03)	57.15170	0.00(.05)	57.15129	0.00(.07)
0.0	0.00(-0.05)	0.0	0.00(0.00)	0.0	0.00(0.04)
57.25571	0.00(.07)	57.25544	0.00(.14)	57.25534	0.00(.13)
0.0	0.00(0.03)	0.0	0.00(0.12)	0.0	0.00(0.10)
57.36207	0.10(.04)	57.35835	0.04(.04)	57.36381	0.07(.04)
0.0	0.00(-0.10)	0.0	0.00(-0.04)	0.0	0.00(-0.07)
57.46869	0.00(.04)	57.46964	0.00(.12)	57.46949	0.00(.12)
0.0	0.00(0.00)	0.0	0.00(0.09)	0.0	0.00(0.07)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
57.57521	0.09(.03)	57.57494	0.05(.03)	57.57485	0.00(.09)
0.0	0.00(-0.09)	0.0	0.00(-0.05)	0.0	0.00(0.04)
57.68064	0.00(.13)	57.68042	0.00(.10)	57.68034	0.00(.07)
0.0	0.00(0.10)	0.0	0.00(0.07)	0.0	0.00(0.02)
57.78599	0.00(.12)	57.78584	0.00(.08)	57.78567	0.15(.05)
0.0	0.00(0.09)	0.0	0.00(0.04)	0.0	0.00(-0.15)
57.89149	0.03(.04)	57.89155	0.05(.04)	57.89113	0.03(.03)
0.0	0.00(-0.03)	0.0	0.00(-0.05)	0.0	0.00(-0.03)
57.99691	0.00(.08)	57.99664	0.12(.03)	57.99653	0.00(.15)
0.0	0.00(0.05)	0.0	0.00(-0.15)	0.0	0.00(0.12)
58.10101	0.00(.05)	58.09599	0.00(.05)	58.10160	0.19(.02)
0.0	0.00(0.03)	0.0	0.00(0.02)	0.0	0.00(-0.19)
58.19009	0.02(.01)	58.20408	0.03(.03)	58.19140	0.00(.05)
0.0	0.00(-0.02)	0.0	0.00(-0.03)	0.0	0.00(0.03)
58.29595	0.01(.03)	58.31071	0.01(.03)	58.31064	0.04(.03)
0.0	0.00(-0.01)	0.0	0.00(-0.01)	0.0	0.00(-0.04)
58.37895	0.00(.05)	58.37945	0.00(.03)	58.37940	0.01(.02)
0.0	0.00(0.03)	0.0	0.00(0.01)	0.0	0.00(-0.01)
58.41778	0.09(.03)	58.41755	0.00(.09)	58.41747	0.00(.07)
0.0	0.00(-0.09)	0.0	0.00(0.06)	0.0	0.00(0.04)
58.47203	0.02(.03)	58.47240	0.00(.08)	58.47223	0.00(.04)
0.0	0.00(-0.02)	0.0	0.00(0.06)	0.0	0.00(0.02)
58.52447	0.01(.02)	58.52431	0.00(.08)	58.52413	0.07(.04)
0.0	0.00(-0.01)	0.0	0.00(0.06)	0.0	0.00(-0.07)
58.56473	0.00(.02)	58.56479	0.00(.05)	58.56487	0.00(.03)
0.0	0.00(0.01)	0.0	0.00(0.04)	0.0	0.00(0.01)
58.63131	0.03(.02)	58.63137	0.06(.02)	58.63094	0.02(.02)
0.0	0.00(-0.03)	0.0	0.00(-0.06)	0.0	0.00(-0.02)
58.73808	0.00(.05)	58.73779	0.01(.03)	58.73769	0.02(.03)
0.0	0.00(0.02)	0.0	0.00(-0.01)	0.0	0.00(-0.02)
58.84343	0.00(.04)	58.84338	0.03(.02)	58.82995	0.00(.04)
0.0	0.00(0.02)	0.0	0.00(-0.03)	0.0	0.00(0.02)
58.92434	0.04(.01)	58.92596	0.04(.01)		
0.0	0.00(-0.04)	0.0	0.00(-0.04)		
59.03153	0.04(.03)	59.03137	0.00(.05)	59.04638	0.00(.06)
0.0	0.00(-0.04)	0.0	0.00(0.04)	0.0	0.00(0.06)
59.11559	0.00(.02)	59.15465	0.00(.05)	59.15456	0.00(.05)
0.0	0.00(0.01)	0.0	0.00(0.02)	0.0	0.00(0.03)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
59.20984	0.00(.04)	59.21022	0.02(.01)	59.21003	0.00(.01)
0.0	0.00(0.03)	0.0	0.00(-0.02)	0.0	0.00(0.00)
59.26292	0.00(.05)	59.26276	0.00(.07)	59.26258	0.03(.03)
0.0	0.00(0.03)	0.0	0.00(0.07)	0.0	0.00(-0.03)
59.30371	0.00(.05)	59.30376	0.02(.01)	59.30384	0.01(.01)
0.0	0.00(0.04)	0.0	0.00(-0.02)	0.0	0.00(-0.01)
59.37111	0.04(.02)	59.37117	0.09(.02)	59.37074	0.04(.02)
0.0	0.00(-0.04)	0.0	0.00(-0.09)	0.0	0.00(-0.04)
59.39952	0.00(.02)	59.39925	0.00(.01)	59.39964	0.01(.01)
0.0	0.00(0.01)	0.0	0.00(0.00)	0.0	0.00(-0.01)
59.47923	0.01(.02)	59.47894	0.00(.04)	59.47882	0.00(.06)
0.0	0.00(-0.01)	0.0	0.00(0.02)	0.0	0.00(0.04)
59.56723	0.03(.01)	59.56810	0.06(.01)	59.56783	0.04(.01)
0.0	0.00(-0.03)	0.0	0.00(-0.06)	0.0	0.00(-0.04)
59.58590	0.06(.01)	59.58571	0.00(.08)	59.58696	0.00(.04)
0.0	0.00(-0.06)	0.0	0.00(0.05)	0.0	0.00(0.02)
59.65858	0.00(.06)	59.67287	0.04(.02)	59.67271	0.00(.04)
0.0	0.00(0.05)	0.0	0.00(-0.04)	0.0	0.00(0.01)
59.76711	0.06(.01)	59.76695	0.00(.02)	59.76688	0.00(.02)
0.0	0.00(-0.06)	0.0	0.00(0.01)	0.0	0.00(0.01)
59.85223	0.01(.01)	59.85273	0.00(.02)	59.85266	0.01(.01)
0.0	0.00(-0.01)	0.0	0.00(0.01)	0.0	0.00(-0.01)
59.94765	0.02(.01)	59.94802	0.00(.02)	59.94783	0.00(.02)
0.0	0.00(-0.02)	0.0	0.00(0.01)	0.0	0.00(0.01)
60.04269	0.01(.01)	60.04275	0.03(.01)	60.04282	0.01(.01)
0.0	0.00(-0.01)	0.0	0.00(-0.03)	0.0	0.00(-0.01)
60.13970	0.01(.01)	60.13942	0.00(.01)	60.13981	0.01(.01)
0.0	0.00(-0.01)	0.0	0.00(0.00)	0.0	0.00(-0.01)
60.22038	0.01(.05)			60.21997	0.00(.15)
0.0	0.00(-0.01)			0.0	0.00(0.09)
60.30038	0.00(.02)	60.30124	0.00(.01)	60.30096	0.01(.01)
0.0	0.00(0.01)	0.0	0.00(0.00)	0.0	0.00(-0.01)
60.32841	0.00(.06)	60.32835	0.04(.06)	60.32948	0.00(.07)
0.0	0.00(0.02)	0.0	0.00(-0.04)	0.0	0.00(0.01)
60.39284	0.02(.01)	60.39450	0.00(.02)	60.39417	0.00(.02)
0.0	0.00(-0.02)	0.0	0.00(0.01)	0.0	0.00(0.01)
60.50270	0.04(.01)	60.50254	0.00(.02)	60.50248	0.00(.01)
0.0	0.00(-0.04)	0.0	0.00(0.01)	0.0	0.00(0.00)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
60.58887	0.01(.01)	60.58937	0.00(.02)	60.58930	0.01(.00)
0.0	0.00(-0.01)	0.0	0.00(0.01)	0.0	0.00(-0.01)
60.68546	0.00(.02)	60.68584	0.01(.01)	60.68565	0.00(.02)
0.0	0.00(0.01)	0.0	0.00(-0.01)	0.0	0.00(0.01)
60.78168	0.00(.02)	60.78173	0.00(.01)	60.78180	0.00(.03)
0.0	0.00(0.01)	0.0	0.00(0.01)	0.0	0.00(0.03)
60.87988	0.03(.01)	60.87959	0.01(.00)	60.87999	0.01(.01)
0.0	0.00(-0.03)	0.0	0.00(-0.01)	0.0	0.00(-0.01)
61.03350	0.01(.00)	61.03437	0.00(.01)	61.03409	0.00(.05)
0.0	0.00(-0.01)	0.0	0.00(0.00)	0.0	0.00(0.04)
61.12708	0.01(.01)	61.12877	0.00(.01)	61.12847	0.03(.01)
0.0	0.00(-0.01)	0.0	0.00(0.00)	0.0	0.00(-0.03)
61.23828	0.00(.02)	61.23816	0.00(.03)	61.23807	0.00(.02)
0.0	0.00(0.01)	0.0	0.00(0.02)	0.0	0.00(0.01)
61.32546	0.00(.00)	61.32601	0.01(.00)	61.32597	0.05(.01)
0.0	0.00(0.00)	0.0	0.00(-0.01)	0.0	0.00(-0.05)
61.42329	0.01(.01)	61.42365	0.01(.01)	61.42345	0.00(.02)
0.0	0.00(-0.01)	0.0	0.00(-0.01)	0.0	0.00(0.01)
61.52068	0.00(.01)	61.52073	0.00(.03)	61.52083	0.01(.01)
0.0	0.00(0.00)	0.0	0.00(0.02)	0.0	0.00(-0.01)
61.62006	0.01(.00)	61.61979	0.01(.01)	61.62016	0.00(.05)
0.0	0.00(-0.01)	0.0	0.00(-0.01)	0.0	0.00(0.04)
61.76662	0.00(.00)	61.76752	0.01(.01)	61.76721	0.00(.05)
0.0	0.00(0.00)	0.0	0.00(-0.01)	0.0	0.00(0.04)
61.86133	0.01(.01)	61.86303	0.00(.01)	61.86271	0.00(.01)
0.0	0.00(-0.01)	0.0	0.00(0.01)	0.0	0.00(0.01)
61.97387	0.00(.01)	61.97373	0.01(.01)	61.97364	0.00(.01)
0.0	0.00(0.00)	0.0	0.00(-0.01)	0.0	0.00(0.00)
62.06210	0.00(.01)	62.06266	0.00(.01)	62.06260	0.02(.01)
0.0	0.00(0.00)	0.0	0.00(0.01)	0.0	0.00(-0.02)
62.16111	0.00(.02)	62.16146	0.01(.00)	62.16126	0.00(.03)
0.0	0.00(0.01)	0.0	0.00(-0.01)	0.0	0.00(0.02)
62.25966	0.00(.01)	62.25971	0.00(.03)	62.25981	0.01(.00)
0.0	0.00(0.00)	0.0	0.00(0.02)	0.0	0.00(-0.01)
62.36024	0.00(.02)	62.35996	0.00(.01)	62.36033	0.01(.00)
0.0	0.00(0.01)	0.0	0.00(0.00)	0.0	0.00(-0.01)
62.49975	0.01(.00)	62.50064	0.01(.00)	62.50033	0.10(.00)
0.0	0.00(-0.01)	0.0	0.00(-0.01)	0.0	0.00(-0.10)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$	f_x [GHz]	$\alpha_x(\delta\alpha)$
P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$	P [torr]	$\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
62.59558	0.03(.00)	62.59730	0.01(.01)	62.59697	0.01(.01)
0.0	0.00(-0.03)	0.0	0.00(-0.01)	0.0	0.00(-0.01)
62.70946	0.00(.00)	62.70932	0.00(.00)	62.70922	0.01(.01)
0.0	0.00(0.00)	0.0	0.00(0.00)	0.0	0.00(-0.01)
62.79874	0.00(.04)	62.79930	0.00(.01)	62.79924	0.04(.01)
0.0	0.00(0.03)	0.0	0.00(0.01)	0.0	0.00(-0.04)
62.89892	0.01(.00)	62.89926	0.00(.02)	62.89907	0.03(.01)
0.0	0.00(-0.01)	0.0	0.00(0.01)	0.0	0.00(-0.03)
62.99865	0.00(.01)	62.99869	0.01(.00)	62.99879	0.01(.01)
0.0	0.03(0.03)	0.0	0.01(0.00)	0.0	0.00(-0.01)
63.10043	0.00(.00)	63.10014	0.00(.01)	63.10051	0.00(.02)
0.0	0.00(0.00)	0.0	0.00(0.01)	0.0	0.00(0.01)
63.23287	0.00(.01)	63.23378	0.00(.00)	63.23345	0.06(.01)
0.0	0.00(0.01)	0.0	0.00(0.00)	0.0	0.00(-0.06)
63.32983	0.00(.02)	63.33156	0.00(.03)	63.33123	0.00(.02)
0.0	0.00(0.01)	0.0	0.00(0.02)	0.0	0.00(0.01)
63.44505	0.00(.01)	63.44490	0.01(.01)	63.44481	0.01(.00)
0.0	0.00(0.01)	0.0	0.00(-0.01)	0.0	0.00(-0.01)
63.53538	0.00(.04)	63.53594	0.00(.01)	63.53588	0.01(.01)
0.0	0.00(0.03)	0.0	0.00(0.01)	0.0	0.00(-0.01)
63.63673	0.00(.02)	63.63708	0.00(.01)	63.63688	0.01(.01)
0.0	0.00(0.01)	0.0	0.00(0.00)	0.0	0.00(-0.01)
63.73769	0.00(.03)	63.73767	0.01(.00)	63.73777	0.00(.03)
0.0	0.00(0.00)	0.0	0.00(-0.01)	0.0	0.00(0.02)
63.84061	0.00(.01)	63.84031	0.00(.01)	63.84069	0.01(.01)
0.0	0.00(0.01)	0.0	0.00(0.01)	0.0	0.00(-0.01)
63.96599	0.00(.02)	63.96691	0.00(.03)	63.96658	0.00(.05)
0.0	0.00(0.01)	0.0	0.00(0.02)	0.0	0.00(0.04)
64.06408	0.03(.01)	64.06583	0.00(.04)	64.06549	0.00(.02)
0.0	0.00(-0.03)	0.0	0.00(0.03)	0.0	0.00(0.01)
64.18063	0.03(.01)	64.18049	0.00(.02)	64.18036	0.00(.04)
0.0	0.00(-0.03)	0.0	0.00(0.01)	0.0	0.00(0.03)
64.27202	0.00(.03)	64.27258	0.00(.02)	64.27252	0.01(.01)
0.0	0.00(0.02)	0.0	0.00(0.01)	0.0	0.00(-0.01)
64.37457	0.00(.02)	64.37491	0.00(.02)	64.37468	0.00(.02)
0.0	0.00(0.01)	0.0	0.00(0.01)	0.0	0.00(0.01)
64.47659	0.01(.01)	64.47666	0.01(.01)	64.47678	0.01(.01)
0.0	0.00(-0.01)	0.0	0.00(-0.01)	0.0	0.00(-0.01)

P = 0 torr

6.7°C		29.7°C		52.4°C	
f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$	f_x [GHz] P [torr]	$\alpha_x(\delta\alpha)$ $\alpha_M(\pm\Delta\alpha)$
	dB/km		dB/km		dB/km
64.58079 0.0	0.00(.01) 0.00(0.00)	64.58050 0.0	0.00(.02) 0.00(0.01)	64.58087 0.0	0.00(.05) 0.00(0.04)
64.69948 0.0	0.00(.02) 0.00(0.01)	64.70005 0.0	0.01(.01) 0.00(-0.01)	64.69973 0.0	0.06(.01) 0.00(-0.06)
64.79829 0.0	0.00(.02) 0.00(0.01)	64.80009 0.0	0.01(.01) 0.00(-0.01)	64.79974 0.0	0.00(.05) 0.00(0.04)
64.91622 0.0	0.02(.01) 0.00(-0.02)	64.91607 0.0	0.00(.01) 0.00(0.01)	64.91592 0.0	0.00(.04) 0.00(0.03)
65.00866 0.0	0.00(.06) 0.00(0.05)	65.00922 0.0	0.01(.01) 0.00(-0.01)	65.00915 0.0	0.00(.05) 0.00(0.04)
65.11238 0.0	0.00(.02) 0.00(0.02)	65.11272 0.0	0.00(.01) 0.00(0.01)	65.11248 0.0	0.00(.01) 0.00(0.01)
65.21557 0.0	0.01(.01) 0.00(-0.01)	65.21564 0.0	0.00(.00) 0.00(0.00)	65.21574 0.0	0.01(.01) 0.00(-0.01)
65.32097 0.0	0.00(.01) 0.00(0.00)	65.32066 0.0	0.00(.02) 0.00(0.01)	65.32104 0.0	0.00(.02) 0.00(0.01)
65.43260 0.0	0.01(.01) 0.00(-0.01)	65.43317 0.0	0.01(.01) 0.00(-0.01)	65.43285 0.0	0.06(.01) 0.00(-0.06)
65.53253 0.0	0.01(.01) 0.00(-0.01)	65.53436 0.0	0.00(.02) 0.00(0.01)	65.53400 0.0	0.00(.07) 0.00(0.06)
65.65181 0.0	0.01(.01) 0.00(-0.01)	65.65166 0.0	0.04(.01) 0.00(-0.04)	65.65150 0.0	0.02(.01) 0.00(-0.02)
65.74529 0.0	0.00(.00) 0.00(0.00)	65.74586 0.0	0.00(.01) 0.00(0.00)	65.74579 0.0	0.02(.01) 0.00(-0.02)
65.85020 0.0	0.00(.05) 0.00(0.04)	65.85054 0.0	0.00(.03) 0.00(0.02)	65.85030 0.0	0.01(.01) 0.00(-0.01)
65.95456 0.0	0.01(.00) 0.00(-0.01)	65.95463 0.0	0.00(.02) 0.00(0.01)	65.95473 0.0	0.00(.04) 0.00(0.03)
66.06116 0.0	0.00(.02) 0.00(0.01)	66.06084 0.0	0.01(.01) 0.00(-0.01)	66.06122 0.0	0.03(.01) 0.00(-0.03)
66.16573 0.0	0.00(.02) 0.00(0.01)	66.16631 0.0	0.01(.01) 0.00(-0.01)	66.16597 0.0	0.00(.02) 0.00(0.01)
66.26678 0.0	0.01(.01) 0.00(-0.01)	66.26862 0.0	0.00(.02) 0.00(0.01)	66.26826 0.0	0.04(.01) 0.00(-0.04)

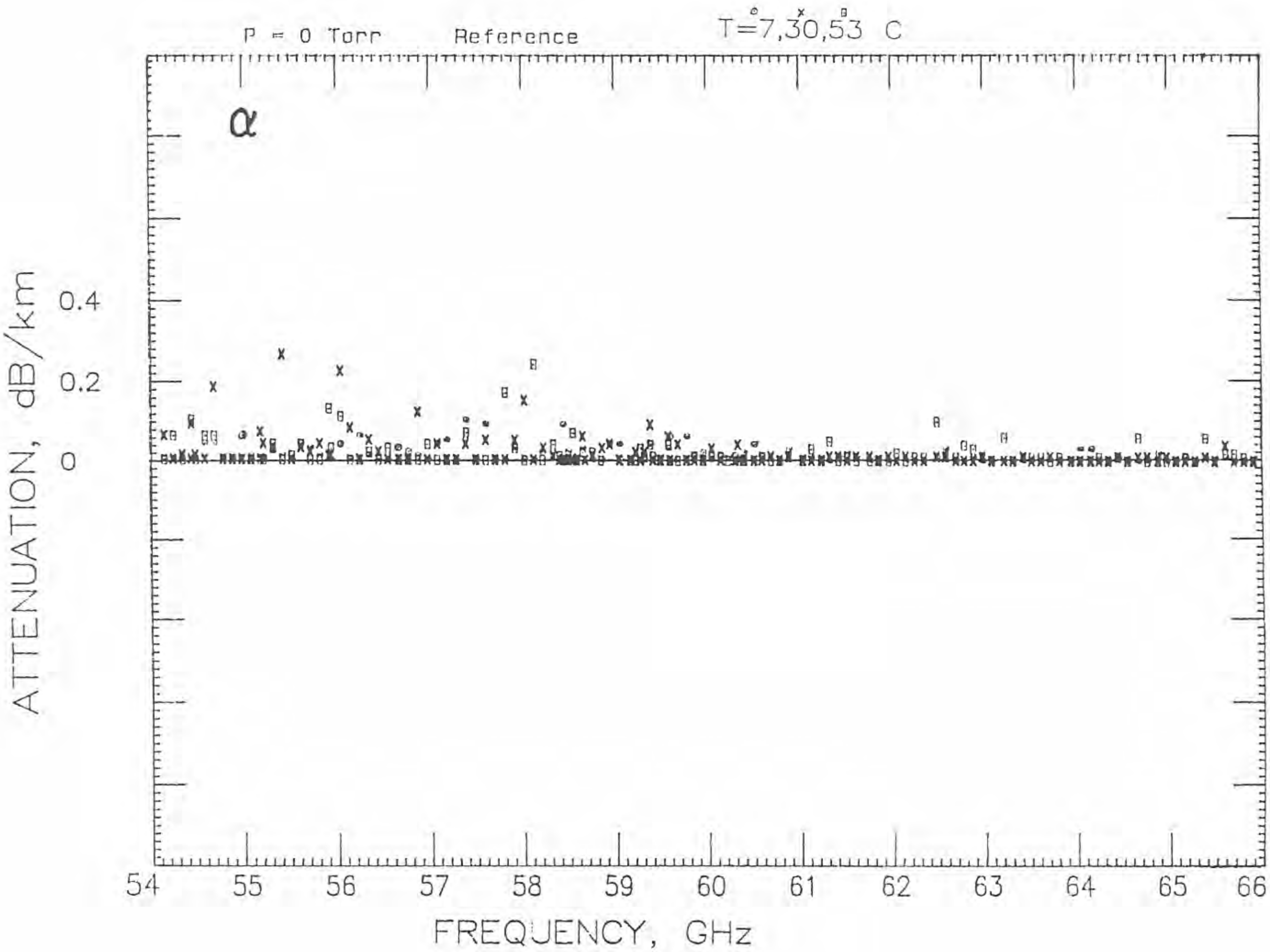

Figure A-12a. Predicted and measured attenuation rates of dry air, α_M and α_x, at P = 0 kPa (see RE) for frequencies between 54 and 66 GHz.

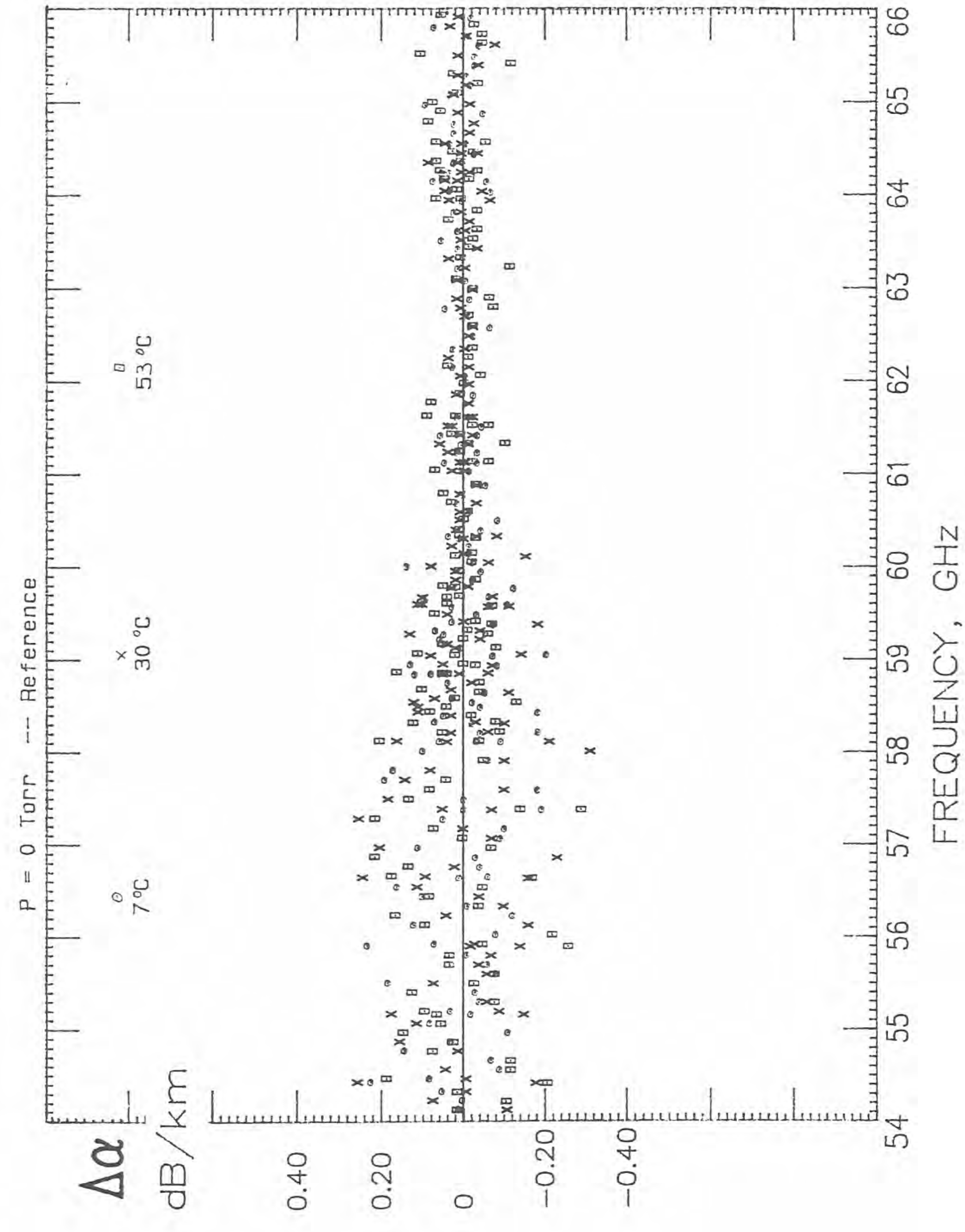

Figure A-12b. Differences $\Delta\alpha = \alpha_M - \alpha_x$ between predicted and measured attenuation for the results listed under **RE**.

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15. ABSTRACT *(A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature*

Molecular oxygen dominates the attenuation and delay rates of dry air throughout the V-band (50-75 GHz). Both rates display as a function of altitude an intricate pattern which, for the most part, has never been confirmed by experiment. The collective spectral behavior of 38 pressure-broadened O_2 lines is described by a complex (230 coefficients) prediction model (MPM89). For atmospheric conditions of pressure equivalent to altitudes between sea level and 30 km (100 to 1 kPa), this behavior was studied under controlled laboratory conditions. The spectrometer consisted of a one-port Fabry-Pérot resonator, which was excited by an automatic network analyzer. All operations were controlled by a microcomputer, including reference level calibrations at multiple (up to 15, separated by 0.73 GHz) resonances and control of the pressure steps. Introducing gas into the spectrometer cell changed the detected resonance response, from which was deduced a complex refractivity by means of a twin, nonlinear least squares method. The analysis of dry air measurements concentrated on the loss part, expressed as attenuation rate α in dB/km. The detection sensitivity was $\pm$ 0.01 dB/km for an effective path length of 0.24 km and a 5 percent coupling ratio of a resonance response. Coupling to a particular resonance and the duration (1-5 hrs) of a measurement sequence influenced the spectrometer performance. Over 4,300 attenuation values are reported. The results were measured between 53.9 and 66.3 GHz in 0.1 GHz frequency increments at eleven pressure steps (1-100 kPa) for three temperatures (7,30,52°C). The measure- ment uncertainties were estimated to be typically $\pm$ 0.05 below 3 dB/km and $\pm$ 2 percent for higher values ($\leq$ 18 dB/km). A first comparison of experimental results with MPM89 predictions revealed, in addition to random data scatter, systematic differences that correlate with line broadening and overlap parameters.

16. Key Words

atmospheric oxygen spectrum; dry air; frequency range; 54 to 66 GHz; frequency, pressure and temperature parameters; laboratory attenuation measurements; parametric studies

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