PL-TR-92-2059
SPECIAL REPORTS, NO. 267

PROCEEDINGS OF THE 14TH ANNUAL REVIEW CONFERENCE ON ATMOSPHERIC TRANSMISSION MODELS, 11-12 JUNE 1991

EDITORS:
L. W. ABREU
F. X. KNEIZYS

26 FEBRUARY 1992

PHILLIPS LABORATORY
AIR FORCE SYSTEMS COMMAND
HANSCOM AIR FORCE BASE, MASSACHUSETTS 01731-5000

LABORATORY MEASUREMENTS OF THE 60-GHz O_2 SPECTRUM IN AIR

H.J. Liebe
Institute for Telecommunication Sciences, National Telecommunications and Information Administration, U.S. Department of Commerce, NTIA/ITS.S1, 325 Broadway, Boulder, CO 80303

The O_2-spectrum of dry air was studied with a resonance spectrometer under controlled laboratory conditions. Key parts of the instrumentation were an automatic network analyzer and a one-port Fabry-Pérot resonator affording an effective path length of 240 m. Measurements were made at frequencies between 49.3 and 67.2 GHz in 0.1 GHz increments for eleven pressure steps (1-100 kPa) and three different temperatures (7-30-53°C). More than $5X10^6$ data points (S_{11} parameters) have been recorded and reduced to about 5,000 absorption values α (dB/km). Measurement uncertainties were estimated to be typically the worse of ±0.05 dB/km or 2 percent. The collective spectral behavior of 38 pressure-broadened O_2 lines is described by the model MPM (NTIA Report 91-**272**, March 1991). A comparison of the absorption results with MPM predictions reveals systematic differences which correlate with O_2 line width and overlap parameters. An interpretation of the extensive data set with *Rosenkranz*'s overlap theory [JQSRT **39**(4), 287-297, 1988] is underway.

14th Annual Review Conf. on *Atmospheric Transmission Models*

AFSC, Hanscom AFB, MA 01731 11-12 June 1991

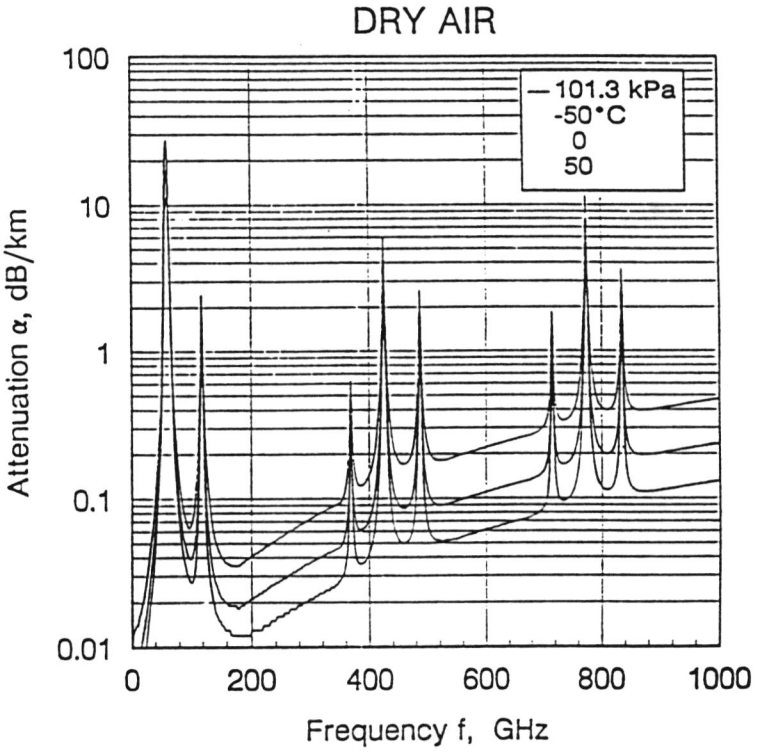
LABORATORY MEASUREMENTS OF THE 60-GHz O_2 SPECTRUM IN AIR

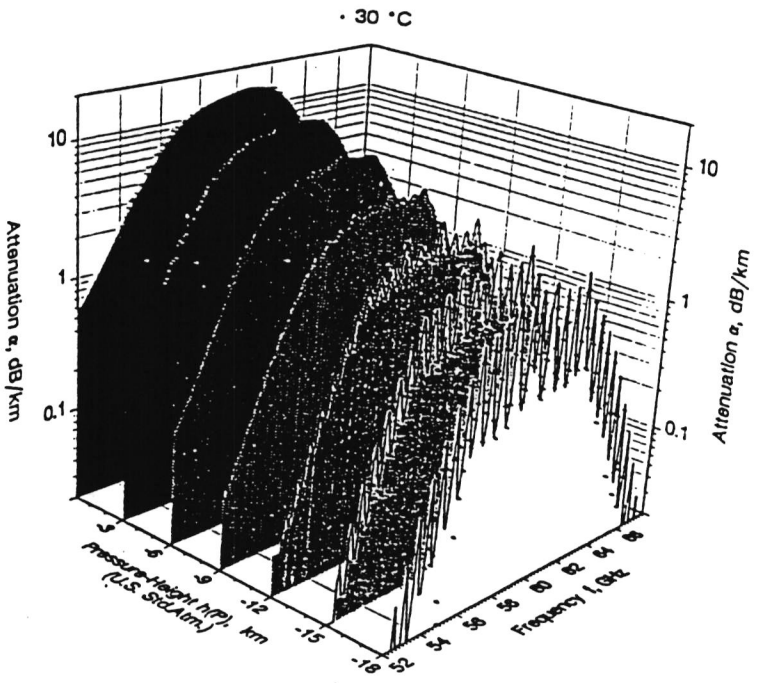
Hans J. Liebe

Institute for Telecommunication Sciences

National Telecommunications and Information Administration
U.S. Department of Commerce

NTIA/ITS.S1, 325 Broadway, Boulder, CO 80303, USA





Microwave Line Spectrum of Dry Air

Line-by-line summation of 40 O_2 transitions (K^2 = 1 to 39) to yield the complex refractivity (6 × 40 = "240-parameter" problem),

$$N_i = \sum_k S_k F_k \qquad \text{ppm}$$

where the line strength is

$$S_k = a_1 P \theta^3 \exp[a_2(1-\theta)] \qquad \text{kHz}$$

and F_k is a complex shape function in GHz^{-1}. The Van Vleck-Weisskopf shape function of a pressure-broadened line was modified by Rosenkranz (1988) to account for overlap interferences,

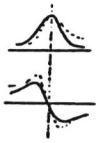
$$F(f) = \frac{f}{\nu_k}\left[\frac{1+jY_k}{\nu_k - f + j\gamma_k} - \frac{1-jY_k}{\nu_k + f - j\gamma_k}\right]$$

which rationalizes to absorption (F'') and dispersion (F') profiles

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

and

$$F'(f) = (1-B)X - (1+B)Y + Y_k A(X-Y),$$



with the abbreviations

$A = \gamma_k/\nu_k$, $\qquad B = f/\nu_k$,

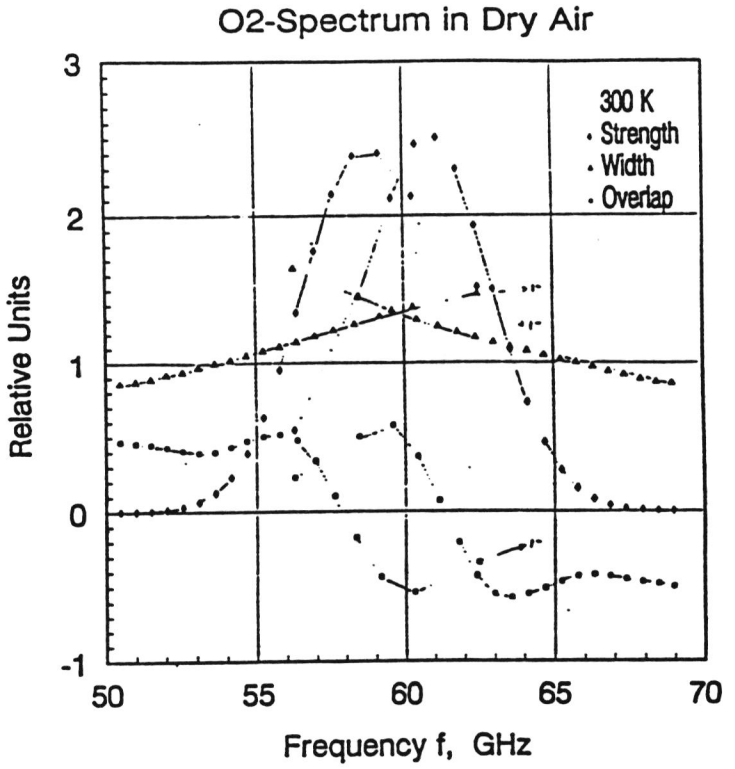
$X = f/[(\nu_k - f)^2 + \gamma_k^2]$, $\qquad Y = f/[(\nu_k + f)^2 + \gamma_k^2]$.

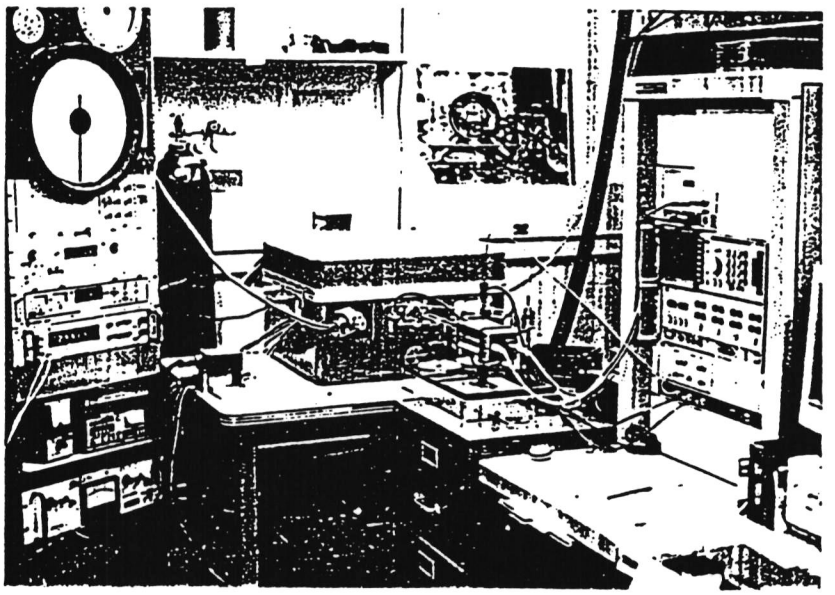
Width and interference parameters are for O_2 lines in air,

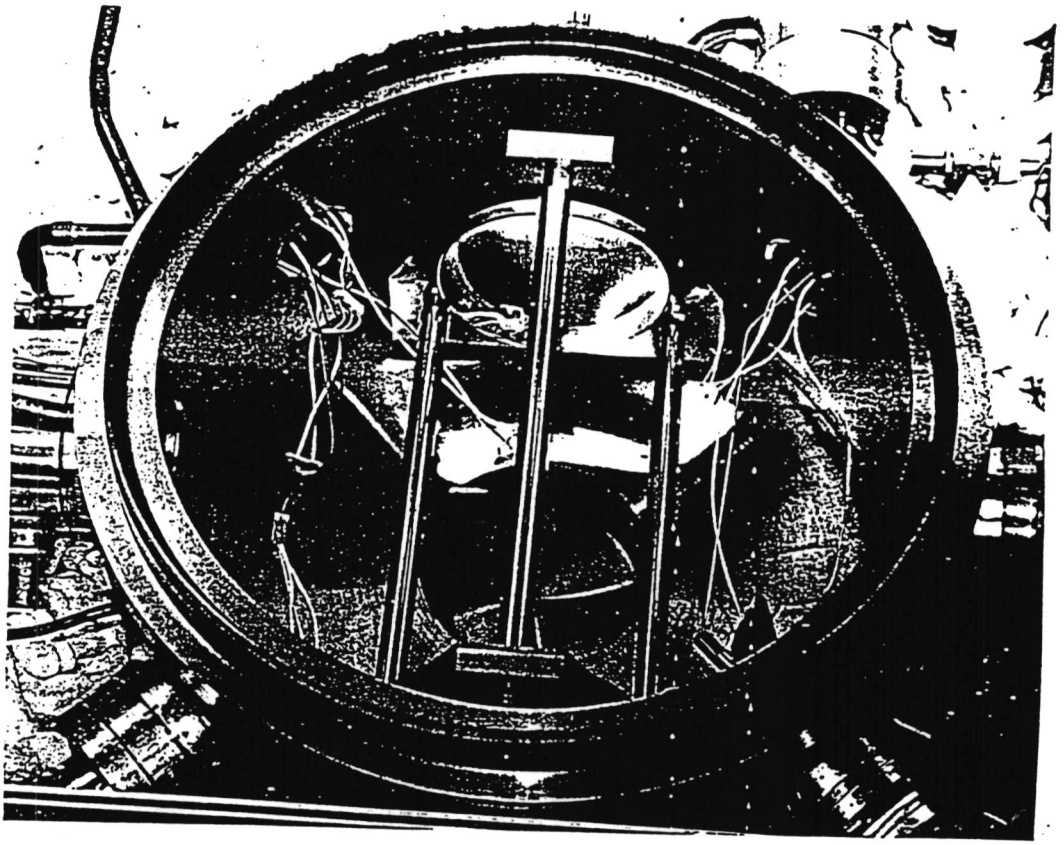
$$\gamma_k = a_3 P \theta^{(0.8 - \underline{a_4})} \quad \text{GHz} \qquad < 1.0 \text{ GHz}$$

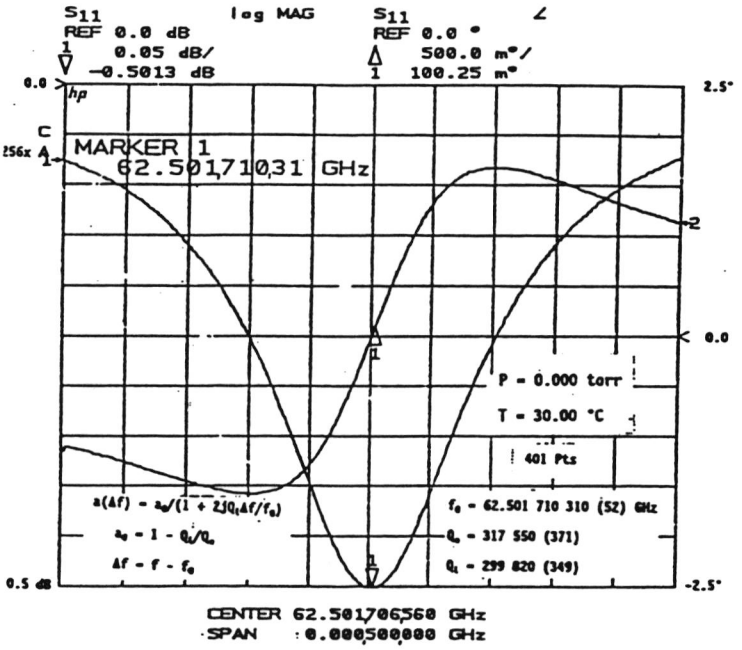
and

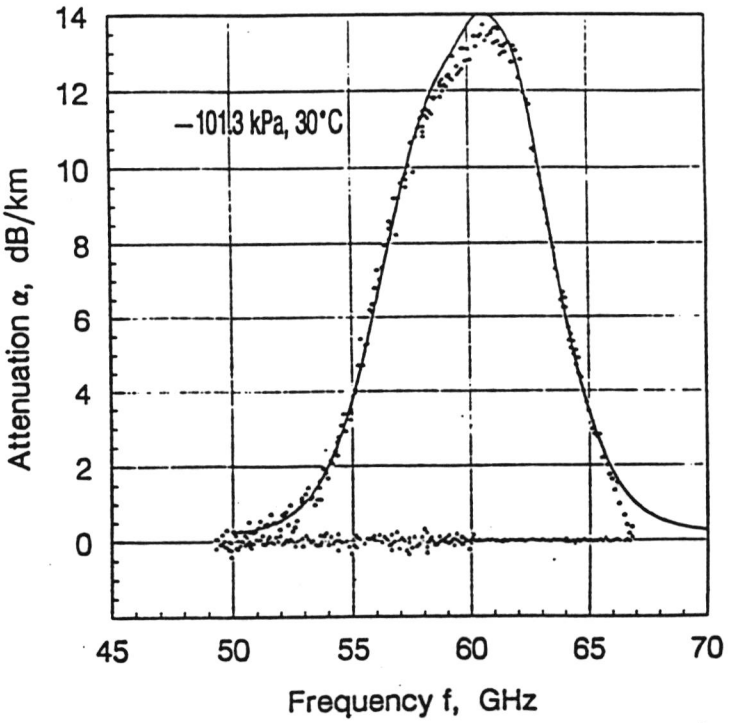
$$Y_k = (a_5 + a_6 \underline{\theta}) P \theta^{0.8} \qquad < 0.1$$

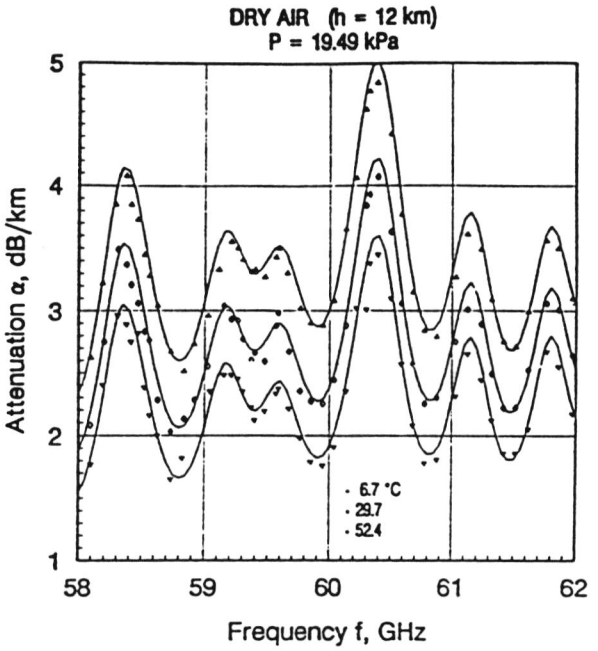

O2-Spectrum in Dry Air
300 K
Strength
Width
Overlap
Relative Units
3
2
1
0
-1
50
55
60
65
70
Frequency f, GHz

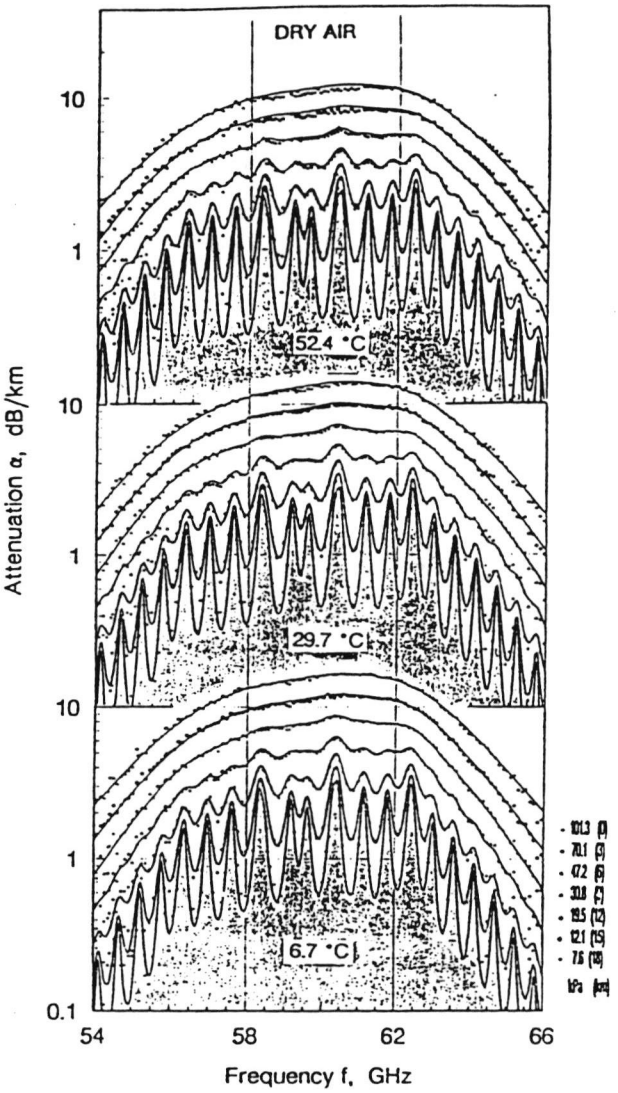


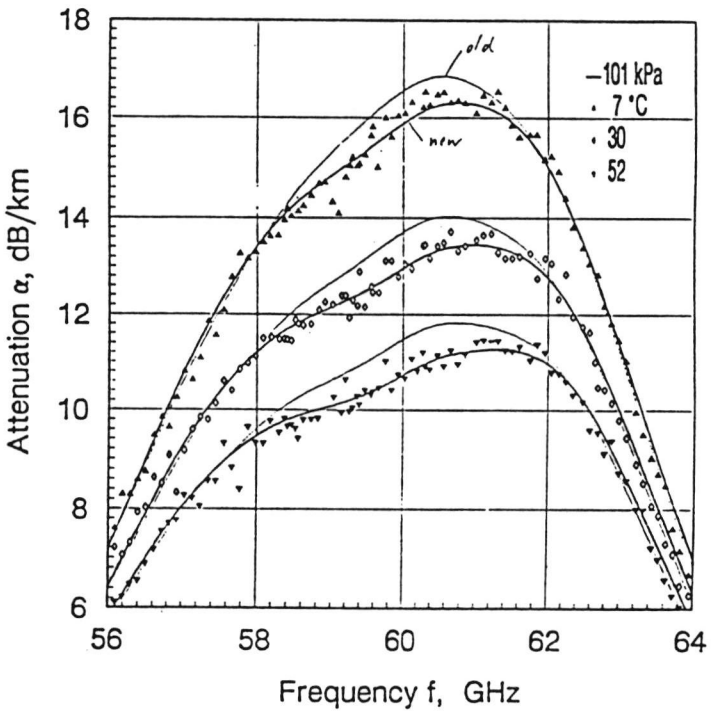


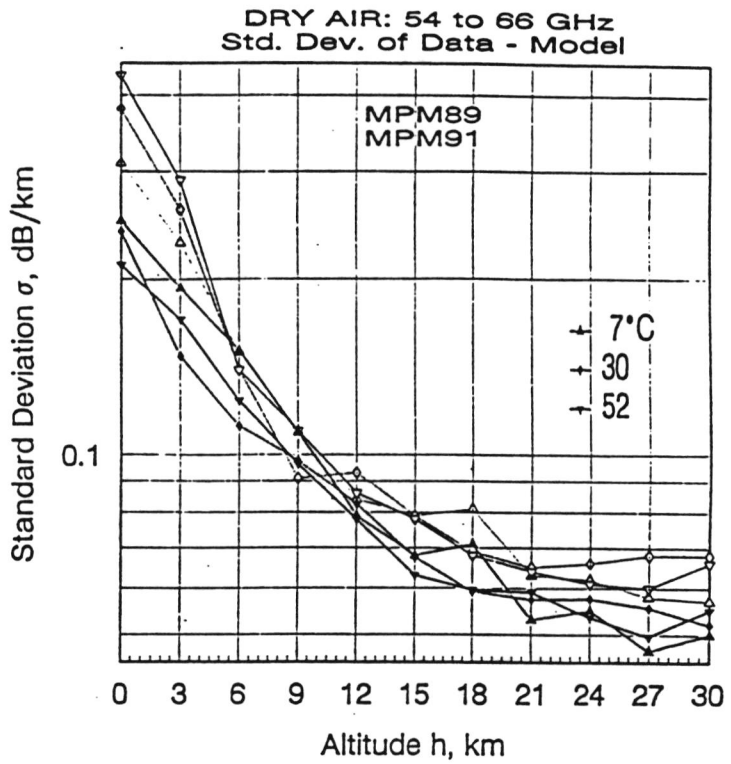

S11 log MAG
REF 0.0 dB
0.05 dB/
-0.5013 dB
S11 ∠
REF 0.0 °
500.0 m°/
100.25 m°
MARKER 1
62.501,710,31 GHz
P = 0.000 torr
T = 30.00 °C
401 Pts
a(Δf) = a0/(1 + 2jQLΔf/f0)
a0 = 1 - QL/Qe
Δf = f - f0
f0 = 62.501 710 310 (SZ) GHz
Qe = 317 550 (371)
QL = 299 820 (349)
CENTER 62.501706560 GHz
SPAN : 0.000500000 GHz

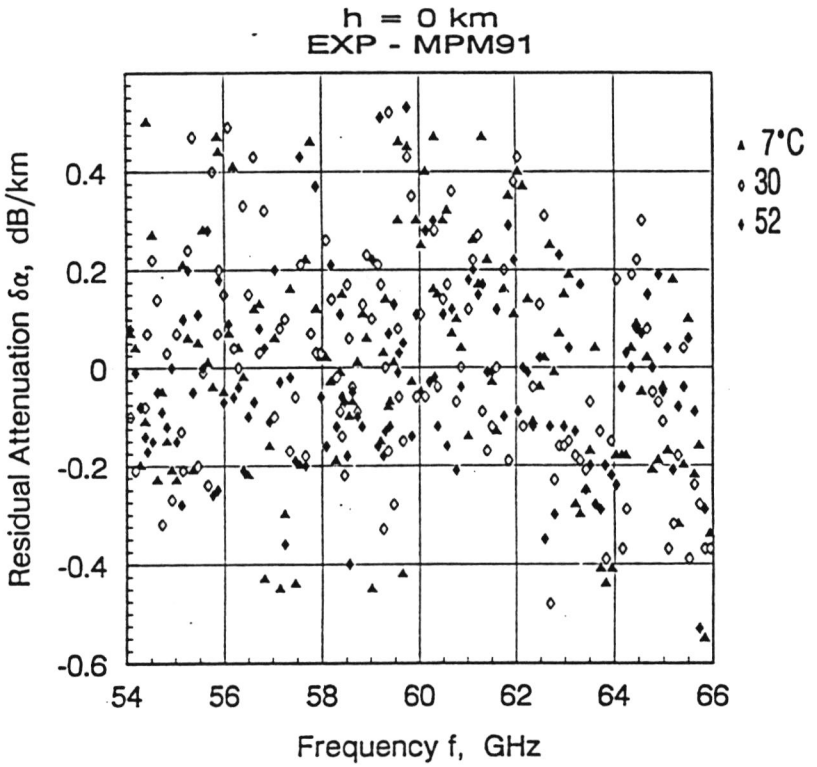

14
12
10
8
6
4
2
0
Attenuation α, dB/km
–101.3 kPa, 30°C
45
50
55
60
65
70
Frequency f, GHz

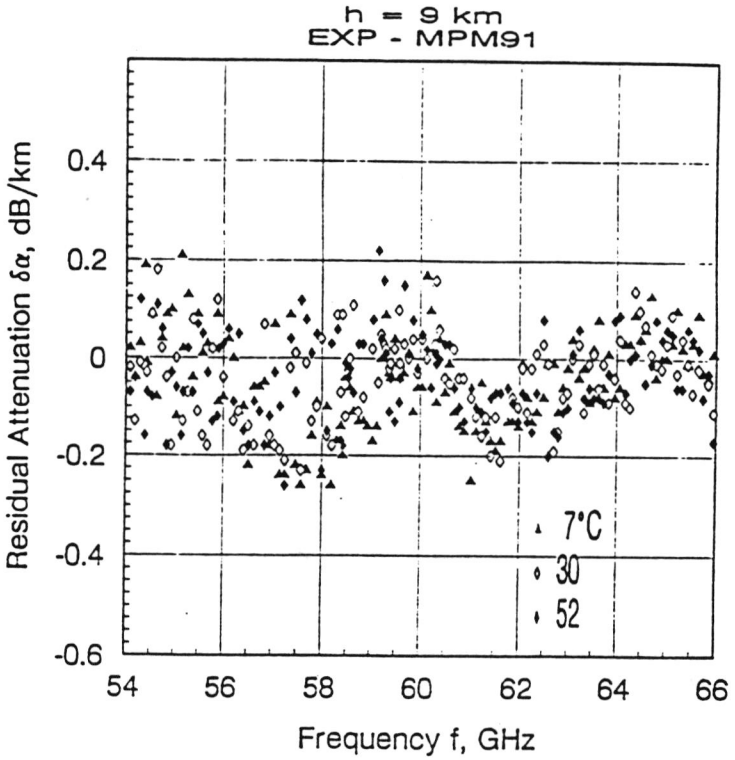

DRY AIR (h = 12 km)
P = 19.49 kPa
5
4
3
2
1
Attenuation α, dB/km
6.7 °C
29.7
52.4
58
59
60
61
62
Frequency f, GHz

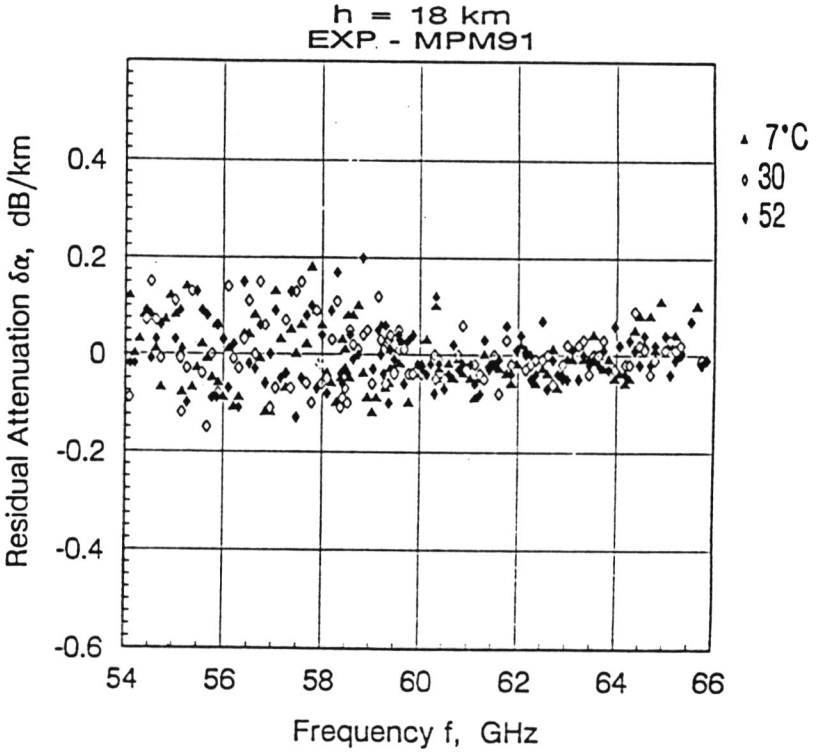

DRY AIR
10
1
52.4 °C
10
1
29.7 °C
10
1
6.7 °C
0.1
54
58
62
66
Attenuation α, dB/km
Frequency f, GHz

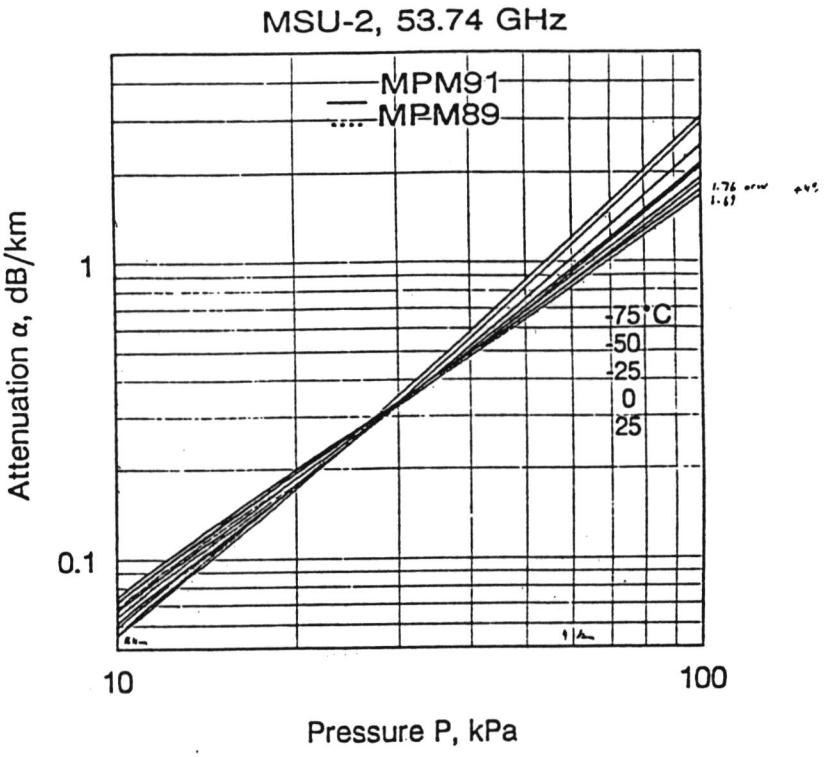

18
16
14
12
10
8
6
56
58
60
62
64
old
new
101 kPa
7 °C
30
52
Attenuation α, dB/km
Frequency f, GHz


DRY AIR: 54 to 66 GHz
Std. Dev. of Data - Model
MPM89
MPM91
7°C
30
52
Standard Deviation σ, dB/km
0.1
0 3 6 9 12 15 18 21 24 27 30
Altitude h, km


h = 0 km
EXP - MPM91
7°C
30
52
Residual Attenuation δα, dB/km
0.4
0.2
0
-0.2
-0.4
-0.6
54 56 58 60 62 64 66
Frequency f, GHz


h = 9 km
EXP - MPM91
Residual Attenuation δα, dB/km
0.4
0.2
0
-0.2
-0.4
-0.6
54
56
58
60
62
64
66
Frequency f, GHz
7°C
30
52


h = 18 km
EXP - MPM91
Residual Attenuation δα, dB/km
0.4
0.2
0
-0.2
-0.4
-0.6
54
56
58
60
62
64
66
Frequency f, GHz
7°C
30
52


MSU-2, 53.74 GHz
MPM91
MPM89
-75°C
-50
-25
0
25
Attenuation α, dB/km
1
0.1
10
100
Pressure P, kPa