Ka-Band Propagation Studies Using the ACTS Propagation Terminal and the CSU-CHILL Multiparameter Radar

Experimenters

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Investigators

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John Beaver, Research Associate

NASA Propagation Experimenters Meeting (NAPEX XXIII)

and

ACTS Propagation Studies Mini-Workshop

June 2-4, 1999

Falls Church, VA

Outline

- CSU-APT Status
  - Terminal status
  - Processing status

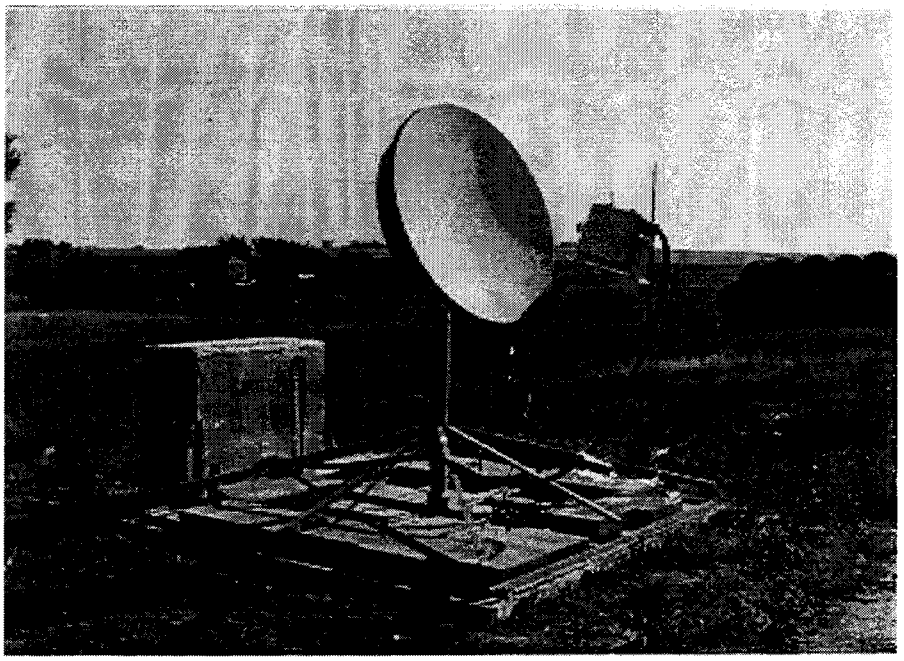
    (Data collection stopped end of Jan, start of Feb, lost lock on signal - never reacquired)

- CSU-APT Attenuation Data
  - 1998 Statistical analysis
  - Statistical analysis from Jan 1994 - Dec 1998

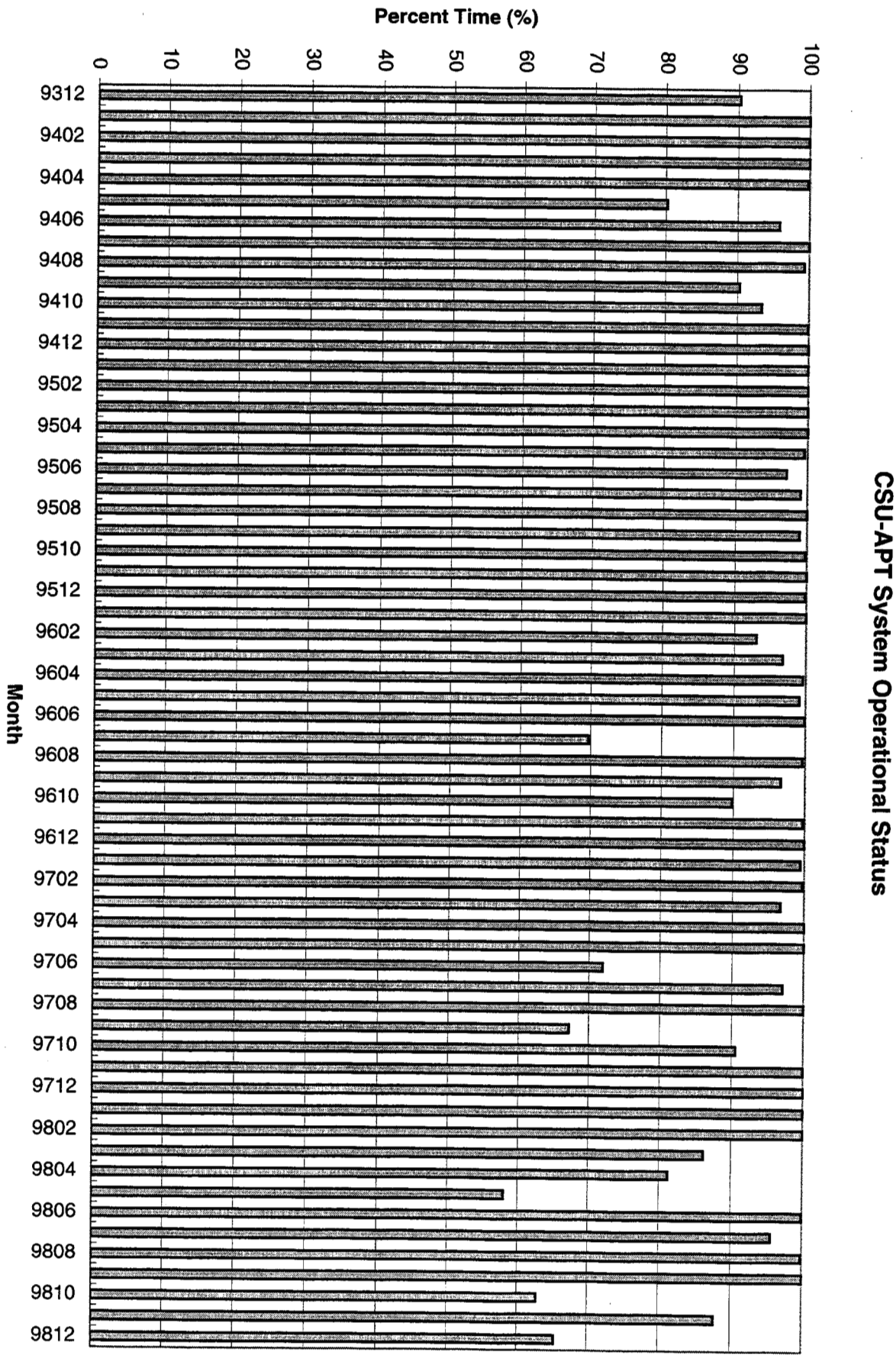
- CSU-CHILL Radar Data and Prediction Results
  - Attenuation curves for Ka-Band
  - Results from 5 case studies
  - Antenna wetting problem

- Future Research
  - Extend prediction model to V-Band
  - Variations in 0°-isotherm levels

CSU-APT Site Location



- CSU-APT is located about 30 km southeast of Fort Collins near LaSalle, Colorado (approx. 13 km south of the CSU-CHILL radar)
- APT elevation angle - 43 deg
- APT azimuth angle - 173 deg
- Altitude 1.52 km
- Latitude - 40.3 N, Longitude - 104.6 W


CSU-APT System Operational Status
Percent Time (%)
0
10
20
30
40
50
60
70
80
90
100
Month
9312
9402
9404
9406
9408
9410
9412
9502
9504
9506
9508
9510
9512
9602
9604
9606
9608
9610
9612
9702
9704
9706
9708
9710
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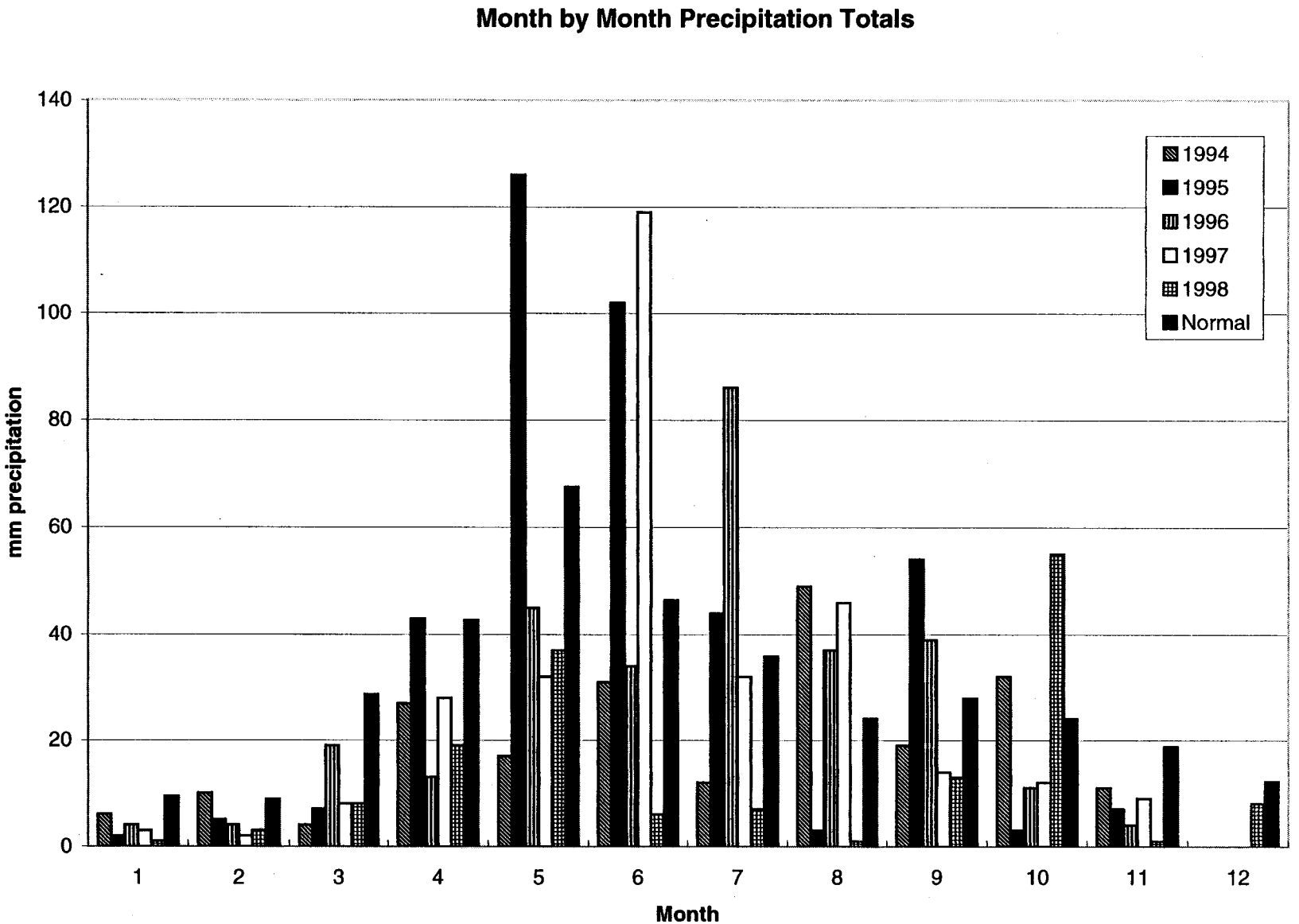
9802
9804
9806
9808
9810
9812


Month by Month Precipitation Totals
140
120
100
80
60
40
20
0
mm precipitation
1
2
3
4
5
6
7
8
9
10
11
12
Month
1994
1995
1996
1997
1998
Normal

Statistics

- Cumulative Distribution Function (CDF)
  - For ACA data at 20 and 27 GHz
  - No average applied to the data
  - Data is binned from -3.0 to 30.0 dB in 0.1 dB steps

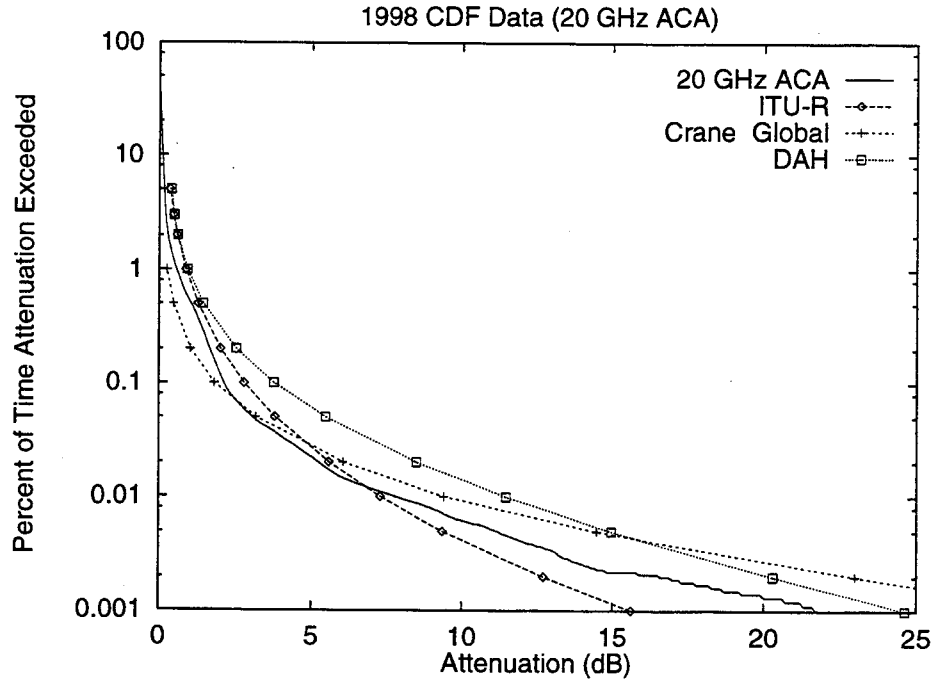
- Attenuation Ratio (RA)
  - 30 second moving average is applied to the data
  - Divide the 27 GHz ACA by the 20 GHz ACA
  - RA values binned from 0 to 10 in 0.05 steps for base attenuation levels greater than 1 dB
  - RA values are also binned from different base attenuation levels ranging from 1 to 15 dB in 1 dB steps

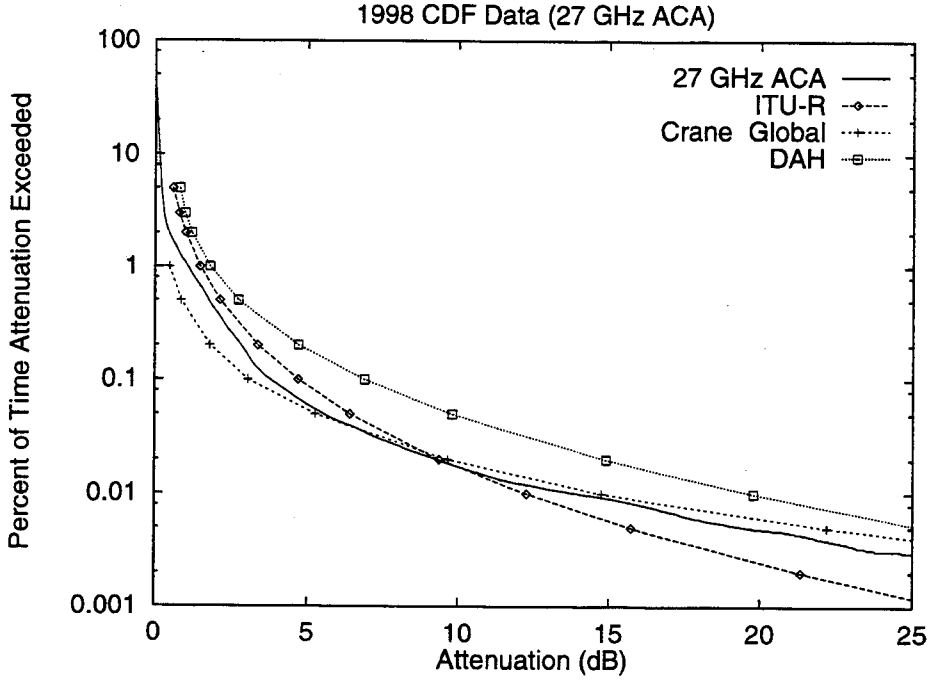
Statistics

- Fade Duration (FD) and Inter-Fade Duration (IF)
  - 30 second moving average is applied to the AFS data
  - threshold levels range from 0 to 30 dB in 1 dB steps
  - fade duration (nonfade duration) bins include 0-1, 1-2, 2-3, 3-5, 5-6, 6-10, 10-15, 15-18, 18-20, 20-30, 30-60, 60-120, 120-180, 180-300, 300-600, 600-1200, 1200-1800, and 1800-3600 seconds

- Fade Slope (FS)
  - 10 second moving average applied to AFS data
  - defined only if attenuation level crosses a threshold for more than 10 seconds (above or below)
  - threshold values range from 0 to 30 dB in 1 dB steps
  - FS data are binned from -1.25 to 1.25 dB/sec in 0.05 dB/sec steps

$$FS_i = (AFS_{i+5} - AFS_{i-5}) / 10.0$$


1998 CDF Data (20 GHz ACA)
Percent of Time Attenuation Exceeded
Attenuation (dB)
20 GHz ACA
ITU-R
Crane Global
DAH
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25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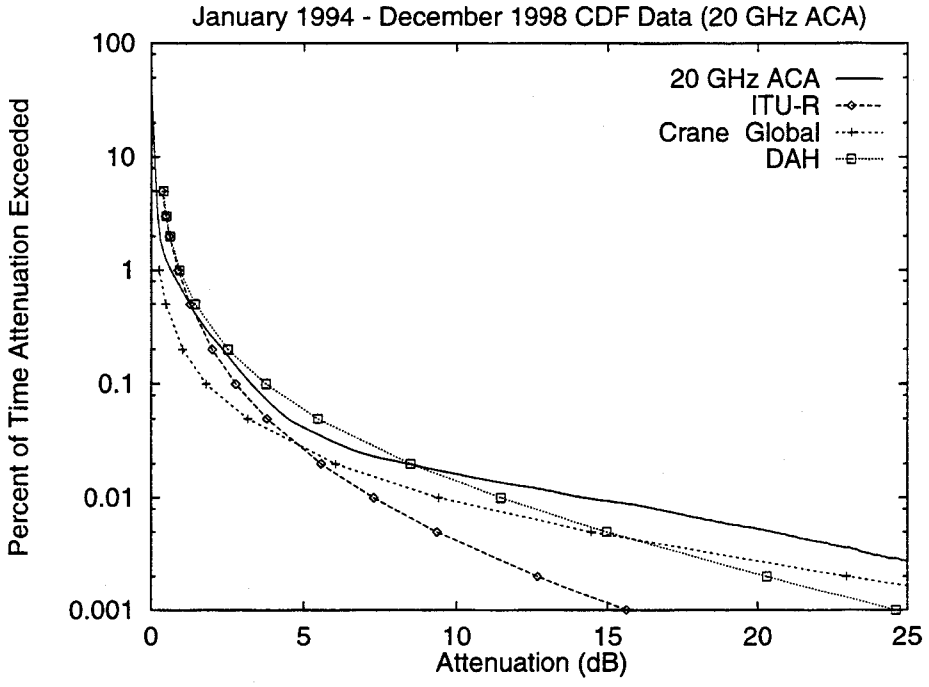
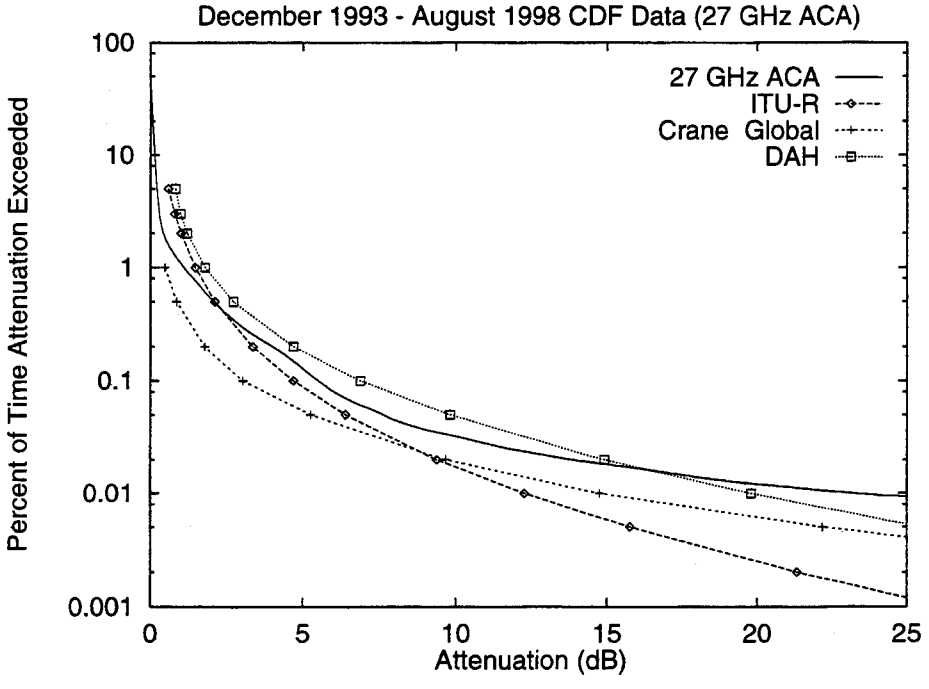
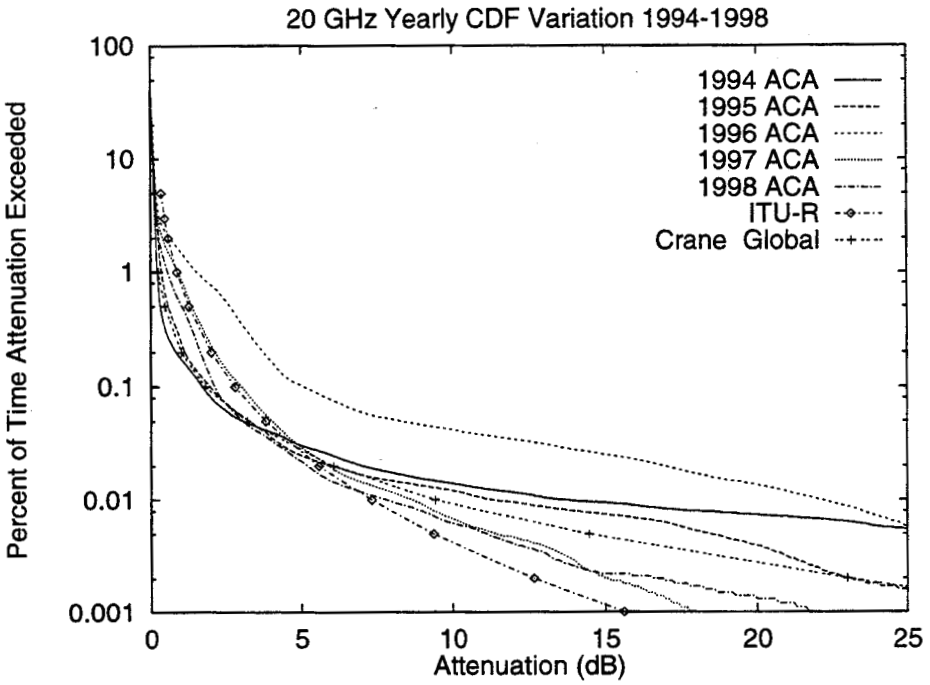
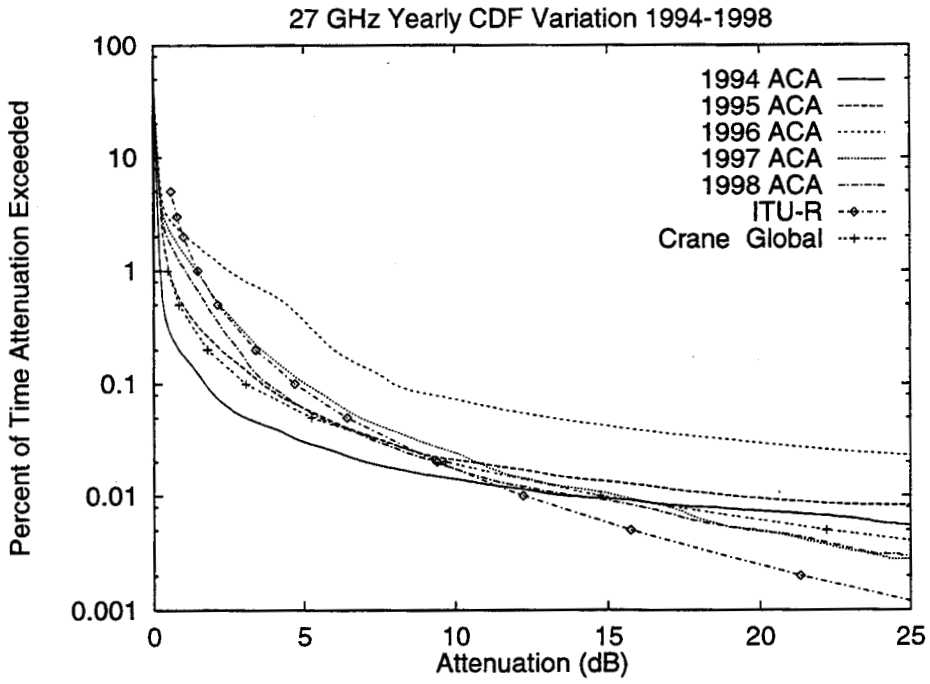
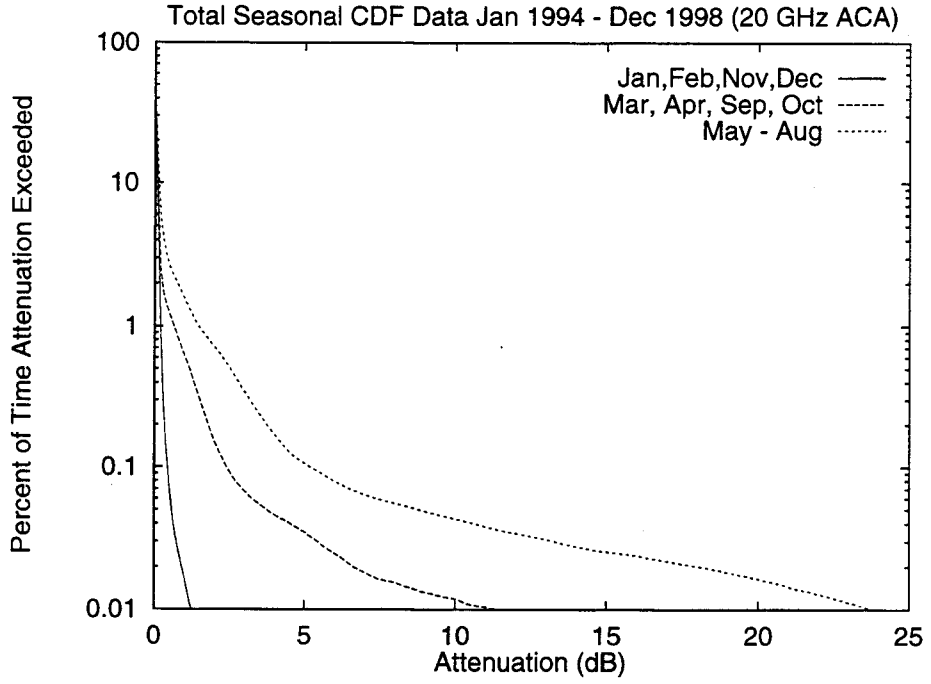
Percent of Time Attenuation Exceeded
Attenuation (dB)
27 GHz ACA
ITU-R
Crane Global
DAH
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25

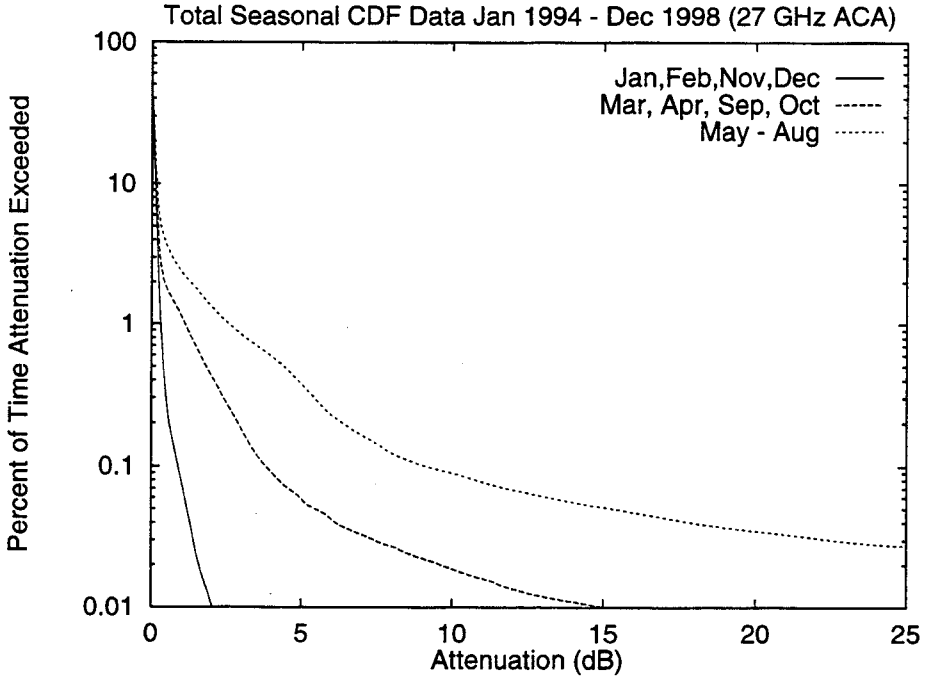

January 1994 - December 1998 CDF Data (20 GHz ACA)
Percent of Time Attenuation Exceeded
Attenuation (dB)
20 GHz ACA
ITU-R
Crane Global
DAH
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25


December 1993 - August 1998 CDF Data (27 GHz ACA)
Percent of Time Attenuation Exceeded
Attenuation (dB)
27 GHz ACA
ITU-R
Crane Global
DAH
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25


20 GHz Yearly CDF Variation 1994-1998
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
1994 ACA
1995 ACA
1996 ACA
1997 ACA
1998 ACA
ITU-R
Crane Global


27 GHz Yearly CDF Variation 1994-1998
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0.001
0
5
10
15
20
25
Attenuation (dB)
1994 ACA
1995 ACA
1996 ACA
1997 ACA
1998 ACA
ITU-R
Crane Global


Total Seasonal CDF Data Jan 1994 - Dec 1998 (20 GHz ACA)
Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0
5
10
15
20
25
Attenuation (dB)
Jan,Feb,Nov,Dec
Mar, Apr, Sep, Oct
May - Aug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Percent of Time Attenuation Exceeded
100
10
1
0.1
0.01
0
5
10
15
20
25
Attenuation (dB)
Jan,Feb,Nov,Dec
Mar, Apr, Sep, Oct
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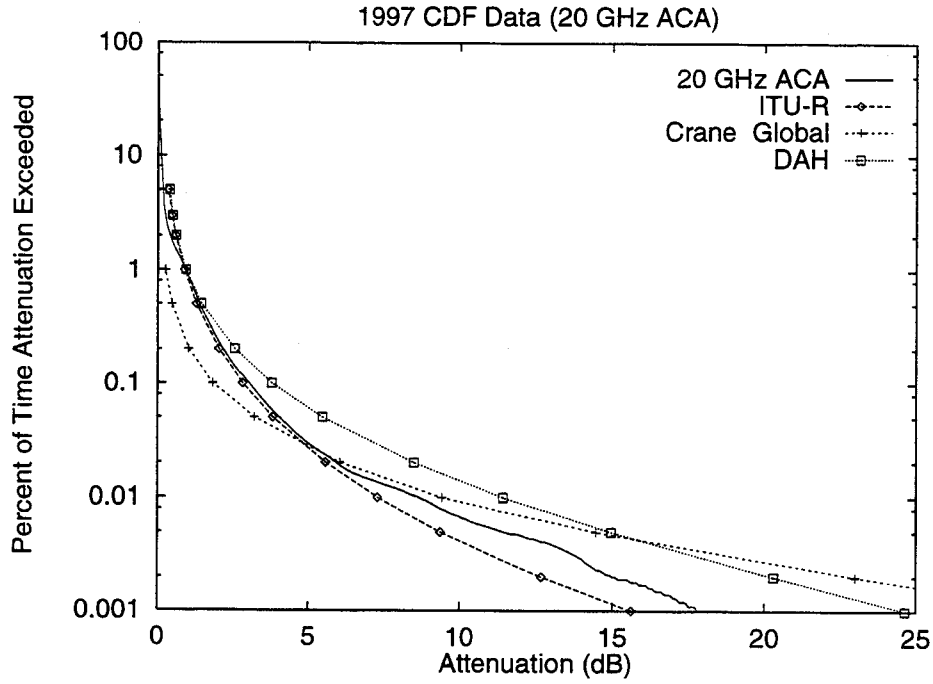
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Attenuation (dB)
20 GHz ACA
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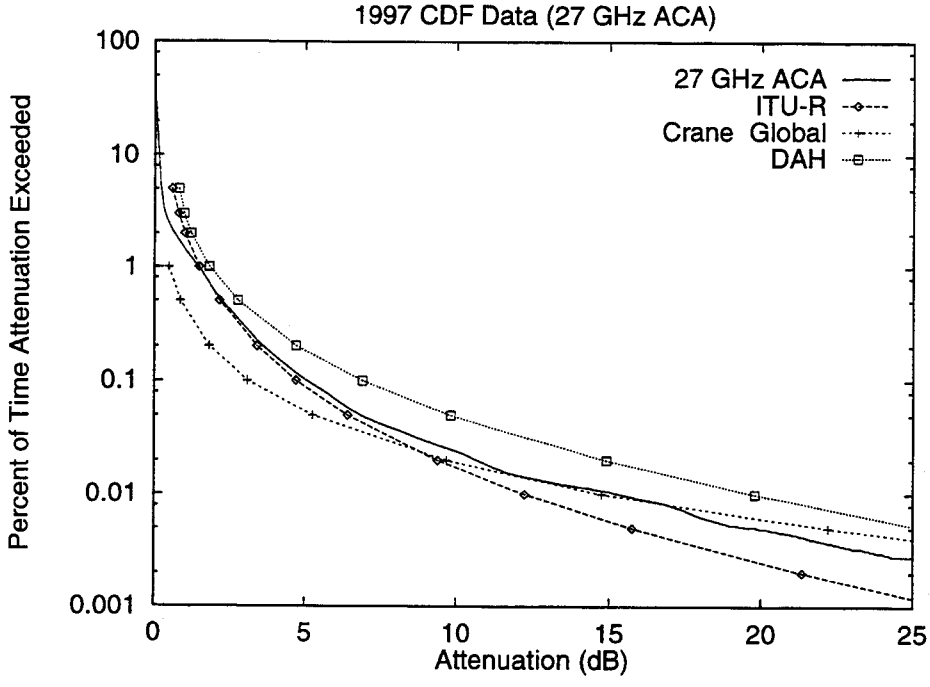
20
25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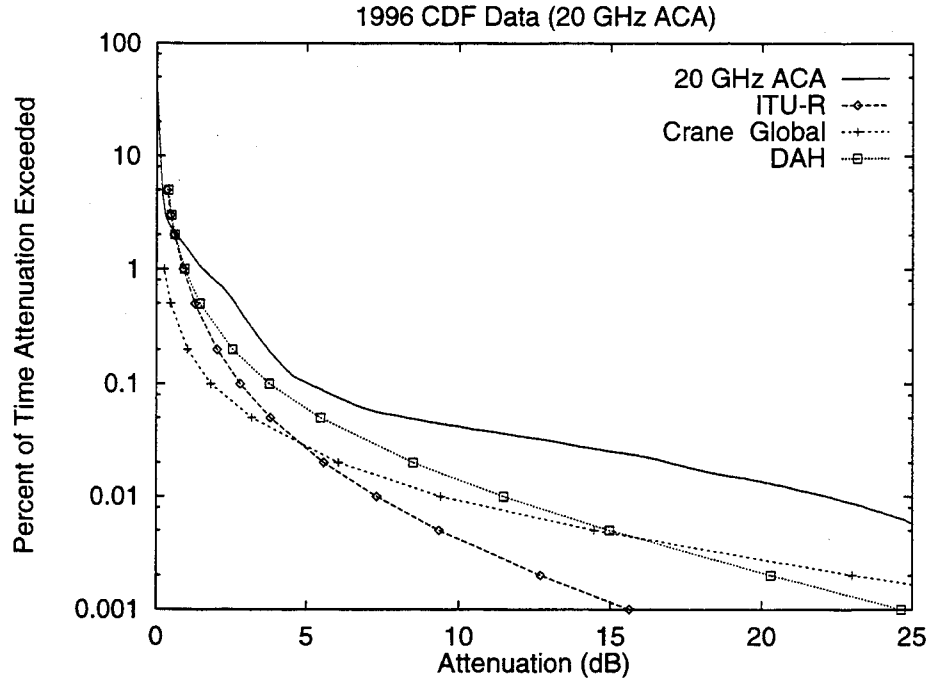
25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Attenuation (dB)
20 GHz ACA
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Crane Global
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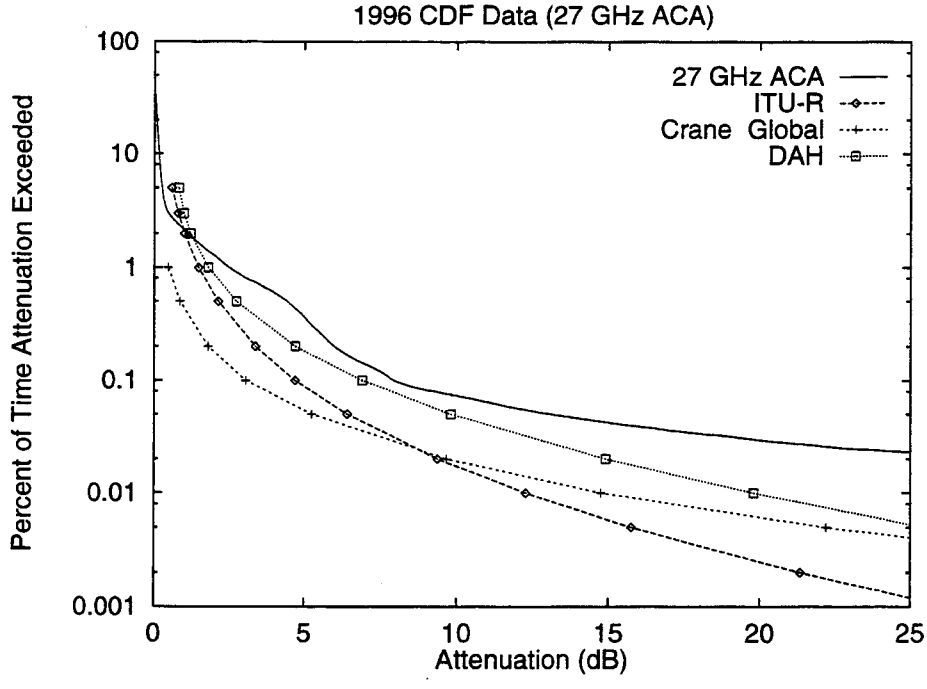
0
5
10
15
20
25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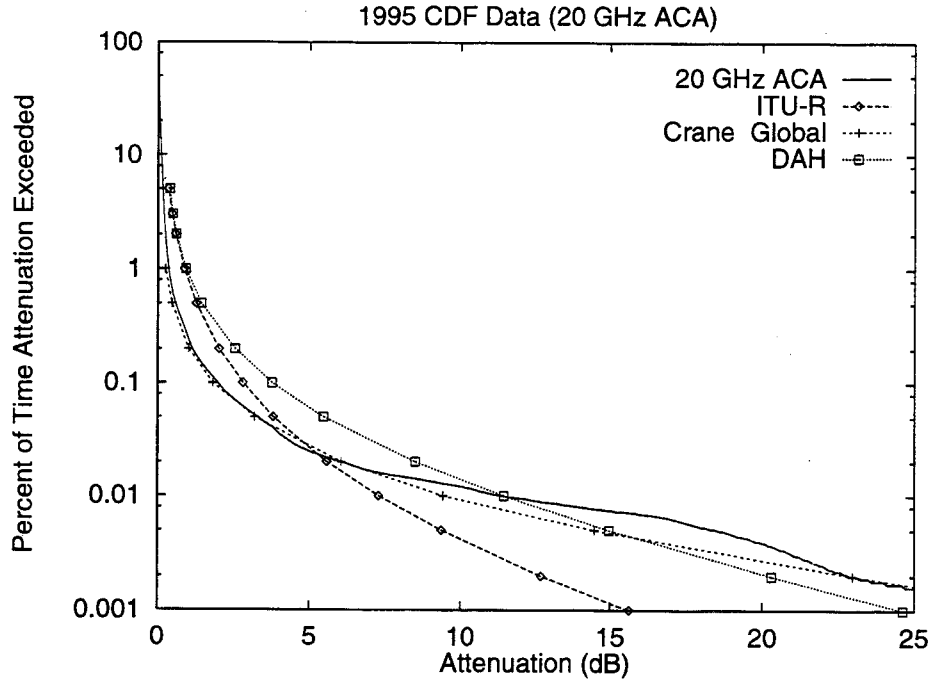
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Attenuation (dB)
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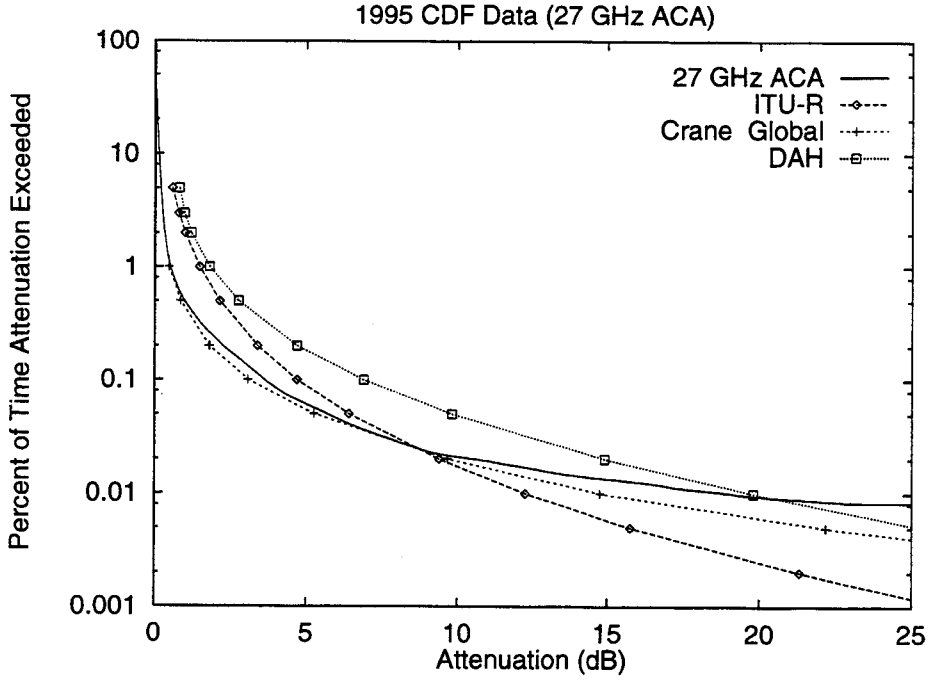
25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Attenuation (dB)
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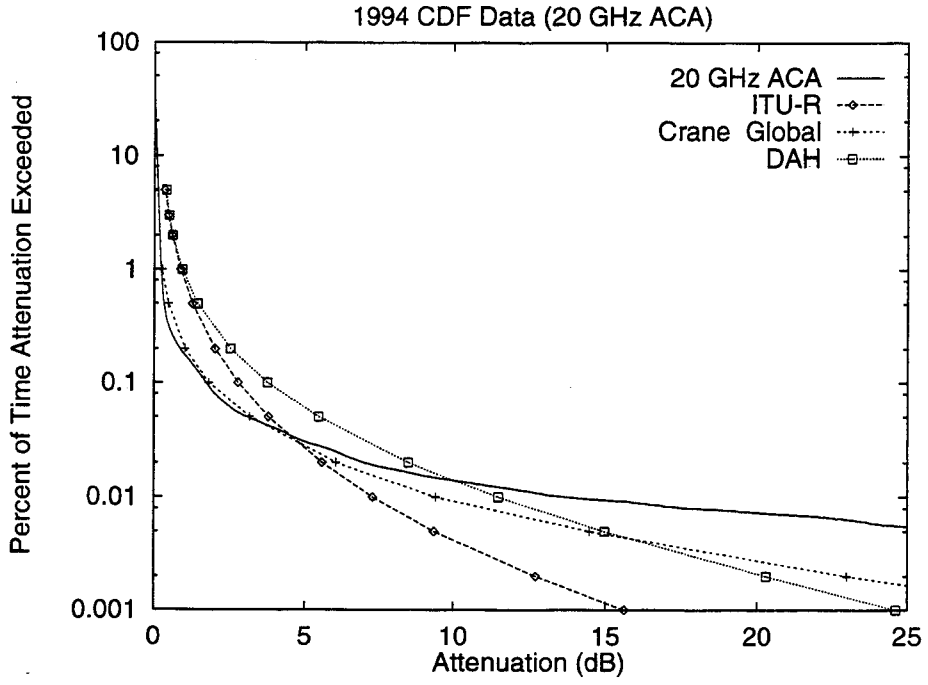
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Attenuation (dB)
20 GHz ACA
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DAH
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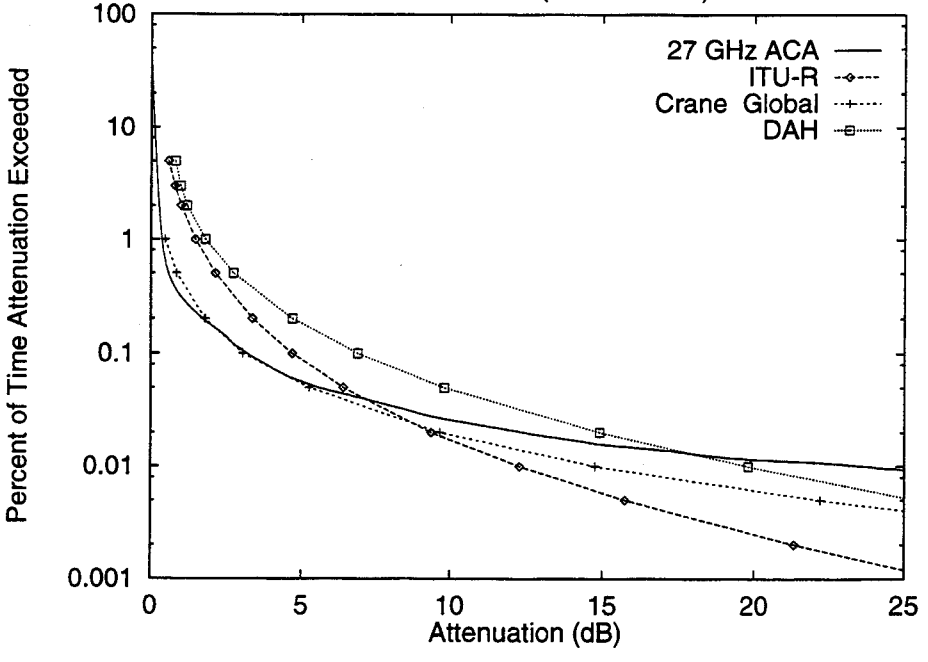
20
25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Percent of Time Attenuation Exceeded
Attenuation (dB)
27 GHz ACA
ITU-R
Crane Global
DAH
100
10
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0.1
0.01
0.001
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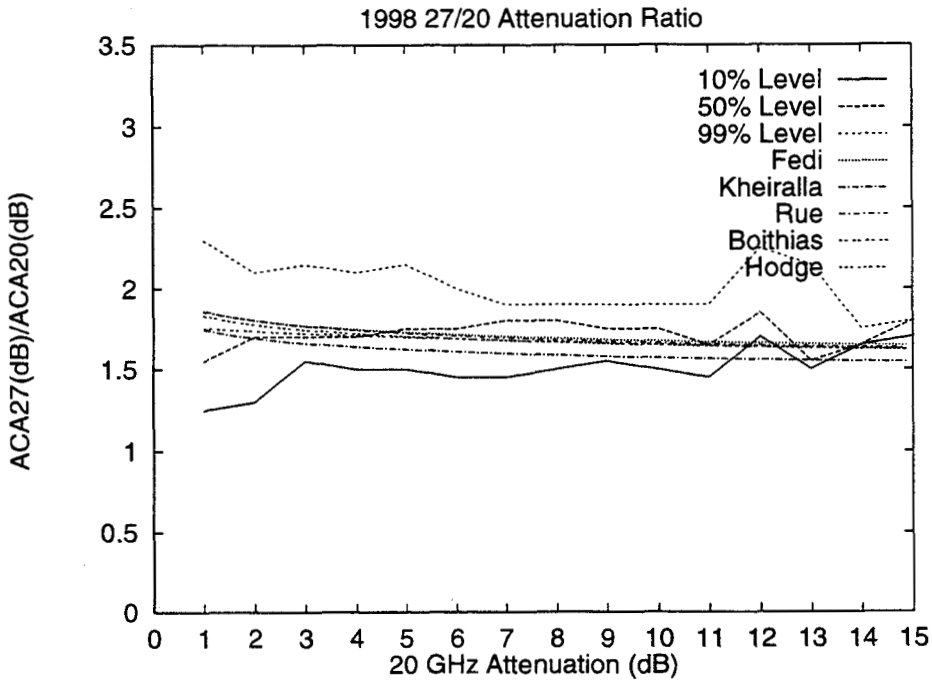
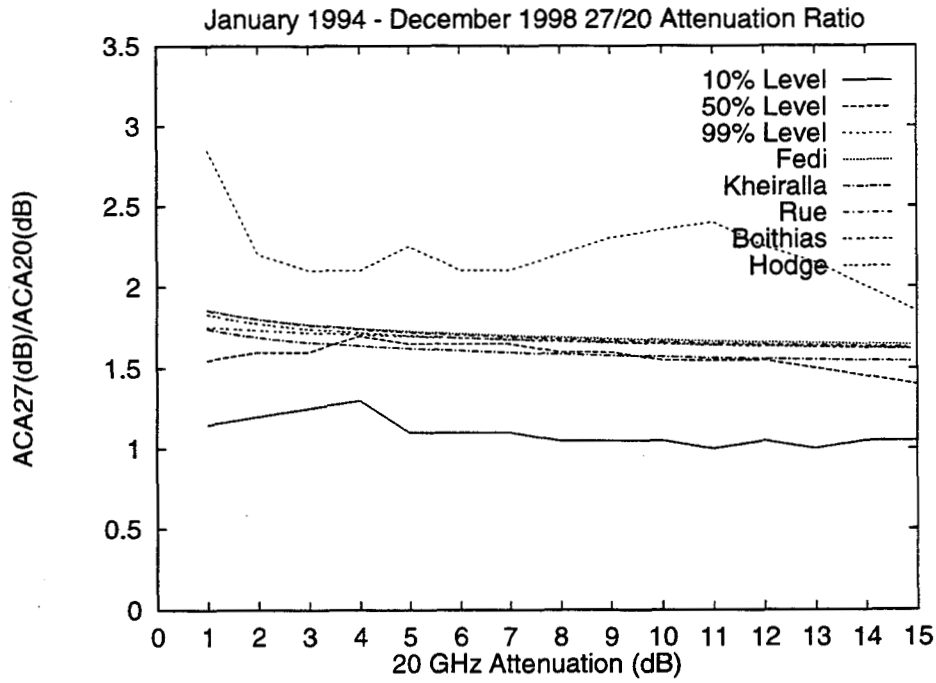
5
10
15
20
25


1998 27/20 Attenuation Ratio
ACA27(dB)/ACA20(dB)
20 GHz Attenuation (dB)
10% Level
50% Level
99% Level
Fedi
Kheiralla
Rue
Boithias
Hodge
0
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


January 1994 - December 1998 27/20 Attenuation Ratio
ACA27(dB)/ACA20(dB)
20 GHz Attenuation (dB)
10% Level
50% Level
99% Level
Fedi
Kheiralla
Rue
Boithias
Hodge
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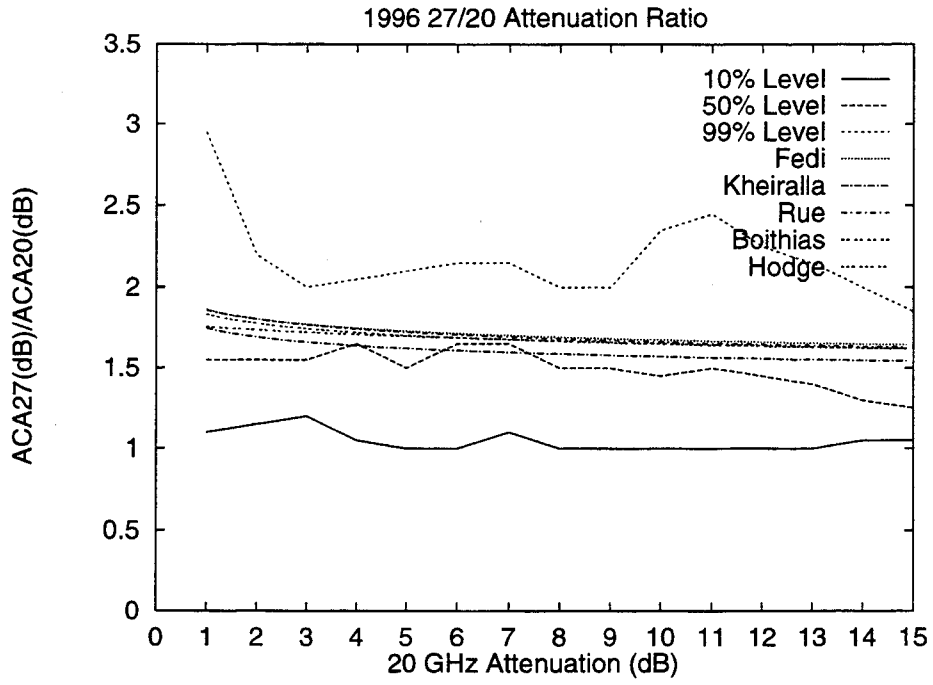
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15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10% Level
50% Level
99% Level
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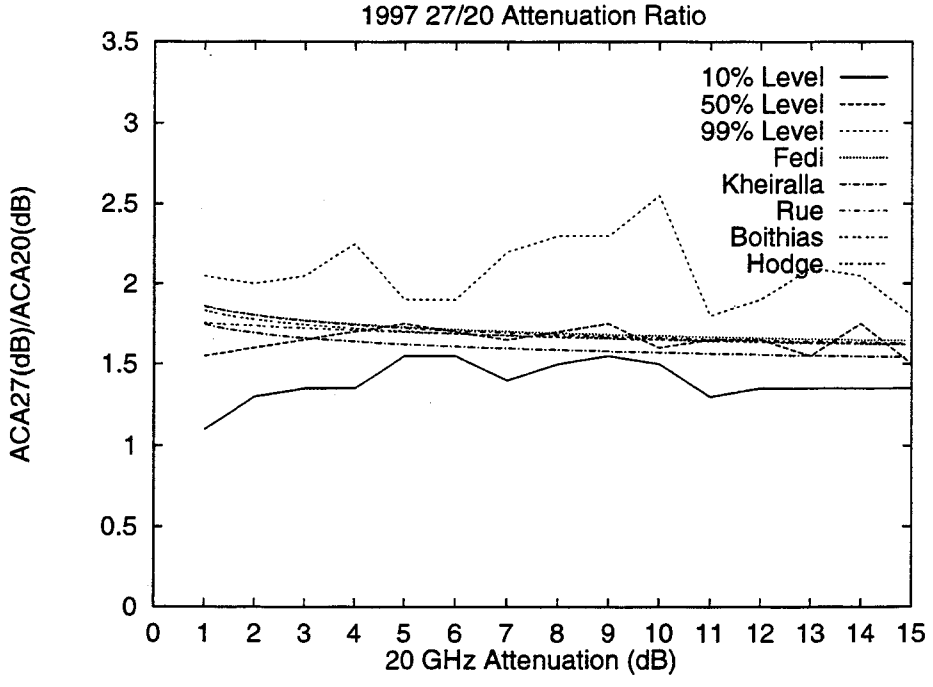
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15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10% Level
50% Level
99% Level
Fedi
Kheiralla
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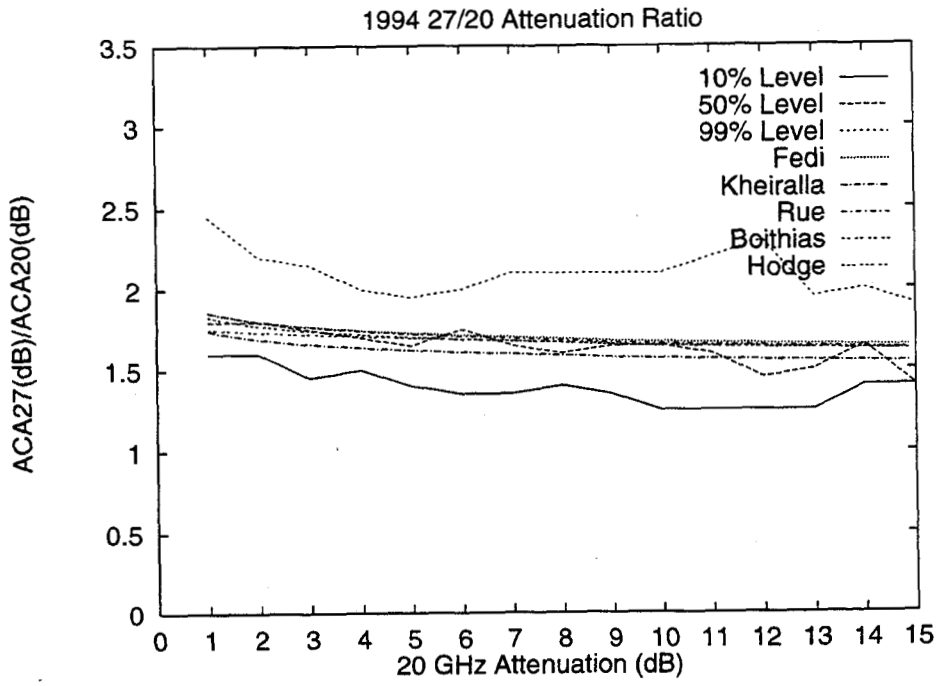
Boithias
Hodge
0
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15


1994 27/20 Attenuation Ratio
ACA27(dB)/ACA20(dB)
20 GHz Attenuation (dB)
10% Level
50% Level
99% Level
Fedi
Kheiralla
Rue
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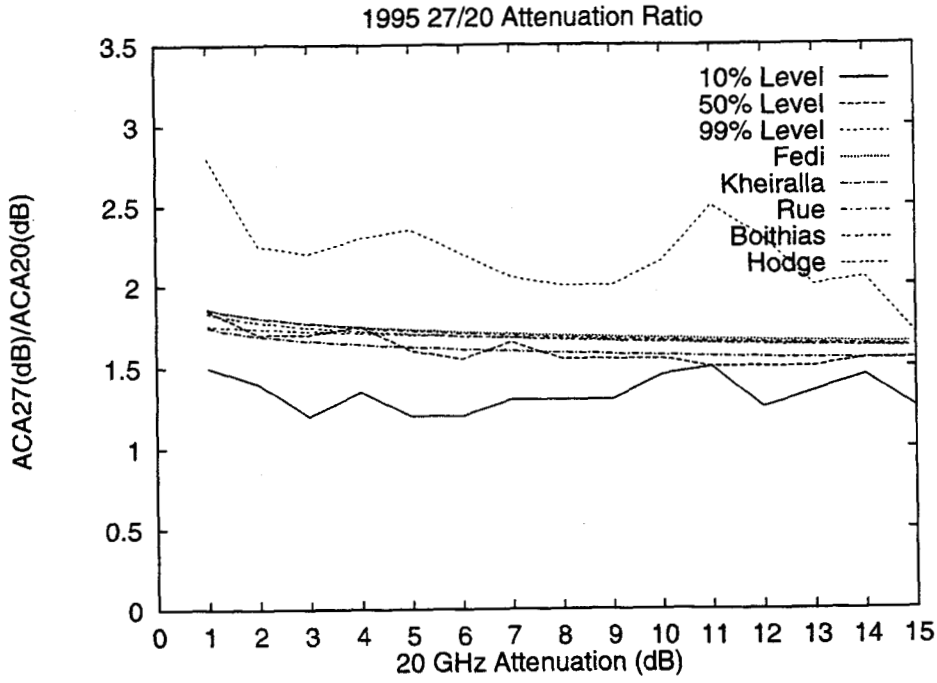
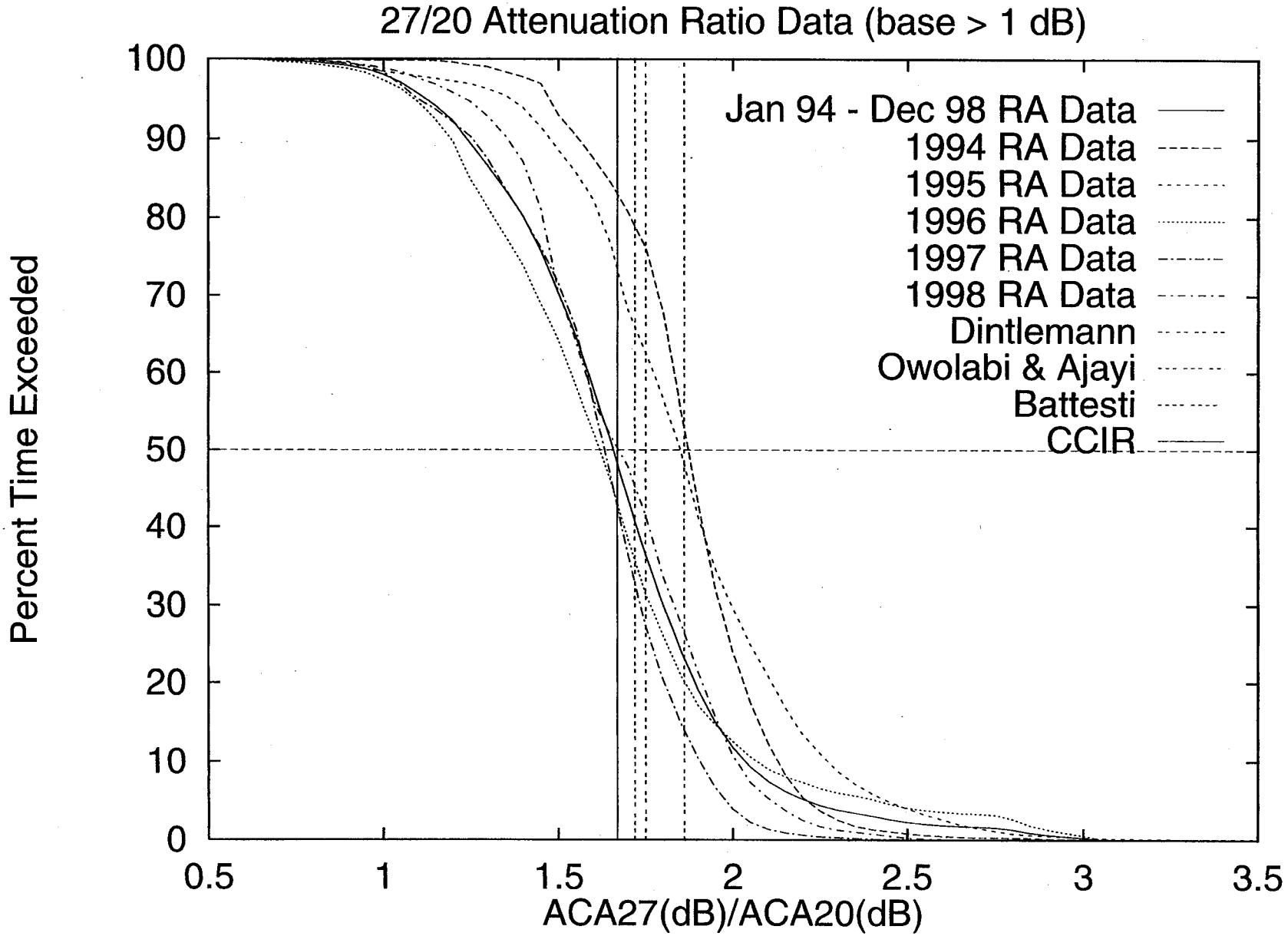
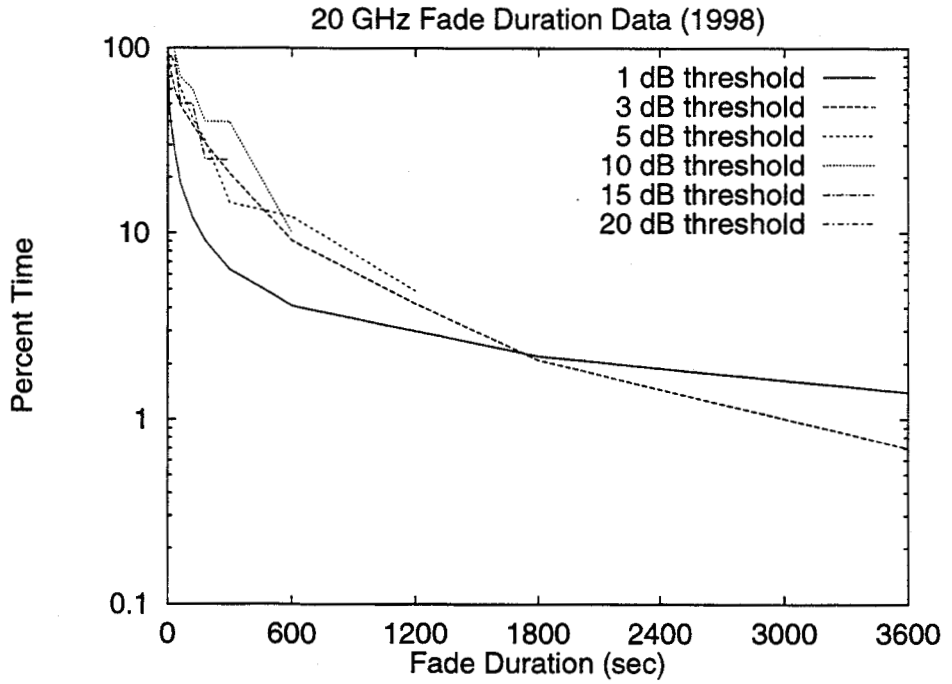
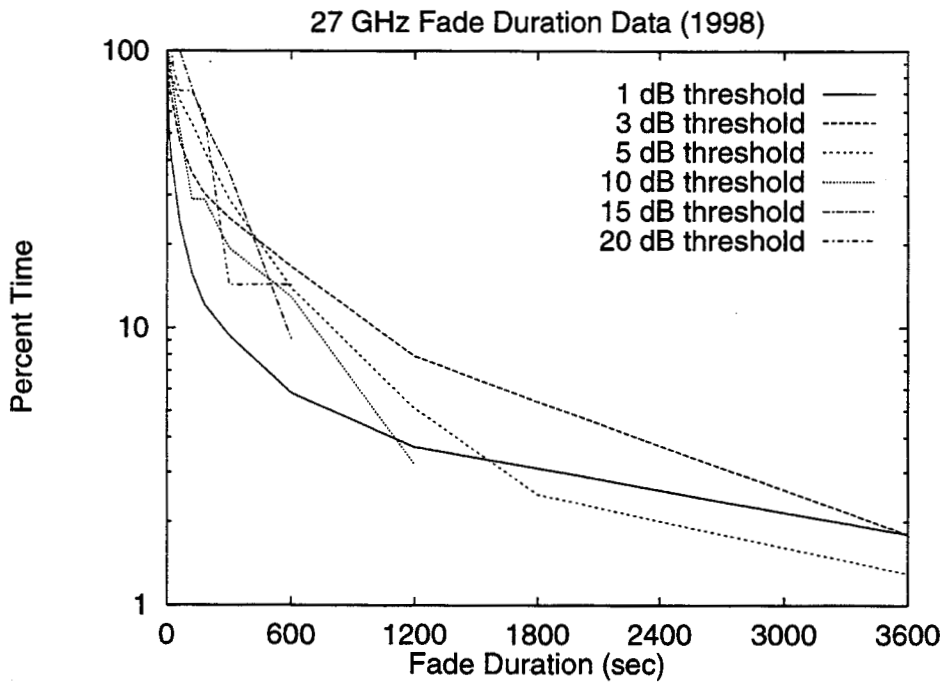
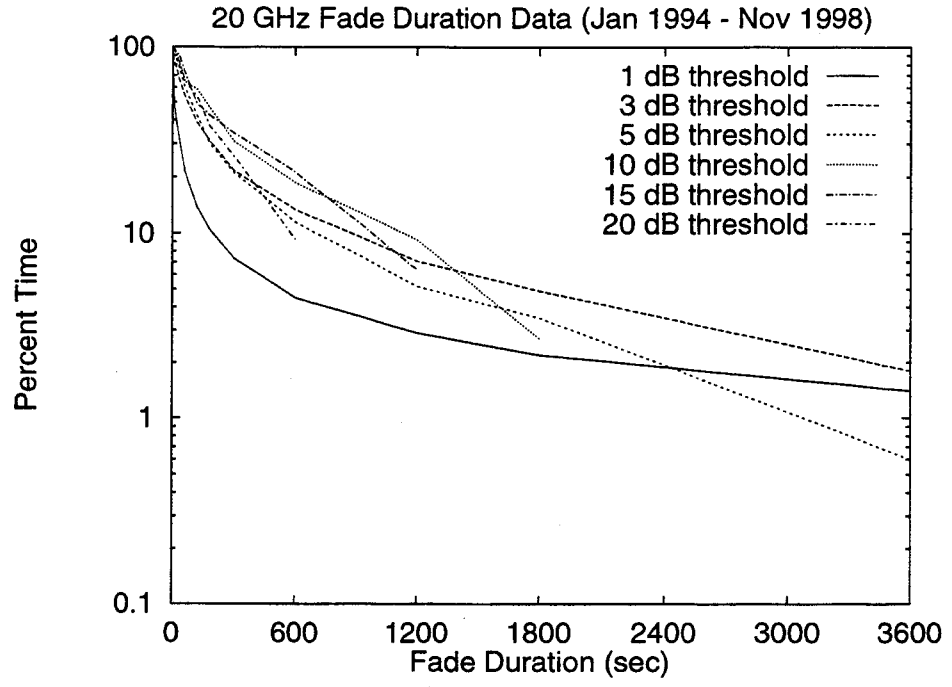
Hodge
0
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

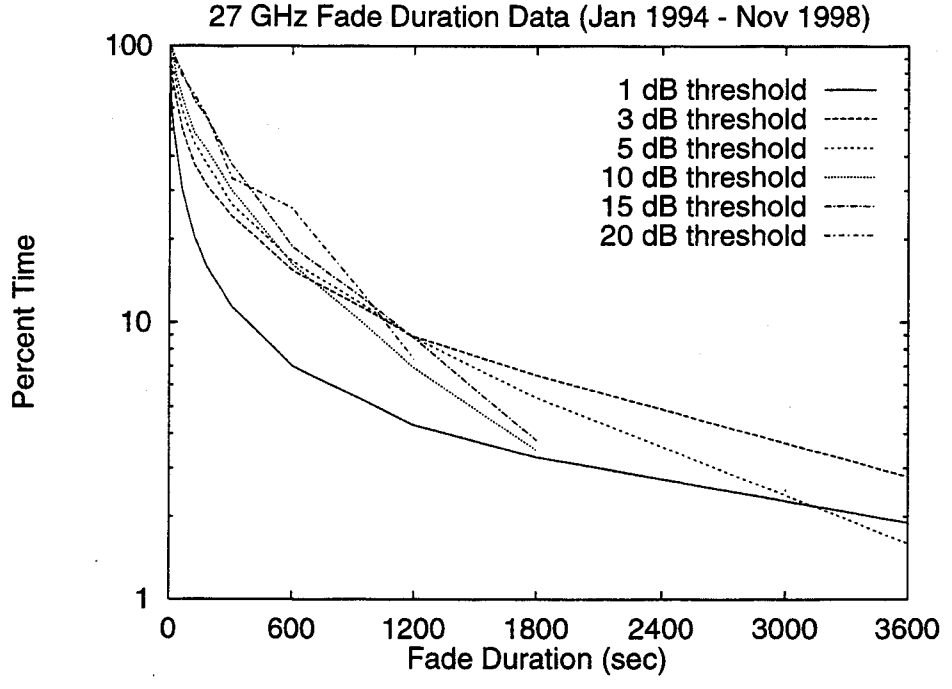

1995 27/20 Attenuation Ratio
ACA27(dB)/ACA20(dB)
20 GHz Attenuation (dB)
10% Level
50% Level
99% Level
Fedi
Kheiralla
Rue
Boithias
Hodge
0
0.5
1
1.5
2
2.5
3
3.5
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15

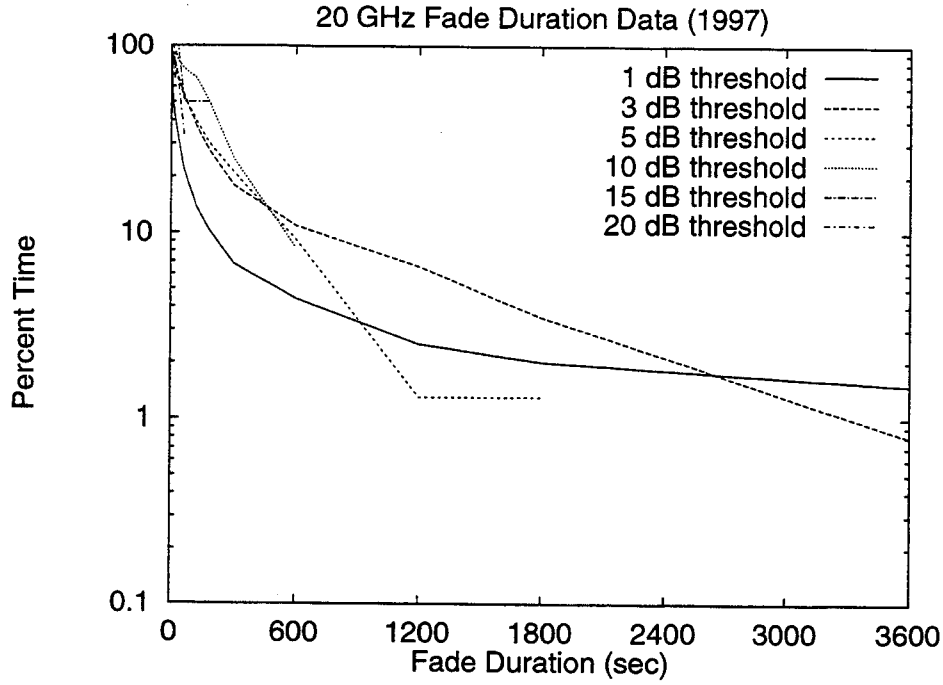

27/20 Attenuation Ratio Data (base > 1 dB)
Percent Time Exceeded
ACA27(dB)/ACA20(dB)
100
90
80
70
60
50
40
30
20
10
0
0.5
1
1.5
2
2.5
3
3.5
Jan 94 - Dec 98 RA Data
1994 RA Data
1995 RA Data
1996 RA Data
1997 RA Data
1998 RA Data
Dintlemann
Owolabi & Ajayi
Battesti
CCIR

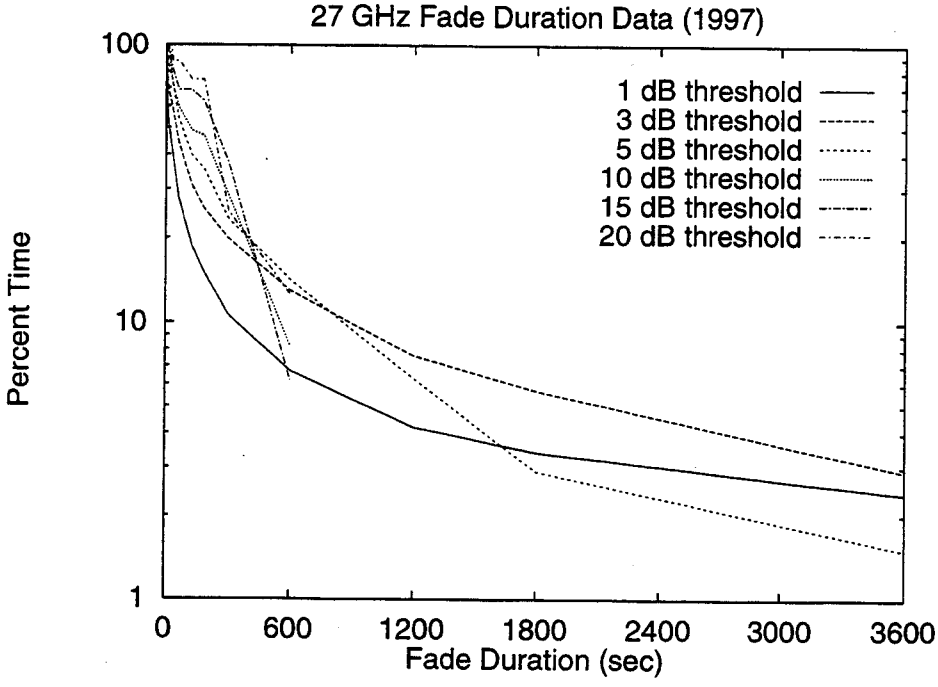

20 GHz Fade Duration Data (1998)
Percent Time
100
10
1
0.1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

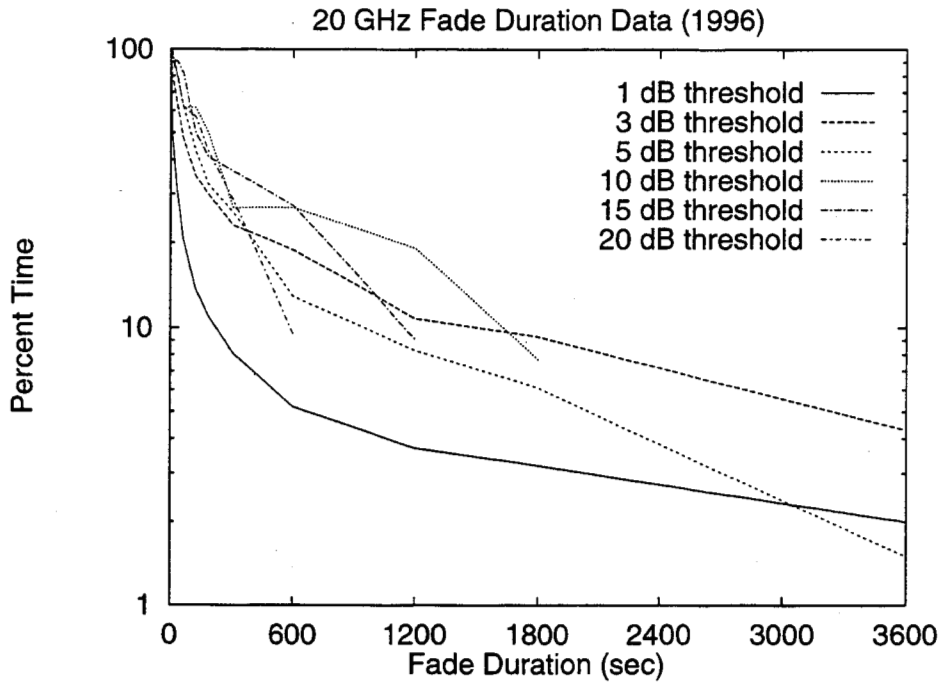

27 GHz Fade Duration Data (1998)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

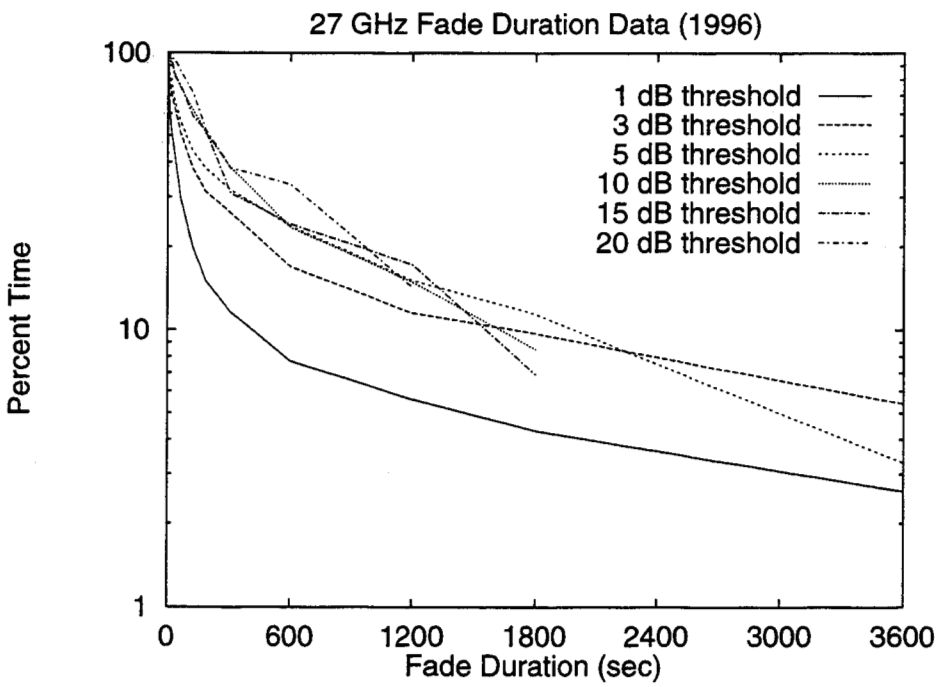

20 GHz Fade Duration Data (Jan 1994 - Nov 1998)
Percent Time
100
10
1
0.1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

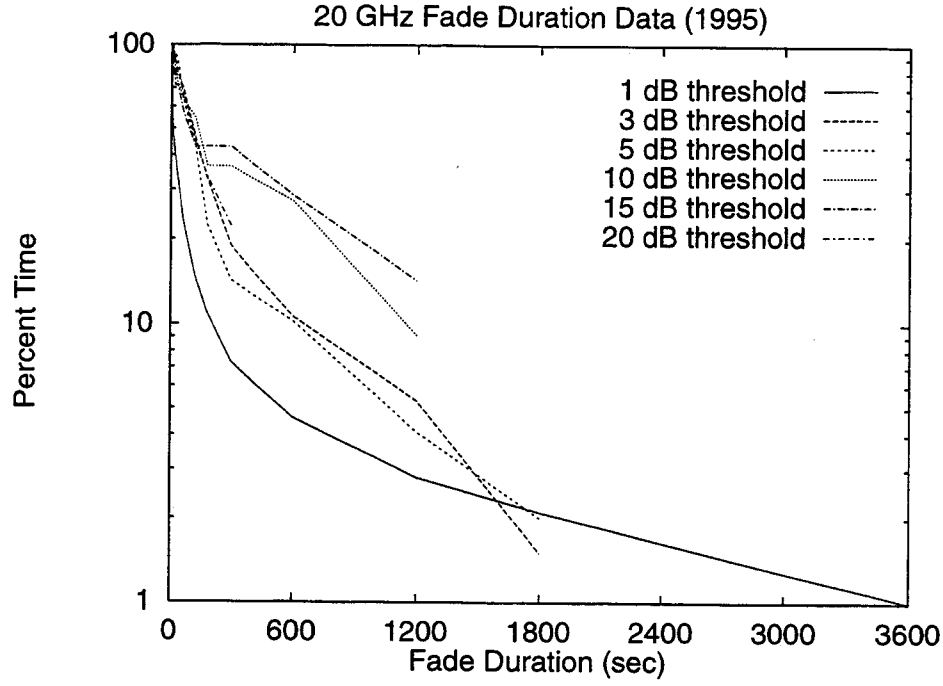

27 GHz Fade Duration Data (Jan 1994 - Nov 1998)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

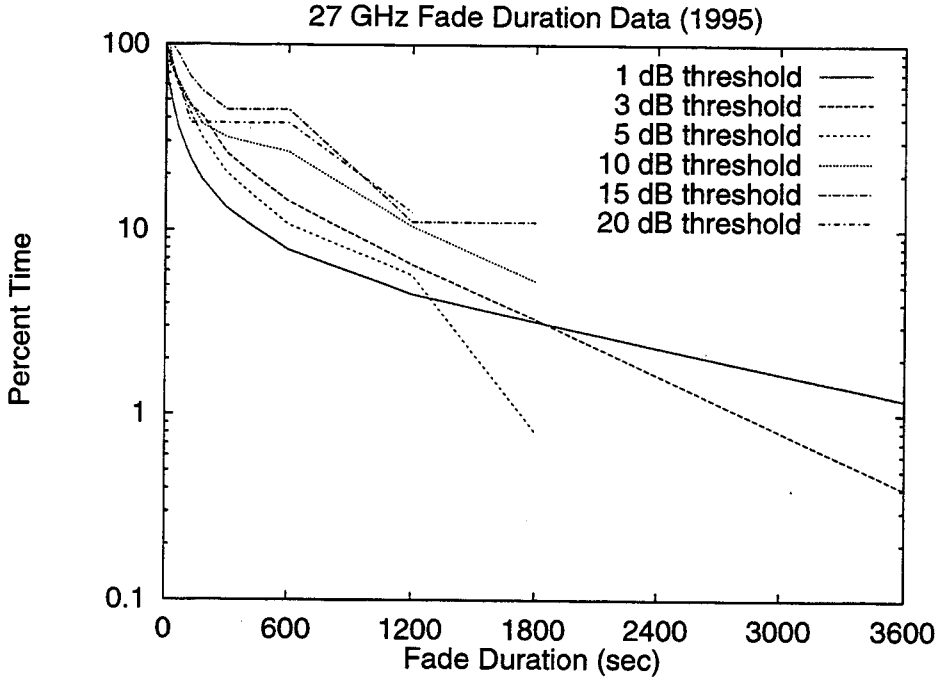

20 GHz Fade Duration Data (1997)
Percent Time
100
10
1
0.1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

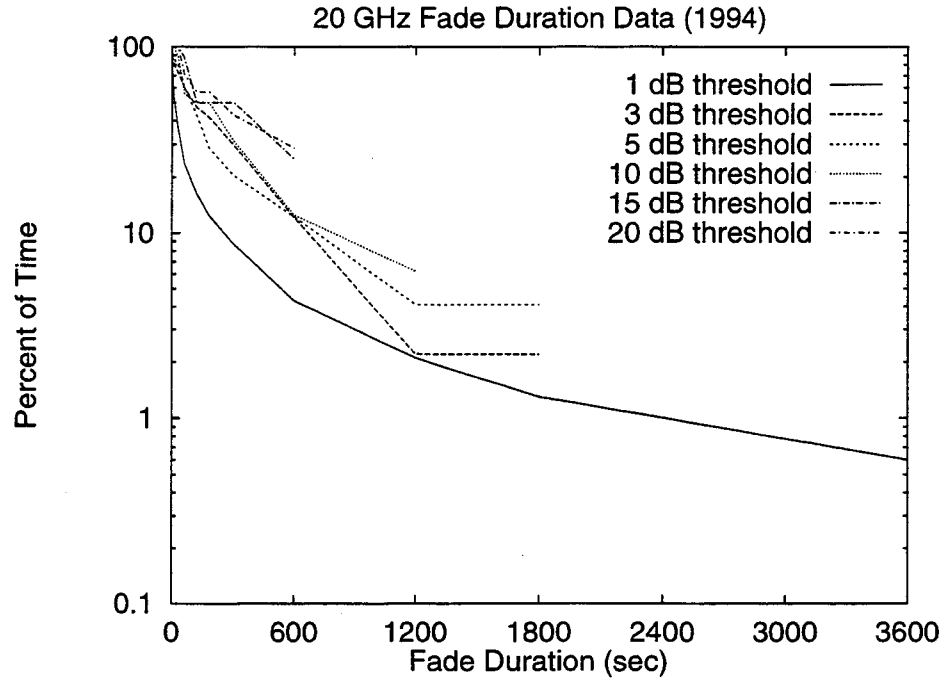

27 GHz Fade Duration Data (1997)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

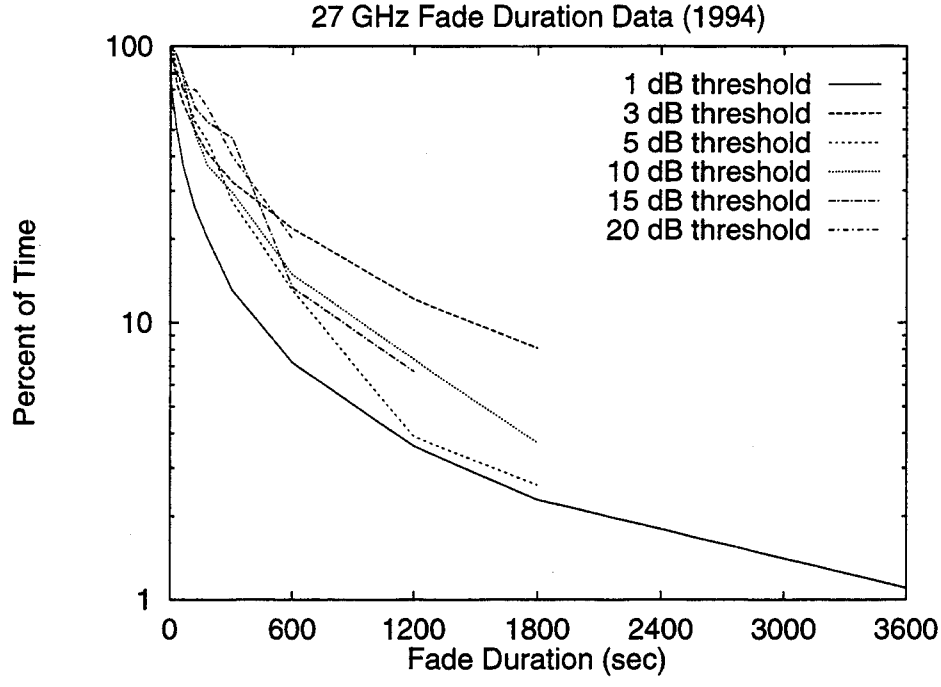

20 GHz Fade Duration Data (1996)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold


27 GHz Fade Duration Data (1996)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

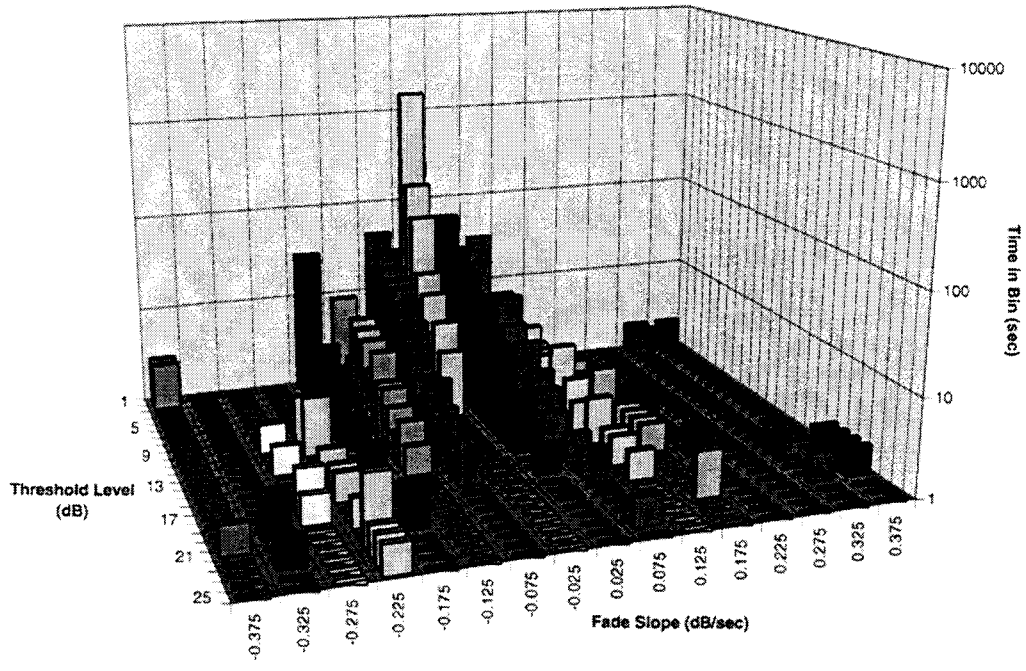

20 GHz Fade Duration Data (1995)
Percent Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold


27 GHz Fade Duration Data (1995)
Percent Time
100
10
1
0.1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

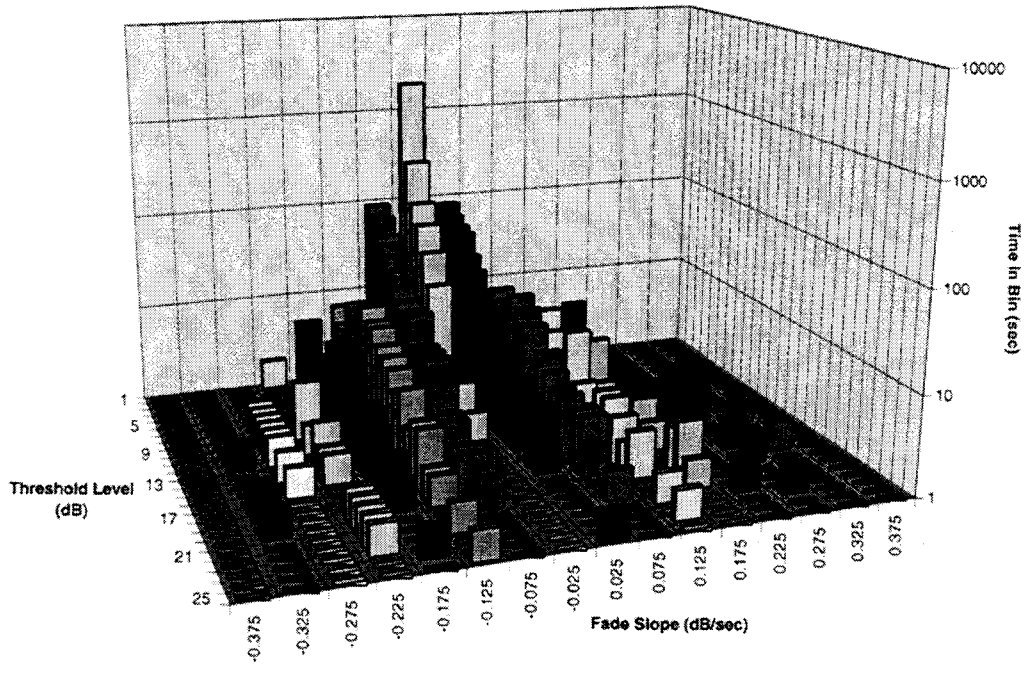

20 GHz Fade Duration Data (1994)
Percent of Time
100
10
1
0.1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold


27 GHz Fade Duration Data (1994)
Percent of Time
100
10
1
0
600
1200
1800
2400
3000
3600
Fade Duration (sec)
1 dB threshold
3 dB threshold
5 dB threshold
10 dB threshold
15 dB threshold
20 dB threshold

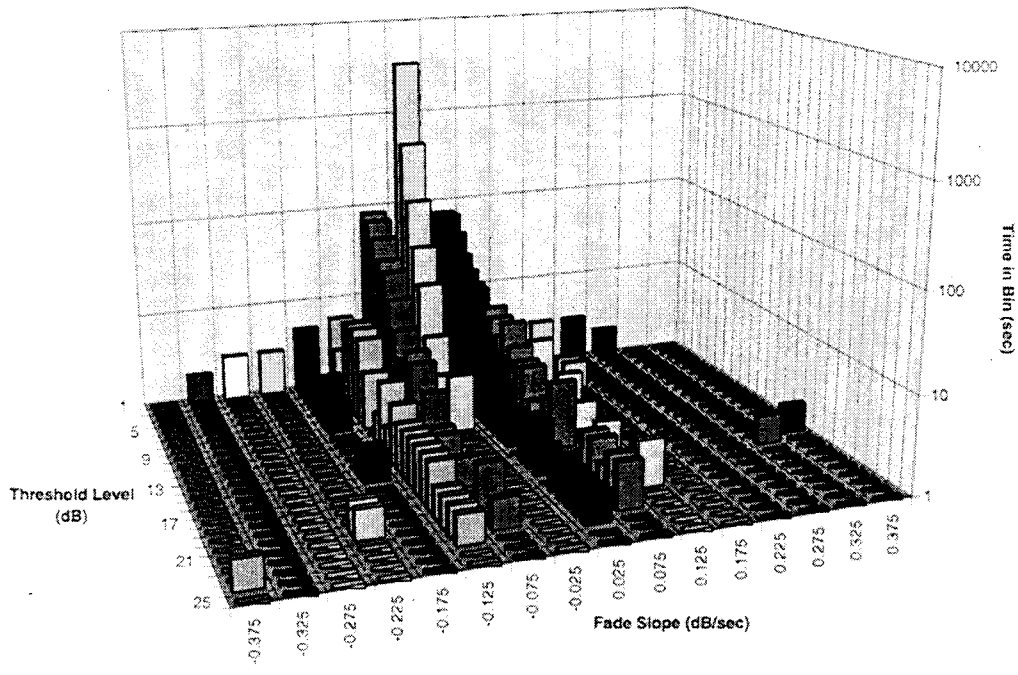
1994 Fade Slope Data (20 GHz)



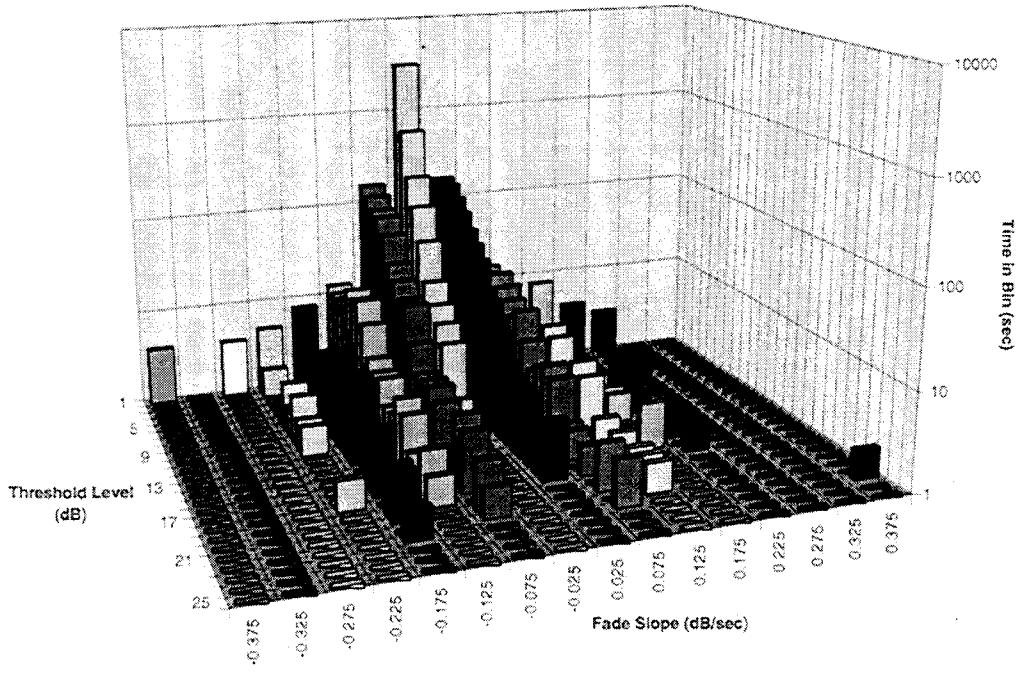
1994 Fade Slope Data (27 GHz)



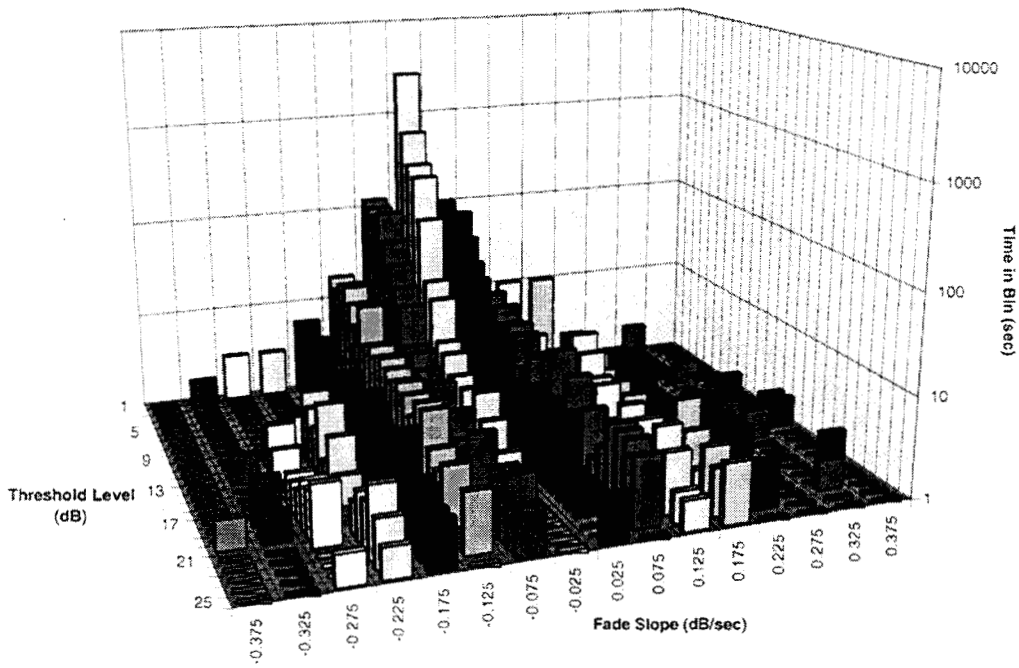
1995 Fade Slope Data (20 GHz)



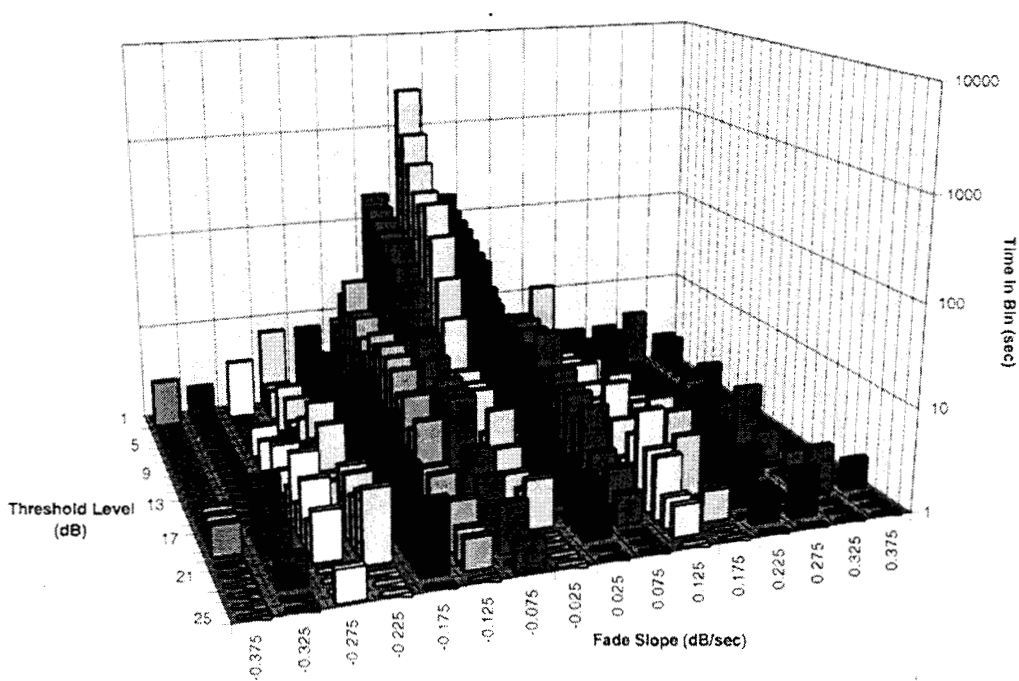
1995 Fade Slope Data (27 GHz)



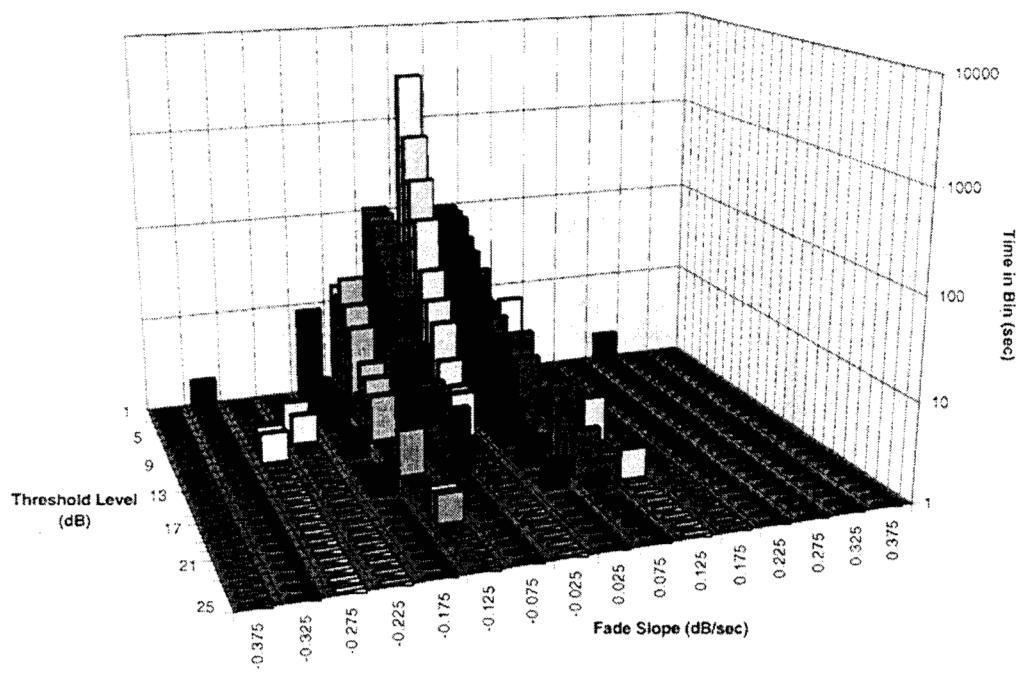
1996 Fade Slope Data (20 GHz)



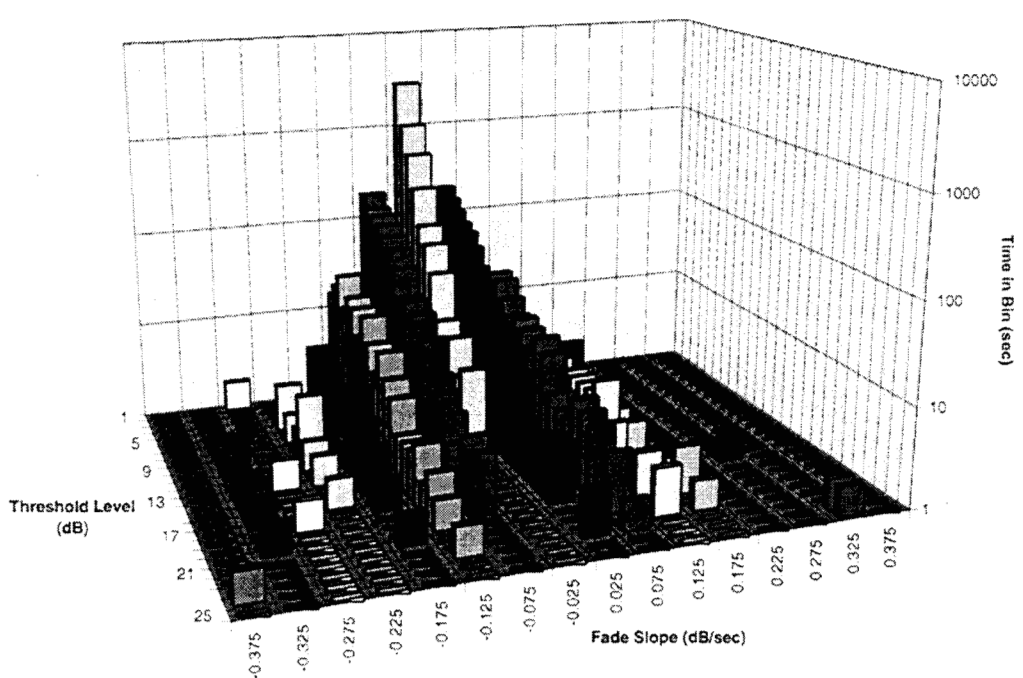
1996 Fade Slope Data (27 GHz)



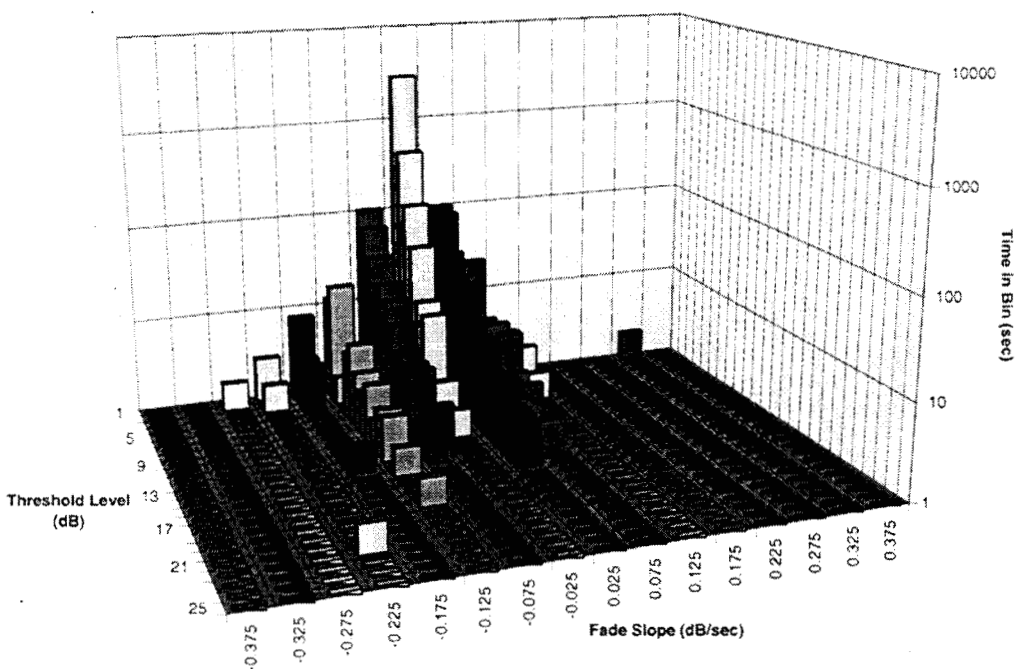
1997 Fade Slope Data (20 GHz)



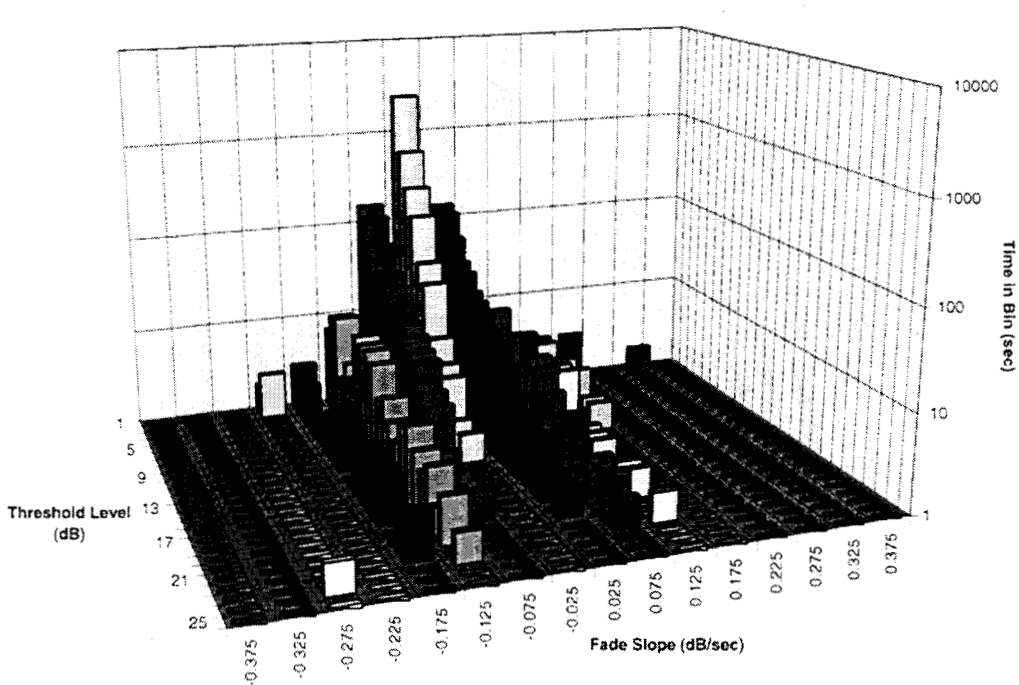
1997 Fade Slope Data (27 GHz)



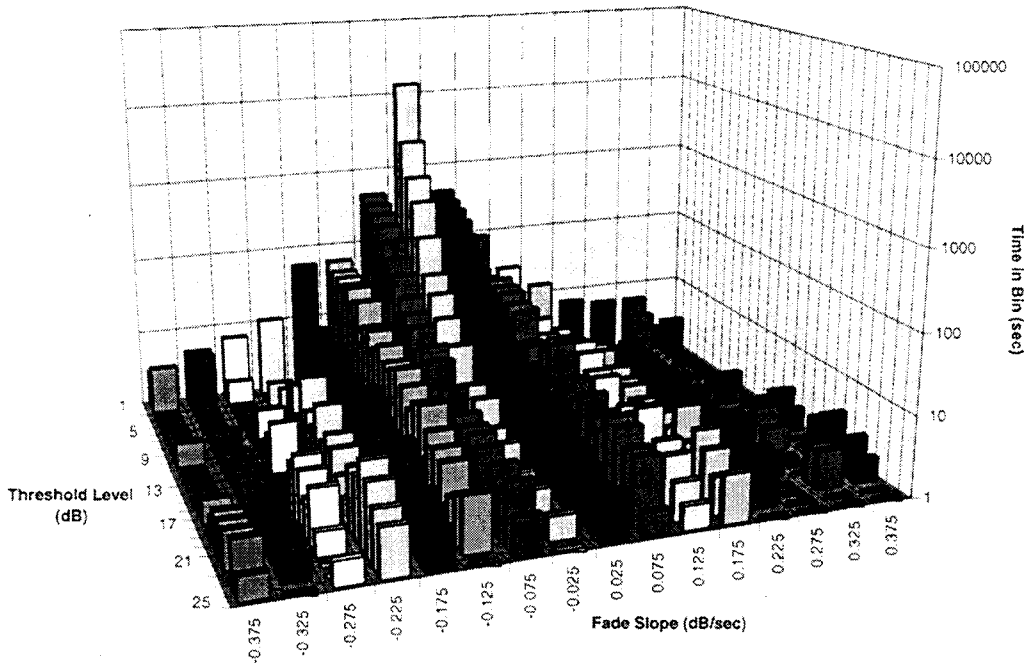
1998 Fade Slope Data (20 GHz)



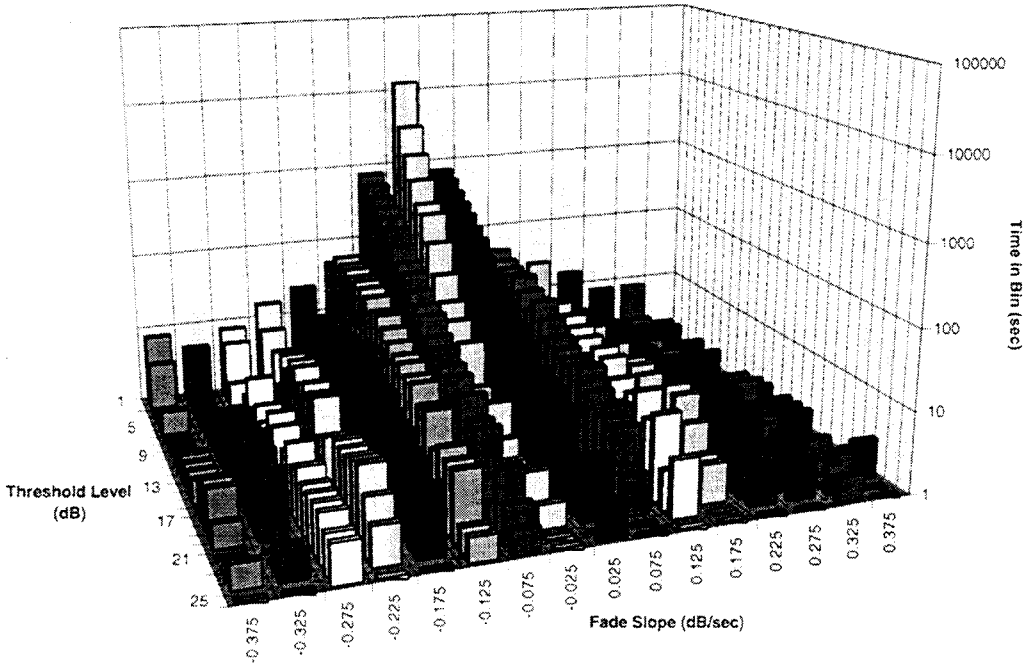
1998 Fade Slope Data (27 GHz)



1994-1998 Fade Slope Data (20 GHz)



1994-1998 Fade Slope Data (27 GHz)



CSU-CHILL Radar Facility

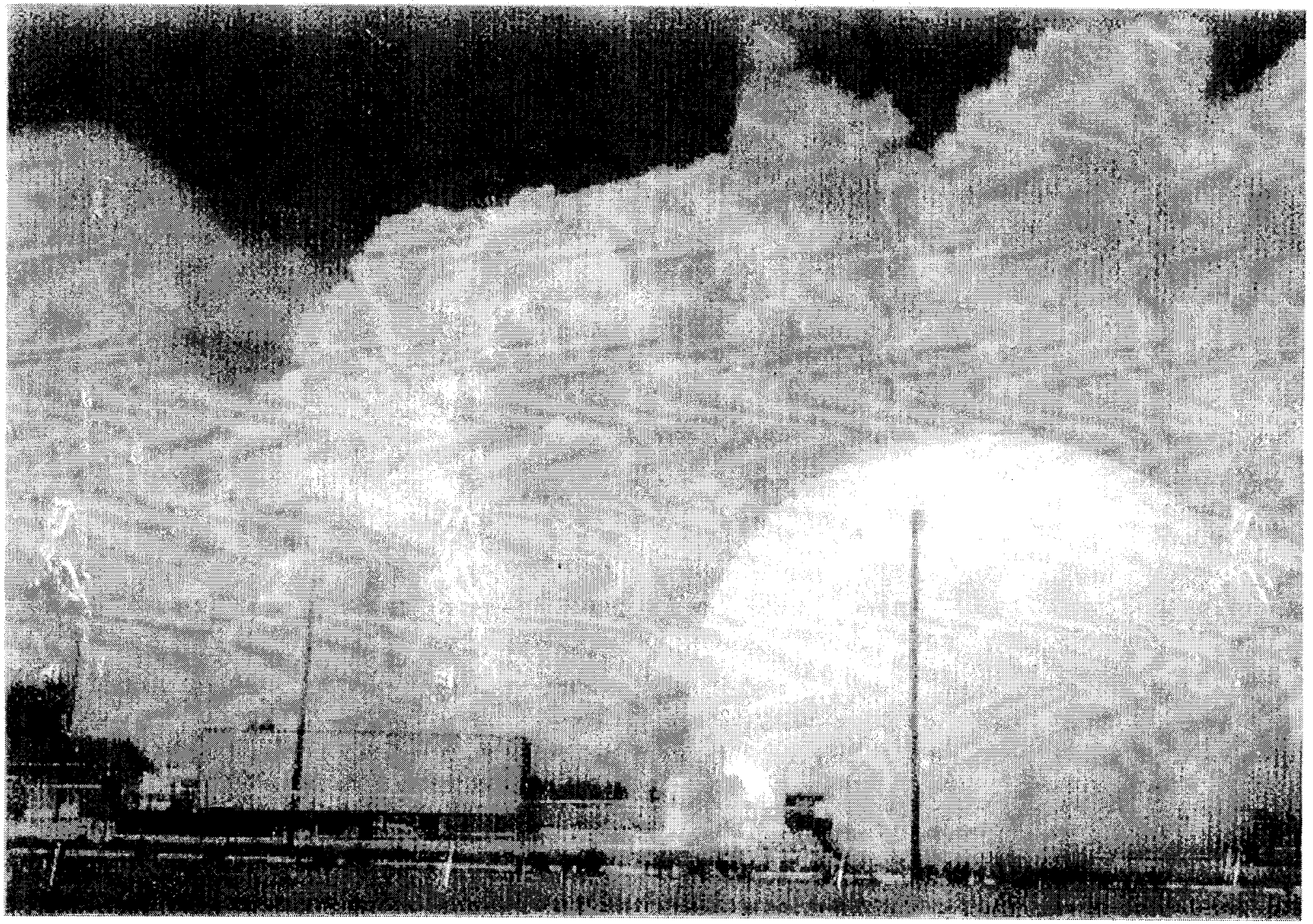
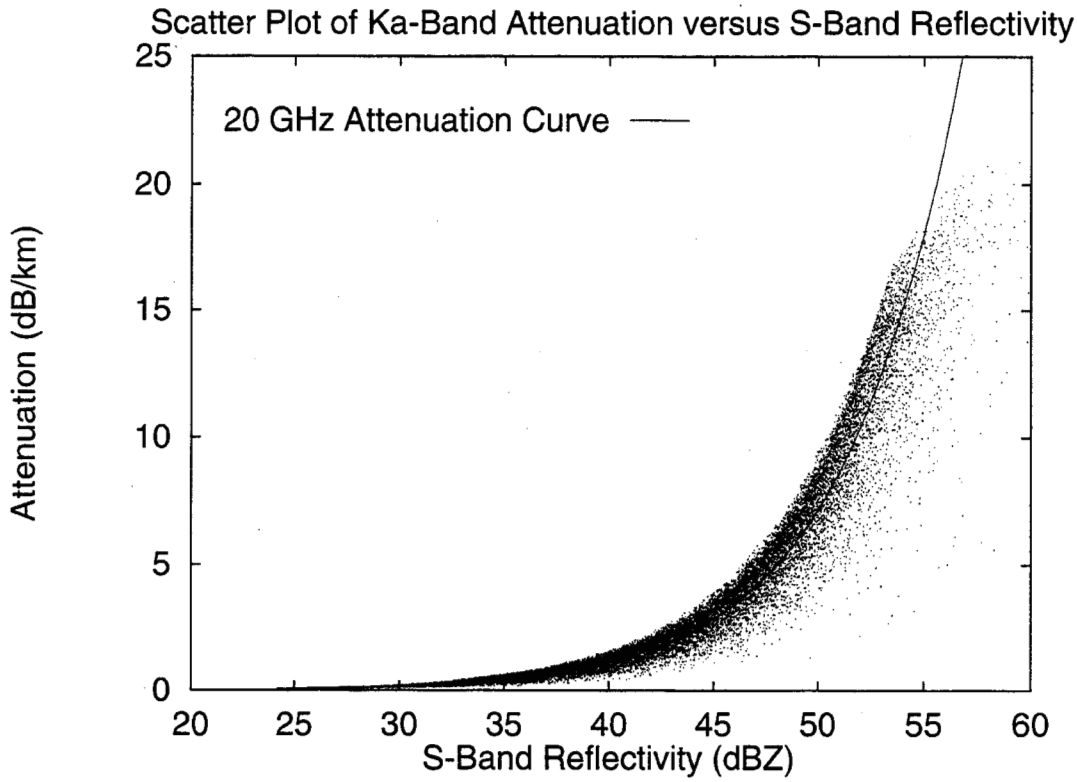
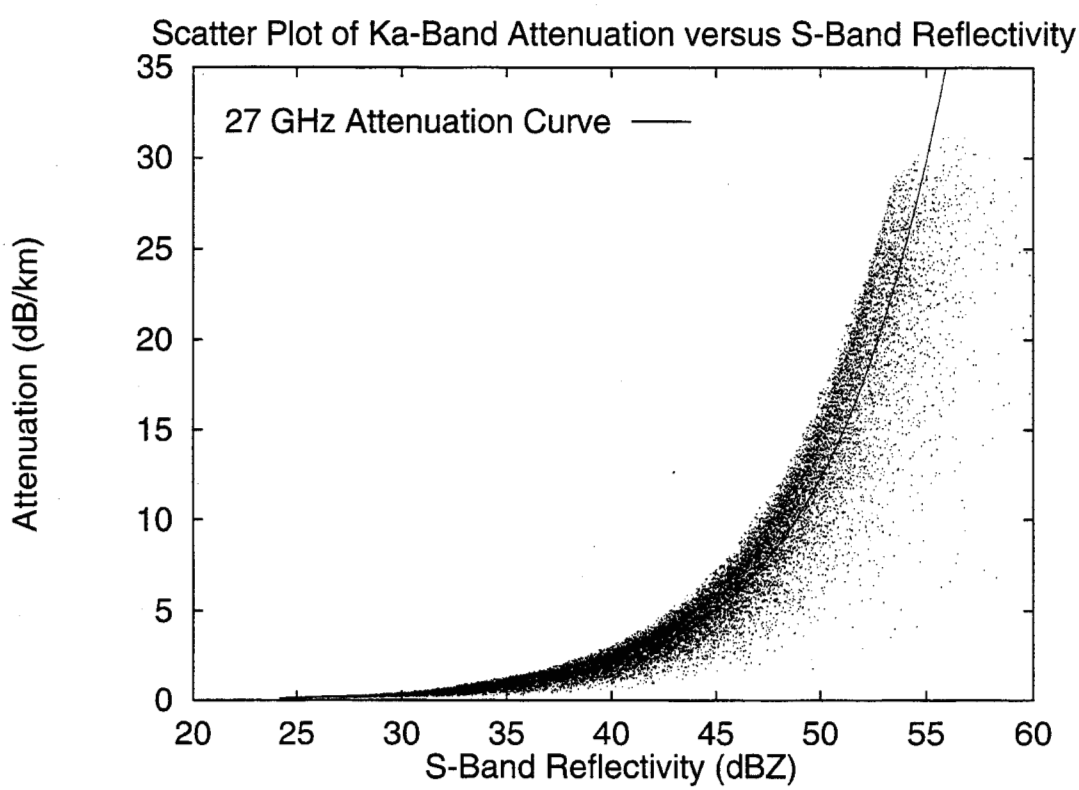
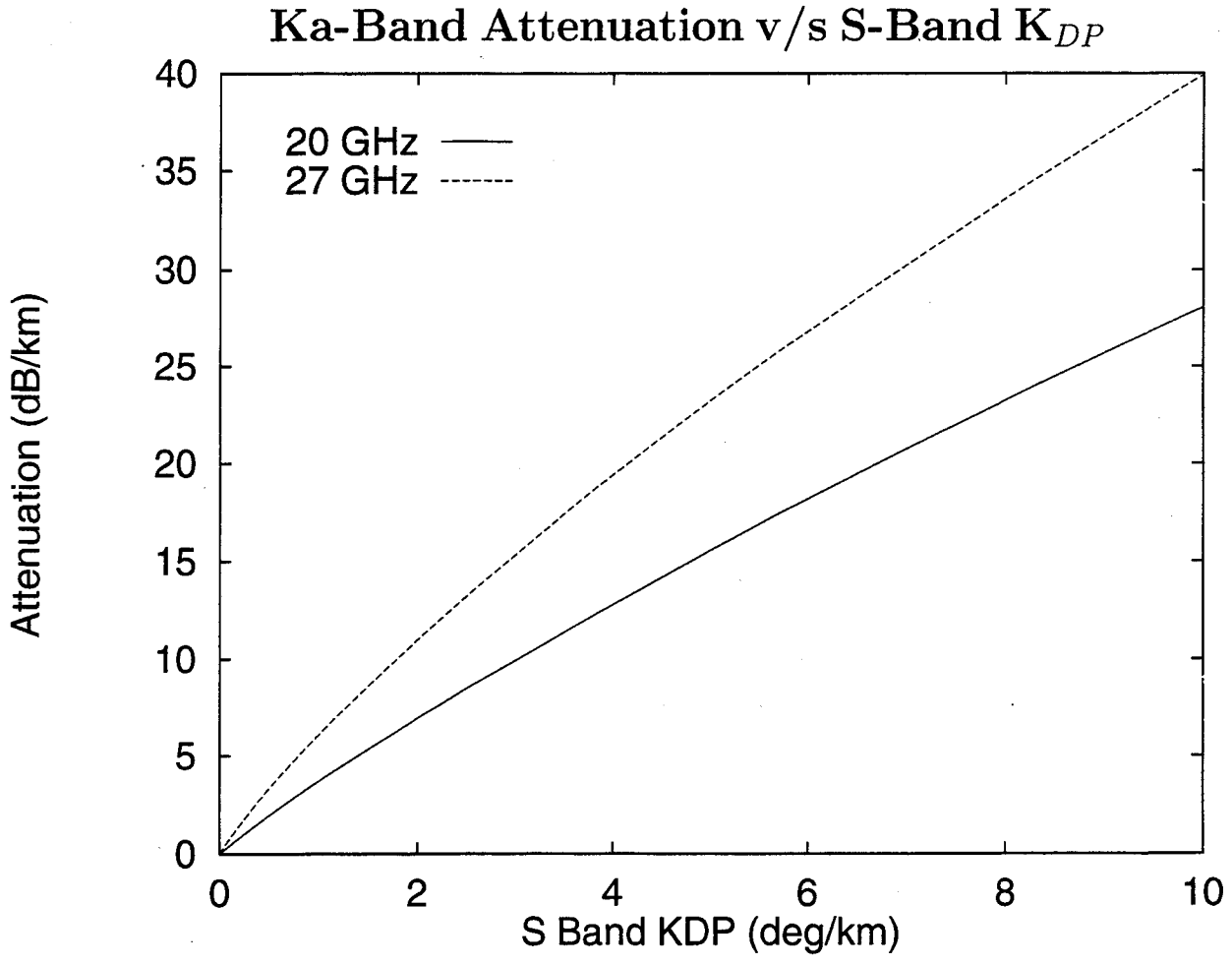


Table 1: System Characteristics of the CSU-CHILL Radar

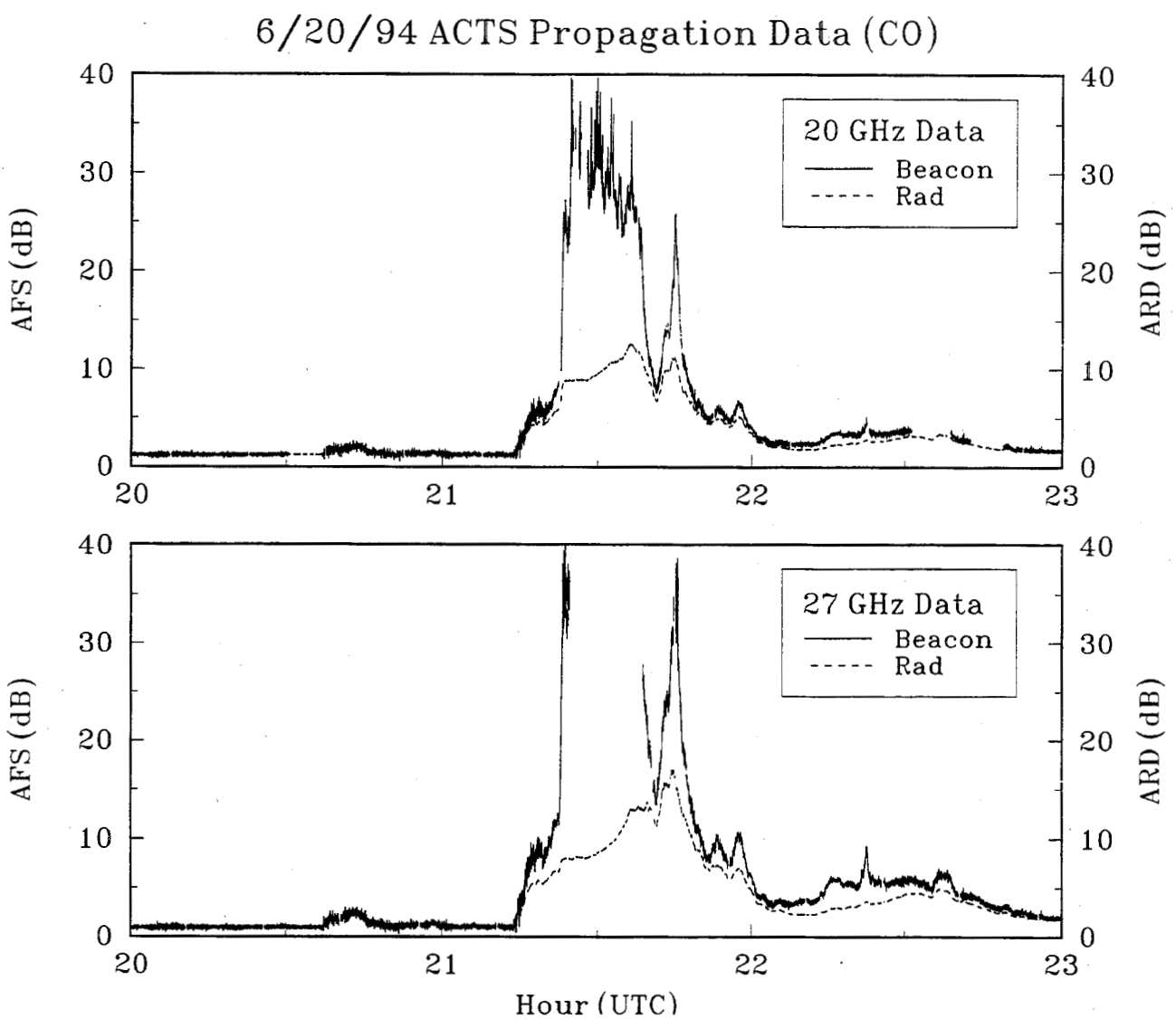
Antenna	
type:	fully steerable, prime focus parabolic reflector
size:	8.5 m
feed:	scalar horn
3 dB beamwidth:	1.0°
directivity :	45 dB
sidelobe level (any ϕ-plane):	≤ -27 dB
cross-pol. level (any ϕ-plane):	≤ -30 dB
polarization radiated:	Horizontal or Vertical
Transmitter	
type:	klystron, modernized FPS-18
wavelength:	10.7 cm
peak Power:	700 – 1000 kW
pulse width:	steps of 0.1 μs up to a max. of 1 μs
PRT:	800 – 2500 μs
max. unambigu. range:	375 km
max. unambigu. velocity:	$\pm$34.3 m/s
Receiver	
noise figure:	0.7 dB
noise power:	– 114 dBm
typical bandwidth:	750 kHz
transfer function:	linear
dynamic range:	90 dB, 0 – 60 dB IAGC in 12 dB steps
Data Acquisition	
signal processor:	SP20 made by Lassen Research
number of range gates:	64 – 2048
range gate spacing:	0.2 μs or 1μs
sampling rate/avg. option:	under micro-code control
video digitizer:	12-bit, in the SP20 input card for I, Q and logP
time series capability:	up to 150 range gates.
Variables Available	
• Reflectivity at H polarization (Z_h)	
• Differential Reflectivity (Z_{dr})	
• Mean Doppler Velocity ($\bar{v}$) and Spectral Width (σ_v)	
• Differential Phase between H and V states (Ψ_{dp})	
• Copolar Correlation Coefficient ($\rho_{hv}(0)$)	
• Linear Depolarization Ratio (LDR)	
• Doppler Spectra from FFT processing	
• I, Q and logP for every pulse in time series mode (up to 150 gates)	

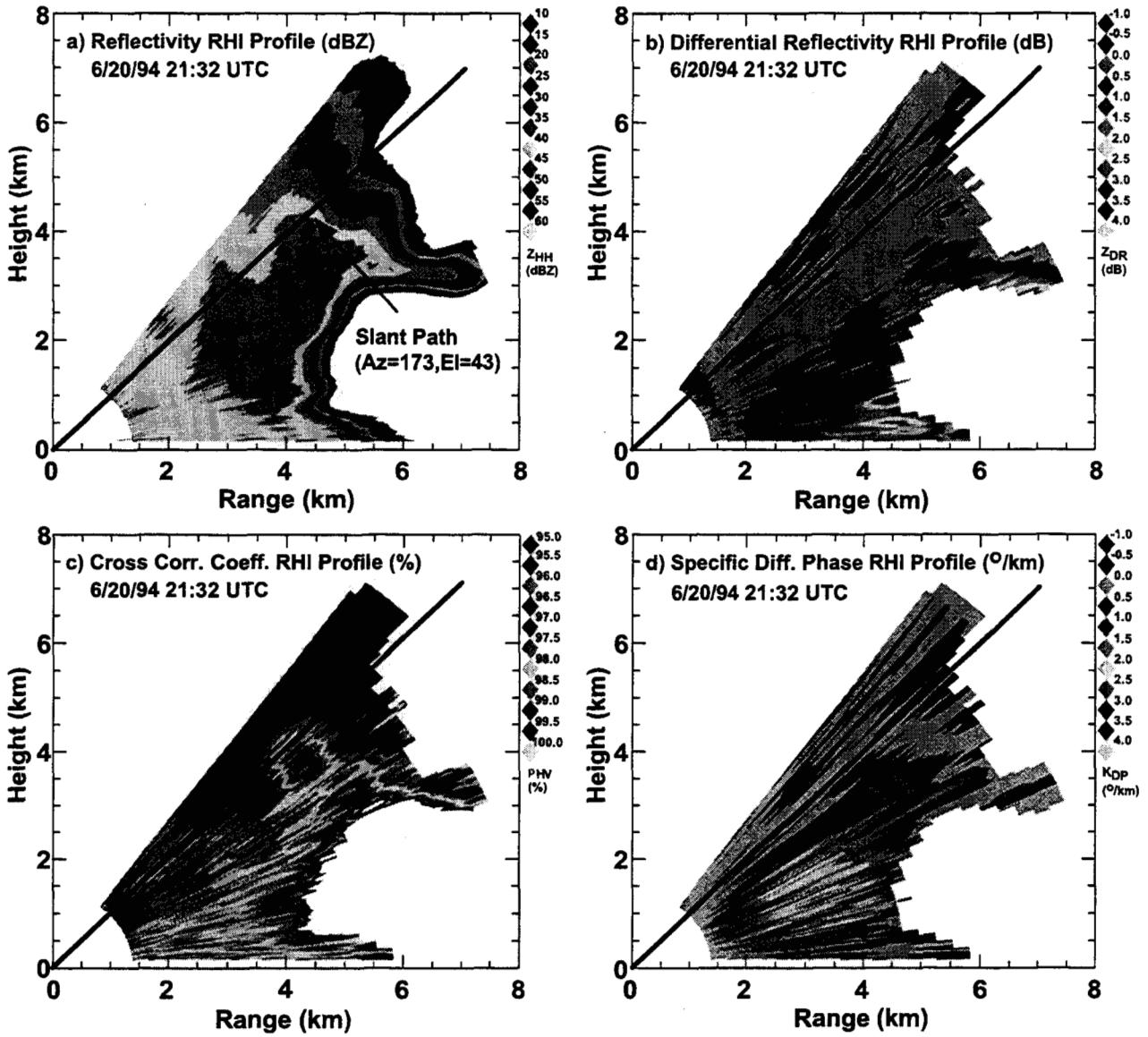

Scatter Plot of Ka-Band Attenuation versus S-Band Reflectivity
20 GHz Attenuation Curve
Attenuation (dB/km)
S-Band Reflectivity (dBZ)
0
5
10
15
20
25
20
25
30
35
40
45
50
55
60


Scatter Plot of Ka-Band Attenuation versus S-Band Reflectivity
27 GHz Attenuation Curve
Attenuation (dB/km)
S-Band Reflectivity (dBZ)
0
5
10
15
20
25
30
35
20
25
30
35
40
45
50
55
60


Ka-Band Attenuation v/s S-Band K_{DP}
20 GHz
27 GHz
Attenuation (dB/km)
S Band KDP (deg/km)
0
5
10
15
20
25
30
35
40
0
2
4
6
8
10

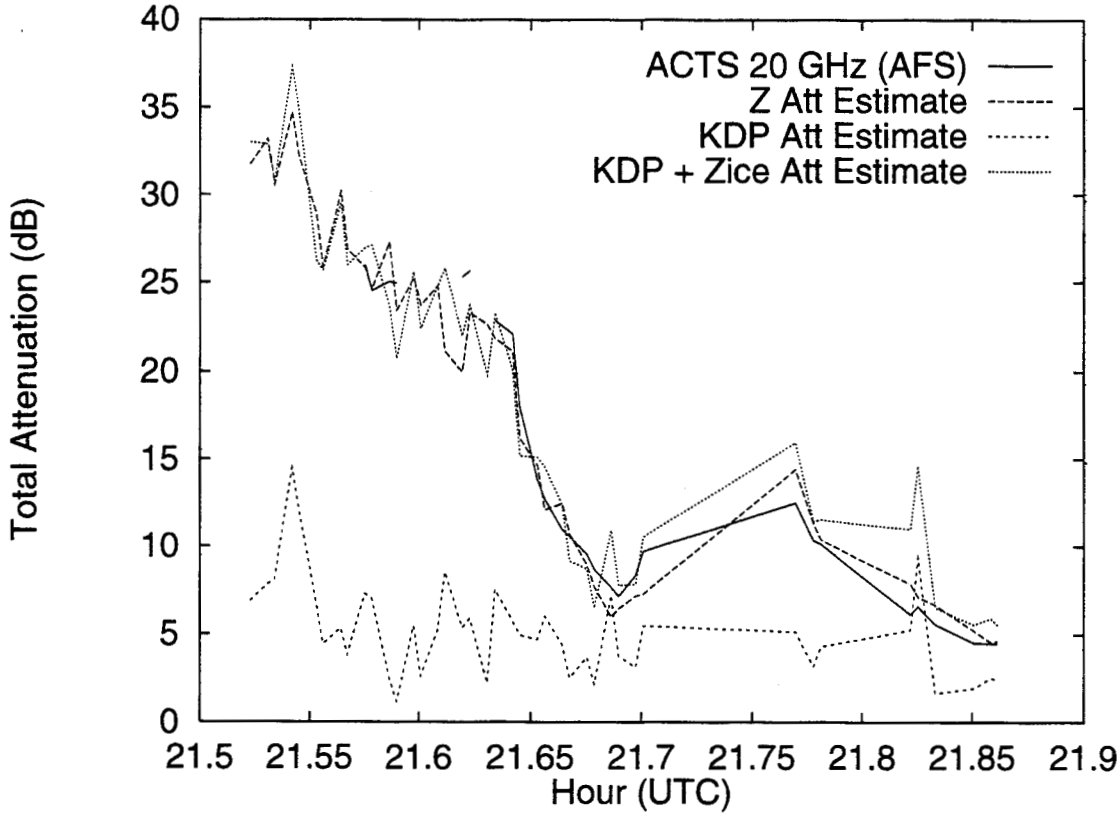
Attenuation Due to Rain Event

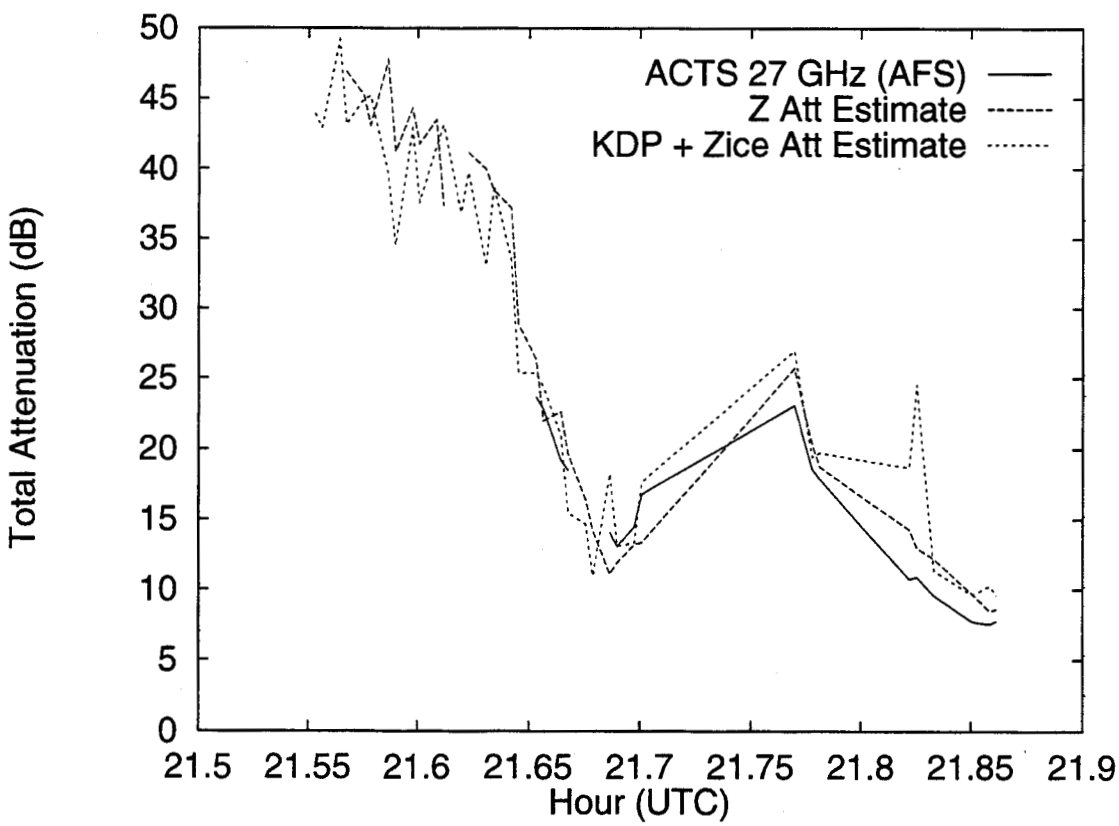


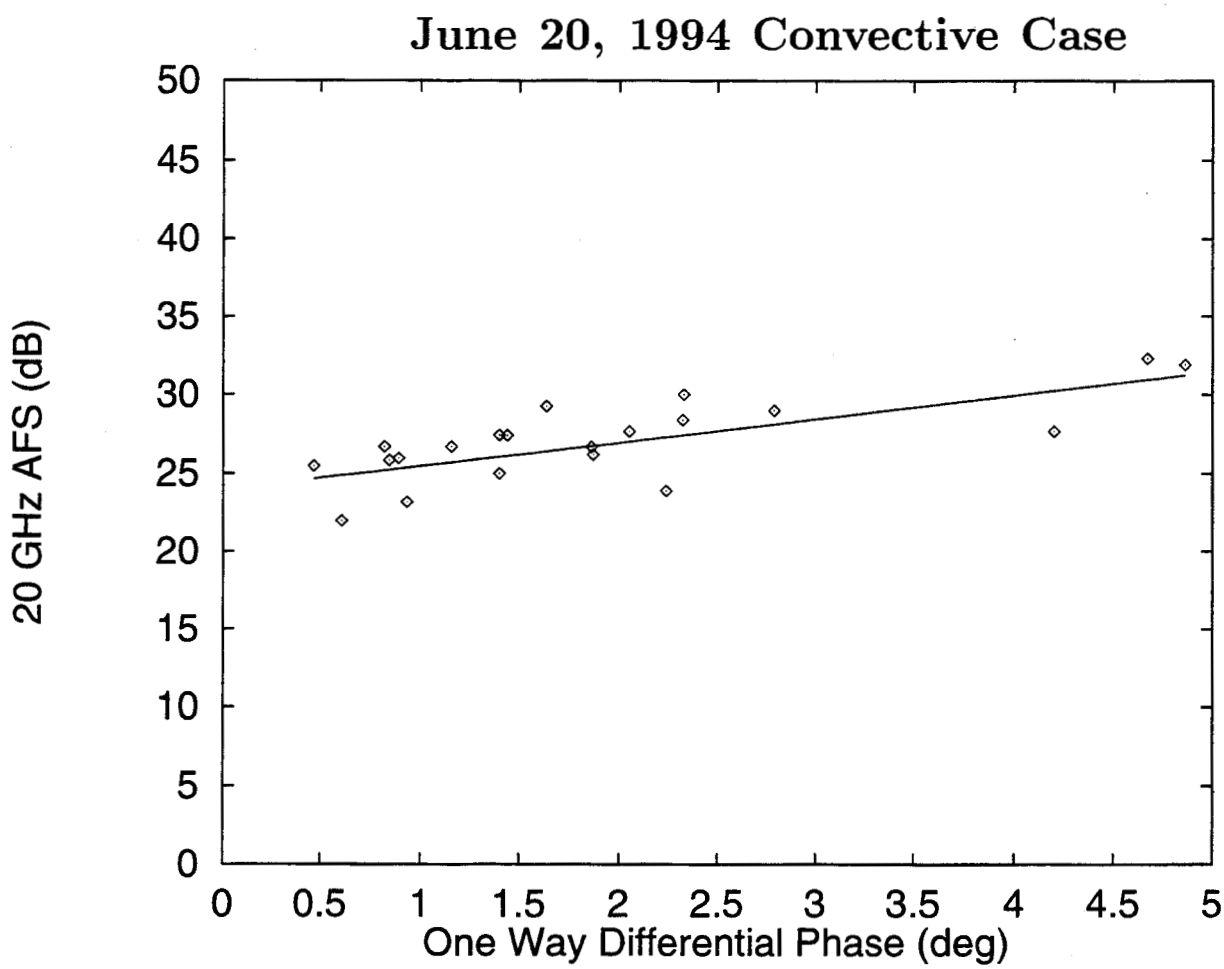


RHI scan for the June 20, 1994 convective case. The scan is taken along the direction of the ACTS propagation path. The CSU–APT elevation angle is 43°. The radar and CSU-APT are located at the origin with the height given in km along the y–axis. Distance away from the radar along the 172° azimuthal angle is given in km along the x–axis. a) Horizontal reflectivity, Z_{HH} (dBZ). b) Differential reflectivity, Z_{DR} (dB). c) The cross correlation coefficient, ρ_{HV} (given as a percentage). d) Specific differential phase, K_{DP} (deg/km).

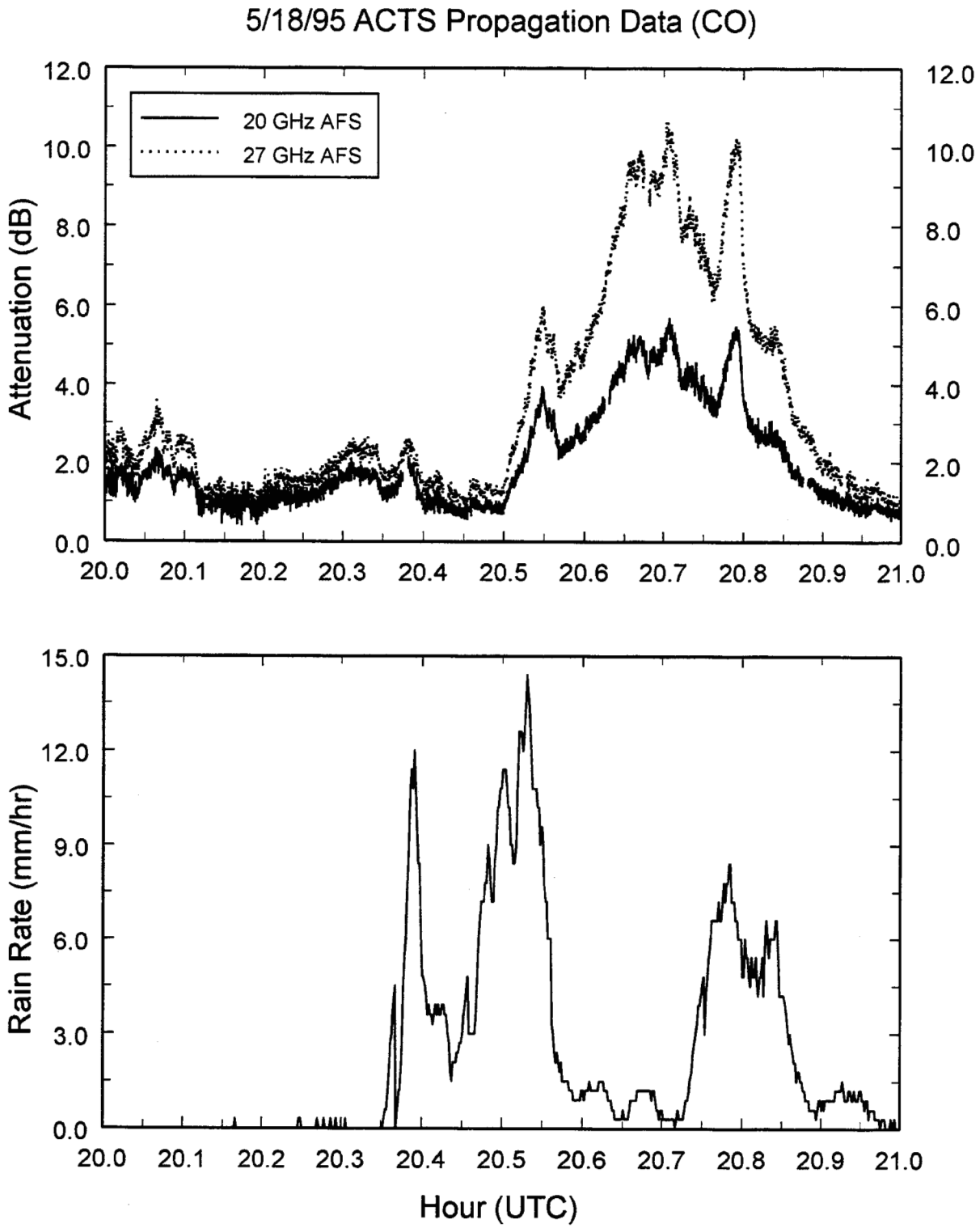
June 20, 1994 Convective Case

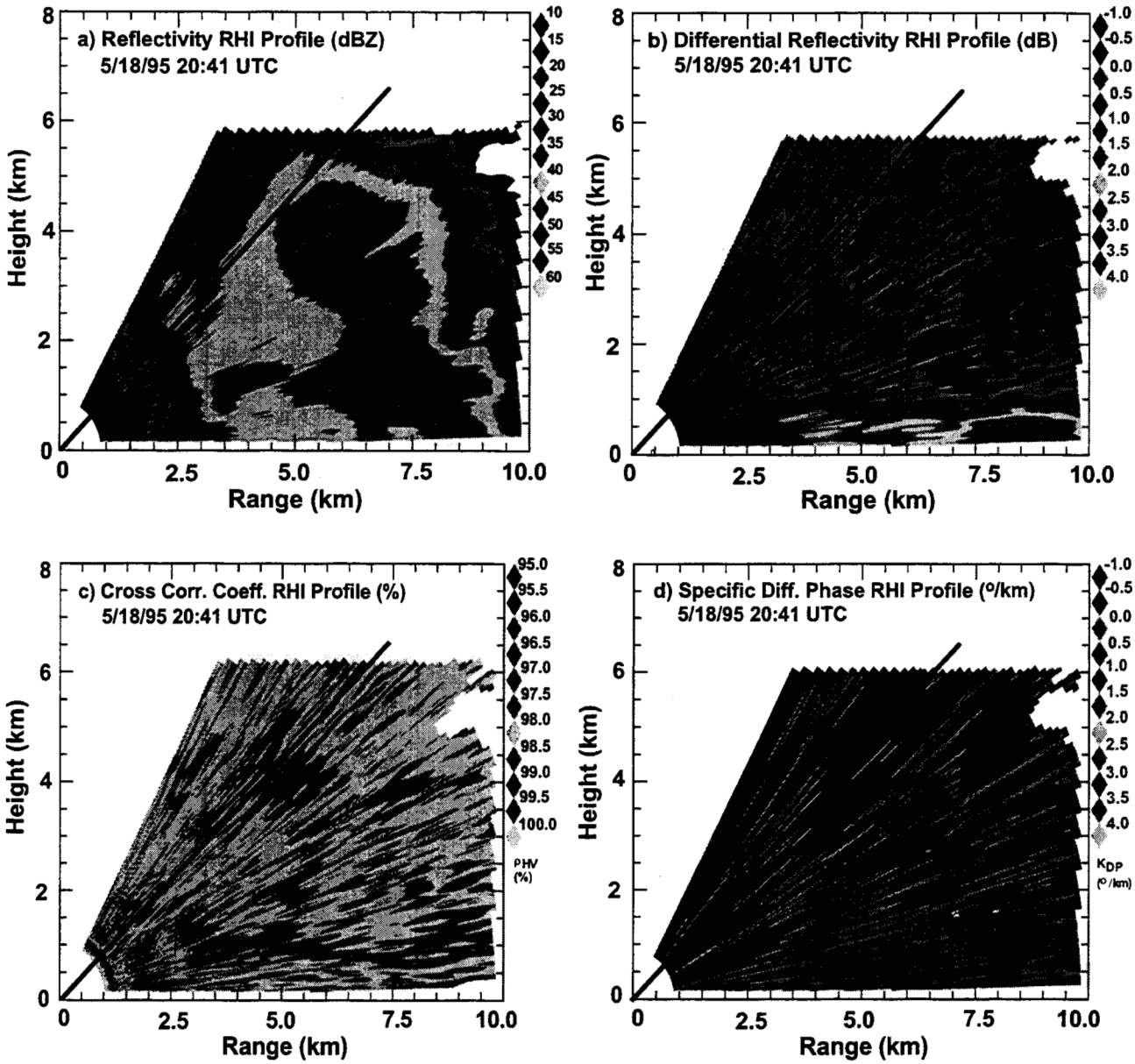





June 20, 1994 Convective Case
20 GHz AFS (dB)
50
45
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
One Way Differential Phase (deg)

ACTS Data - Convective Case

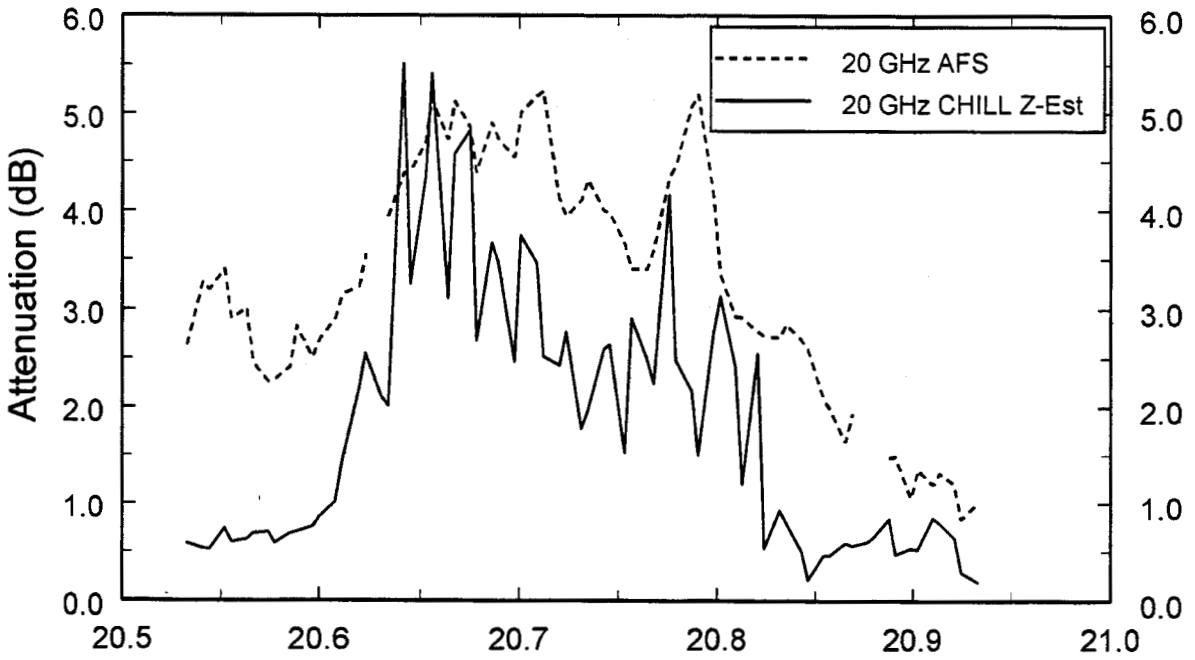


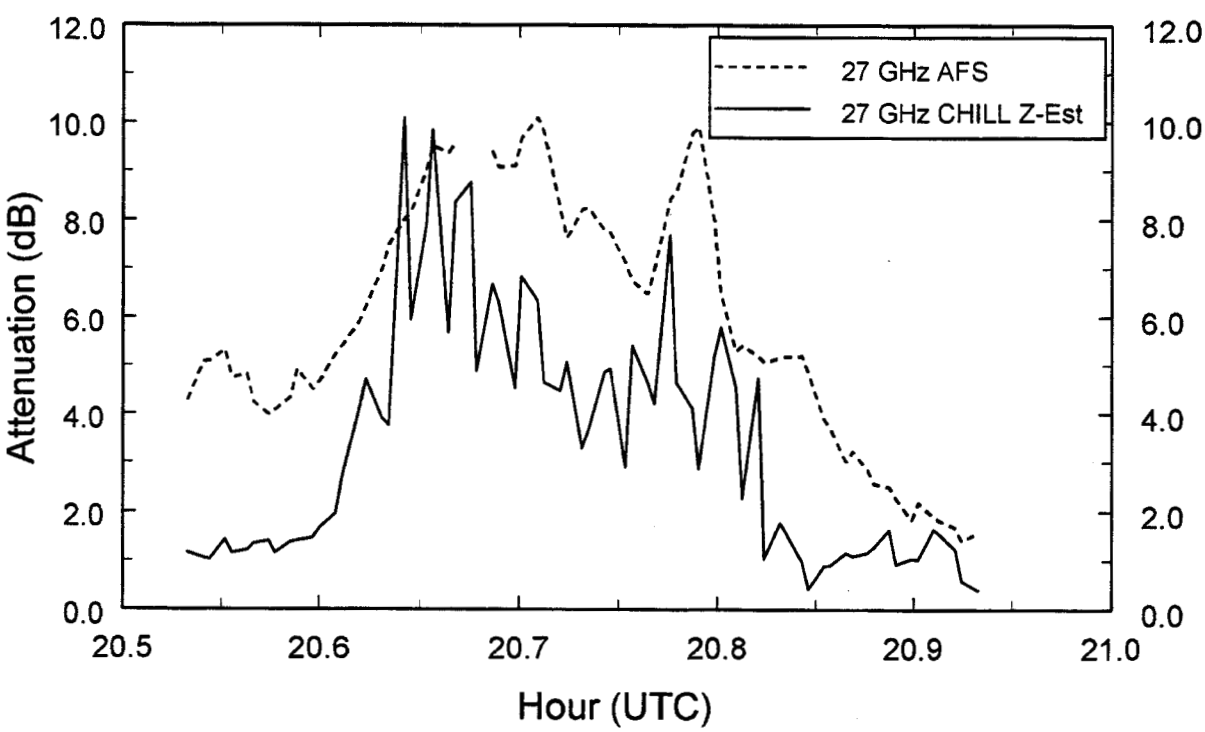


RHI scan for the May 18, 1995 convective case. The scan is taken along the direction of the ACTS propagation path. The CSU–APT elevation angle is 43°. The radar and CSU-APT are located at the origin with the height given in km along the y–axis. Distance away from the radar along the 172° azimuthal angle is given in km along the x–axis. a) Horizontal reflectivity, Z_{HH} (dBZ). b) Differential reflectivity, Z_{DR} (dB). c) The cross correlation coefficient, ρ_{HV} (given as a percentage). d) Specific differential phase, K_{DP} (deg/km).

May 18, 1995 Convective Case

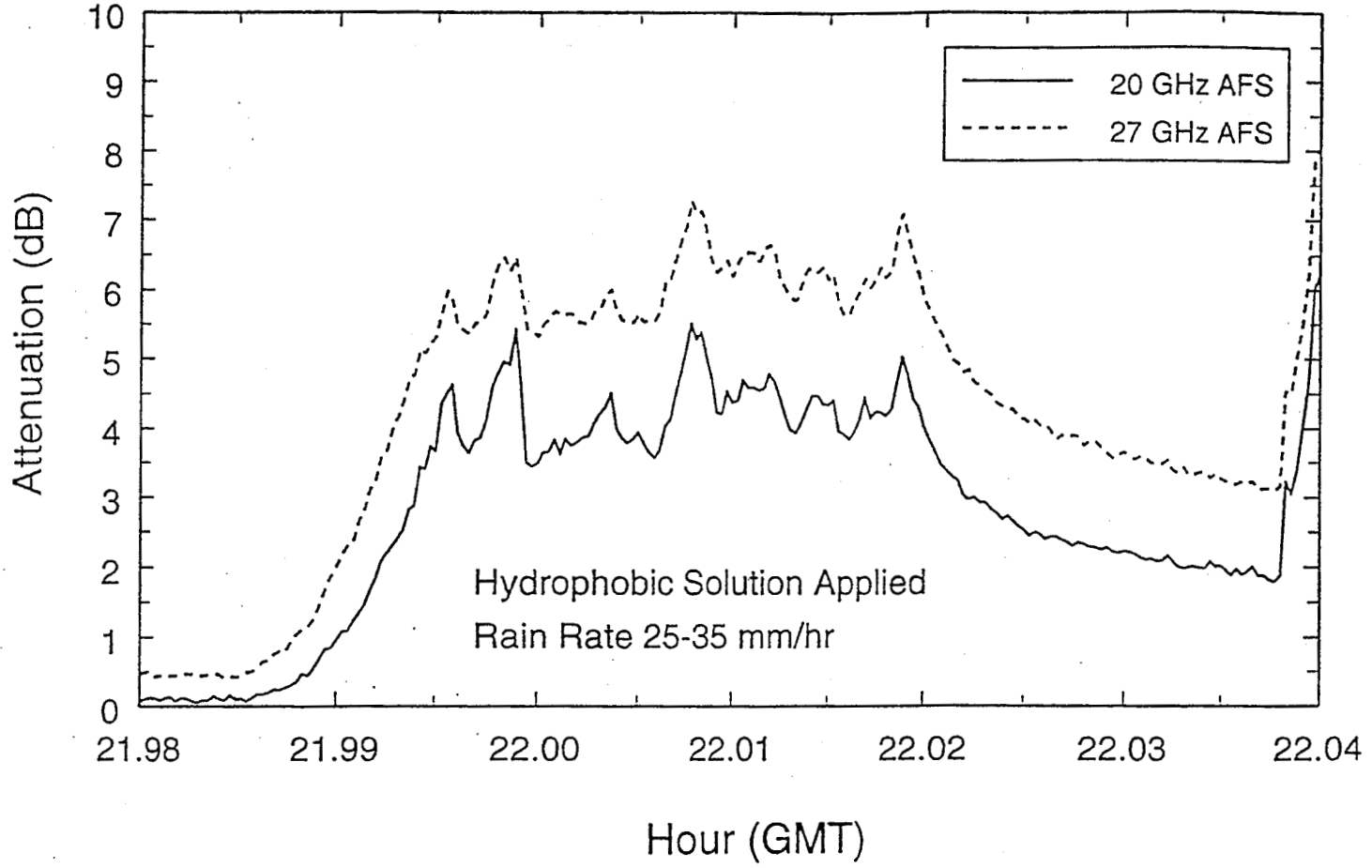
Comparison of CSU-CHILL and CSU-APT Attenuation Estimates



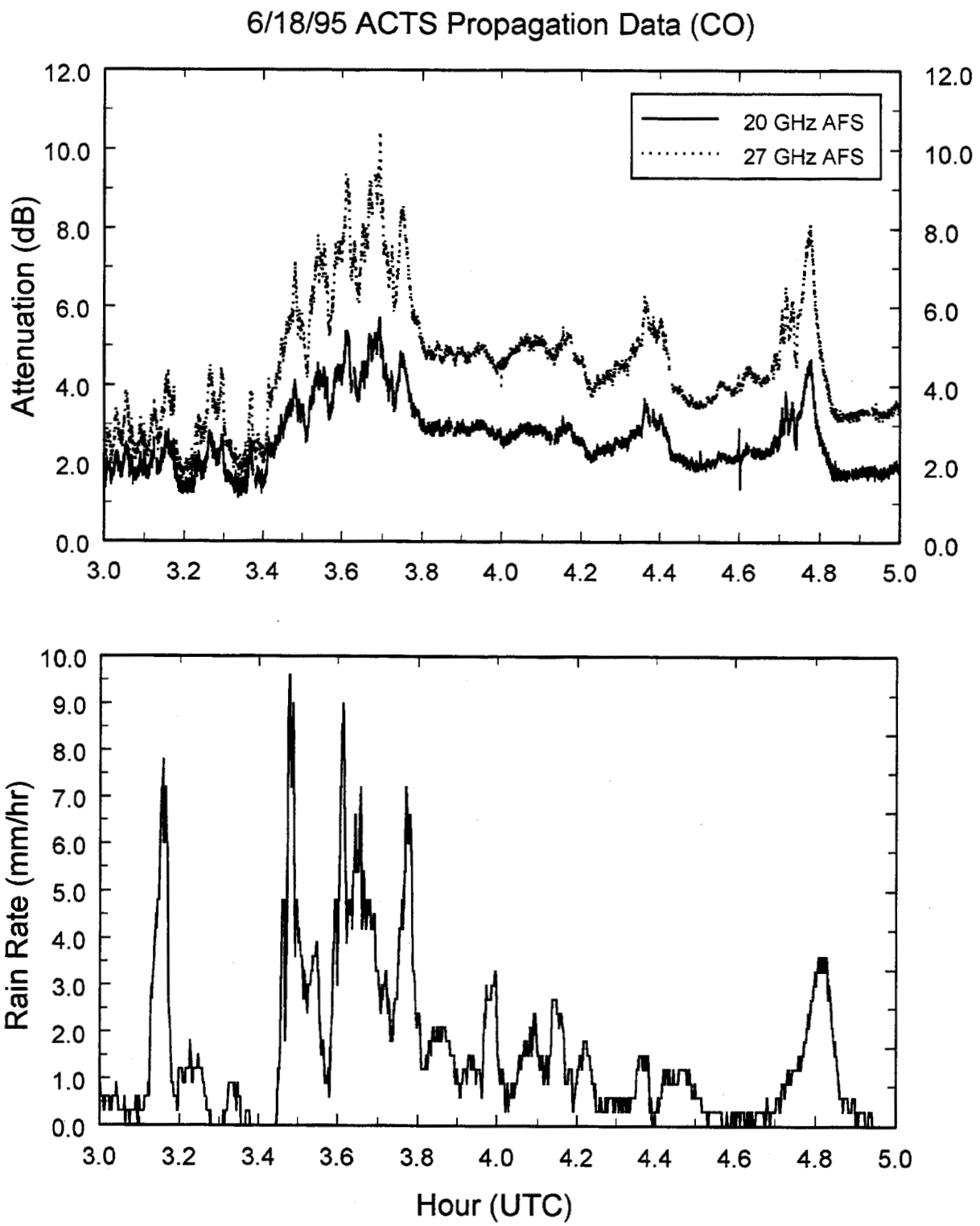


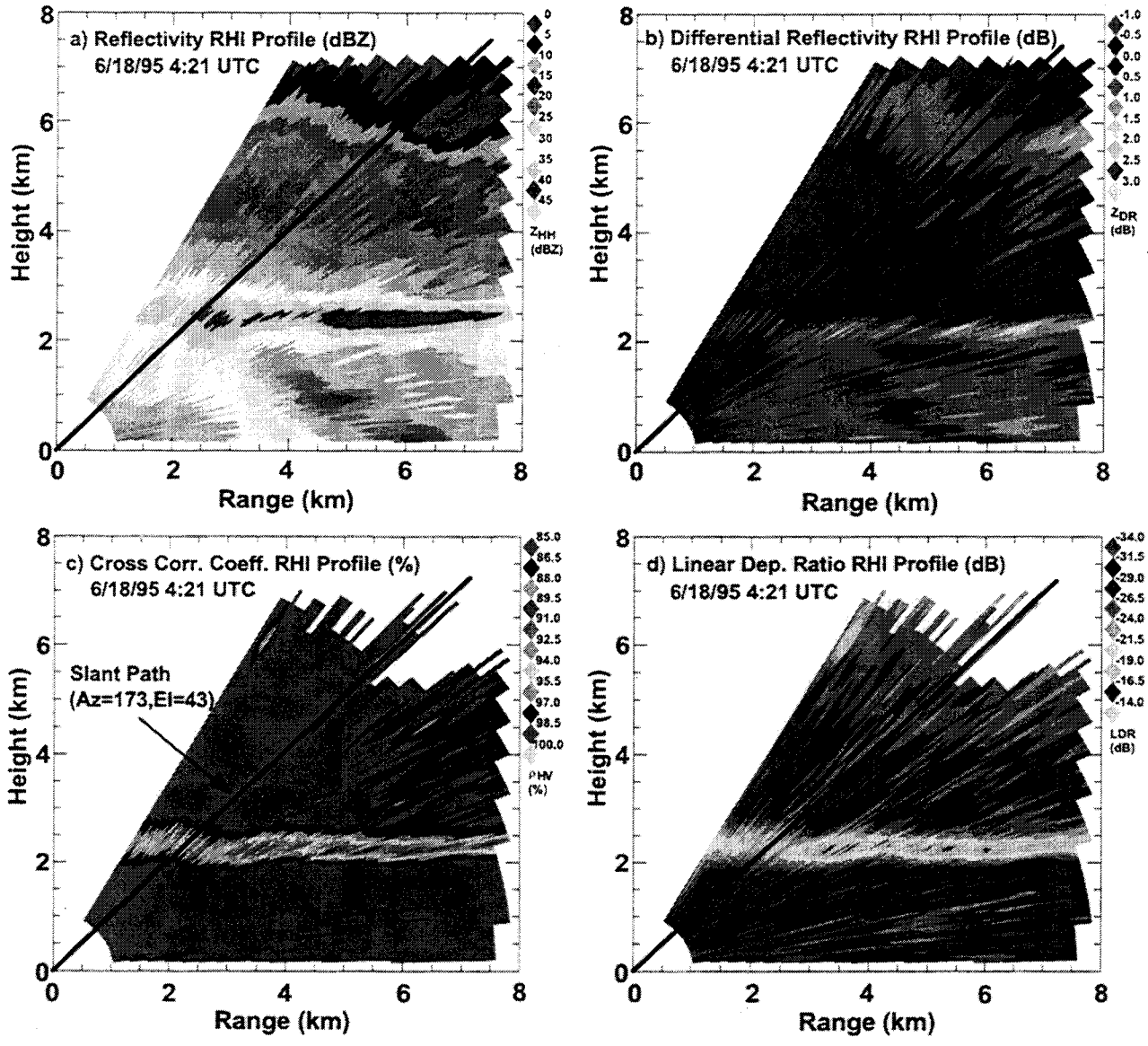
Antenna Wetting Test

Water Sprayed Over Feed and Antenna Surface



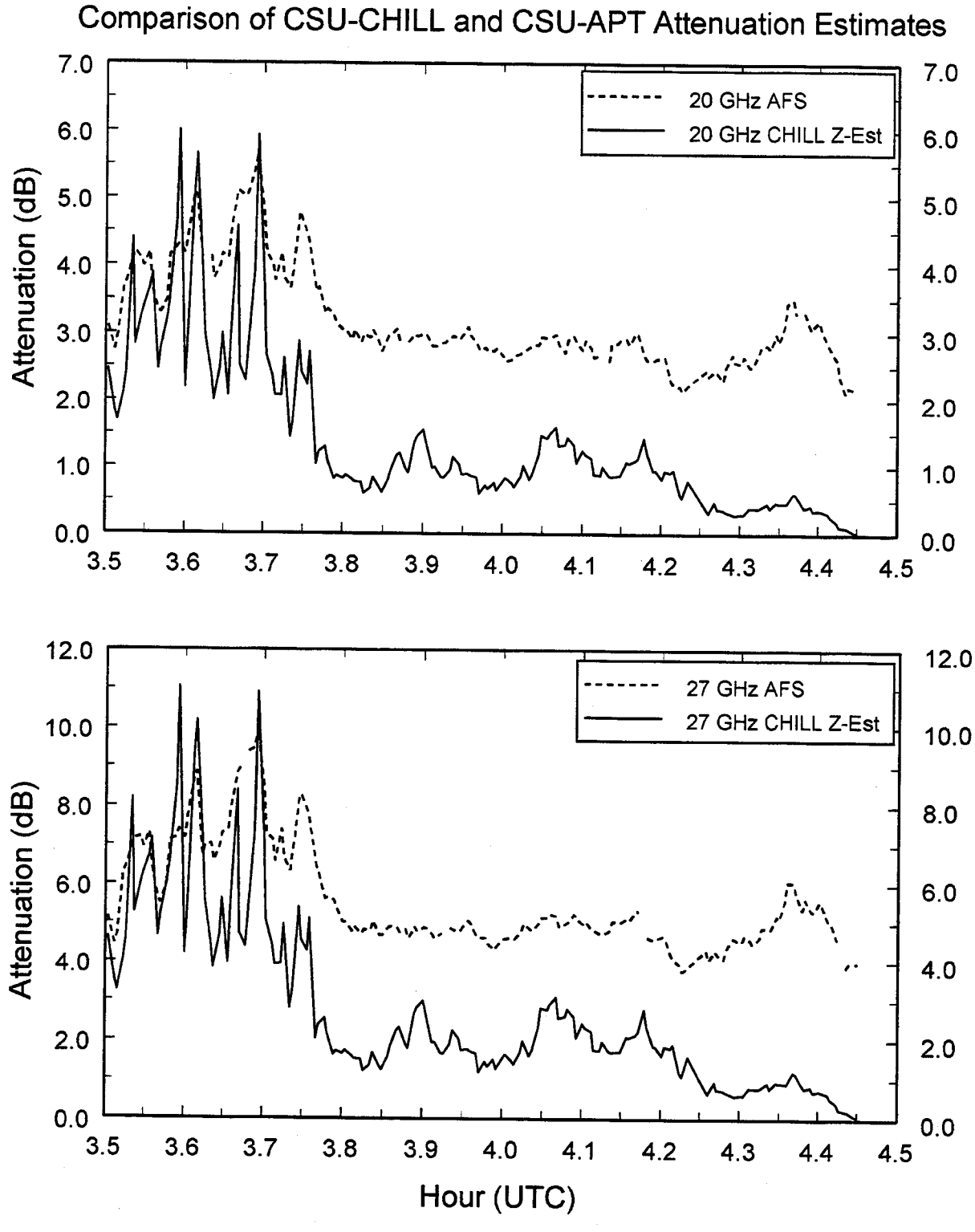
ACTS Data - Stratiform Case





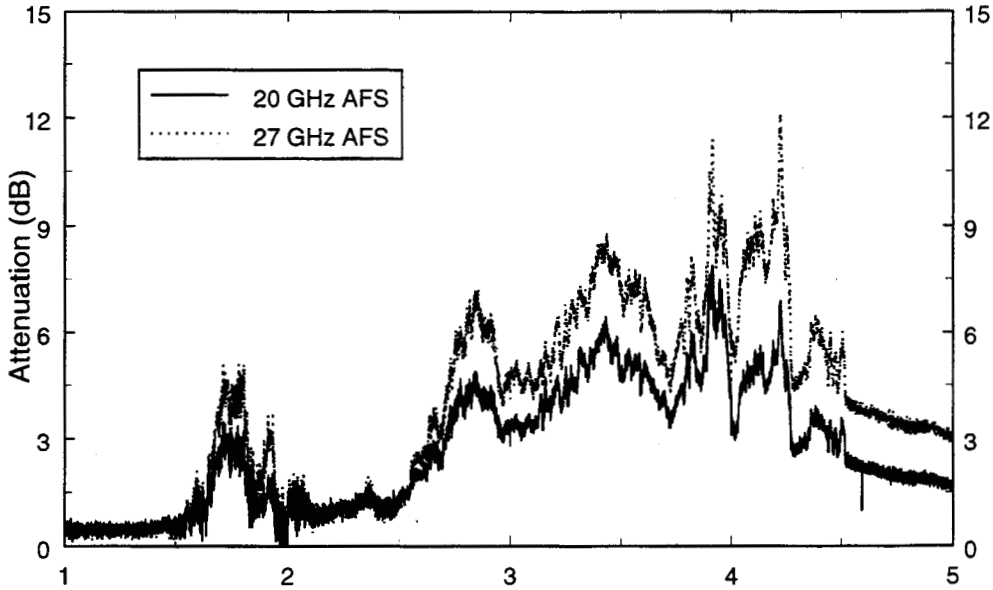
RHI scan for the June 18, 1995 stratiform case. The scan is taken along the direction of the ACTS propagation path. The CSU–APT elevation angle is 43°. The radar and CSU-APT are located at the origin with the height given in km along the y–axis. Distance away from the radar along the 172° azimuthal angle is given in km along the x–axis. a) Horizontal reflectivity, Z_{HH} (dBZ). b) Differential reflectivity, Z_{DR} (dB). c) The cross correlation coefficient, ρ_{HV} (given as a percentage). d) The linear depolarization ratio, LDR (dB).

June 18, 1995 Stratiform Case



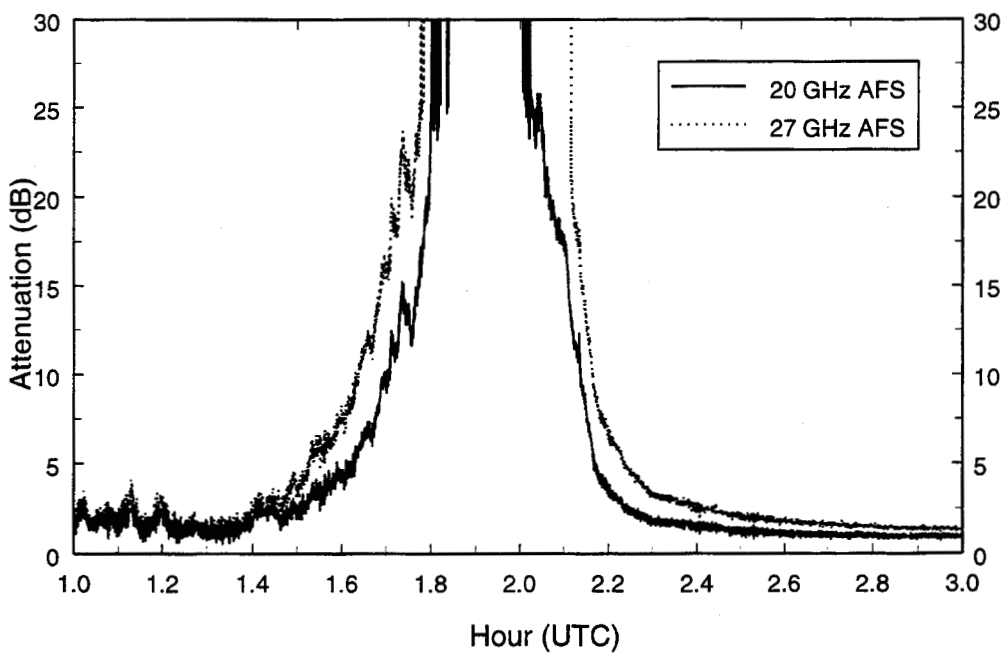
ACTS Data - Stratiform Case

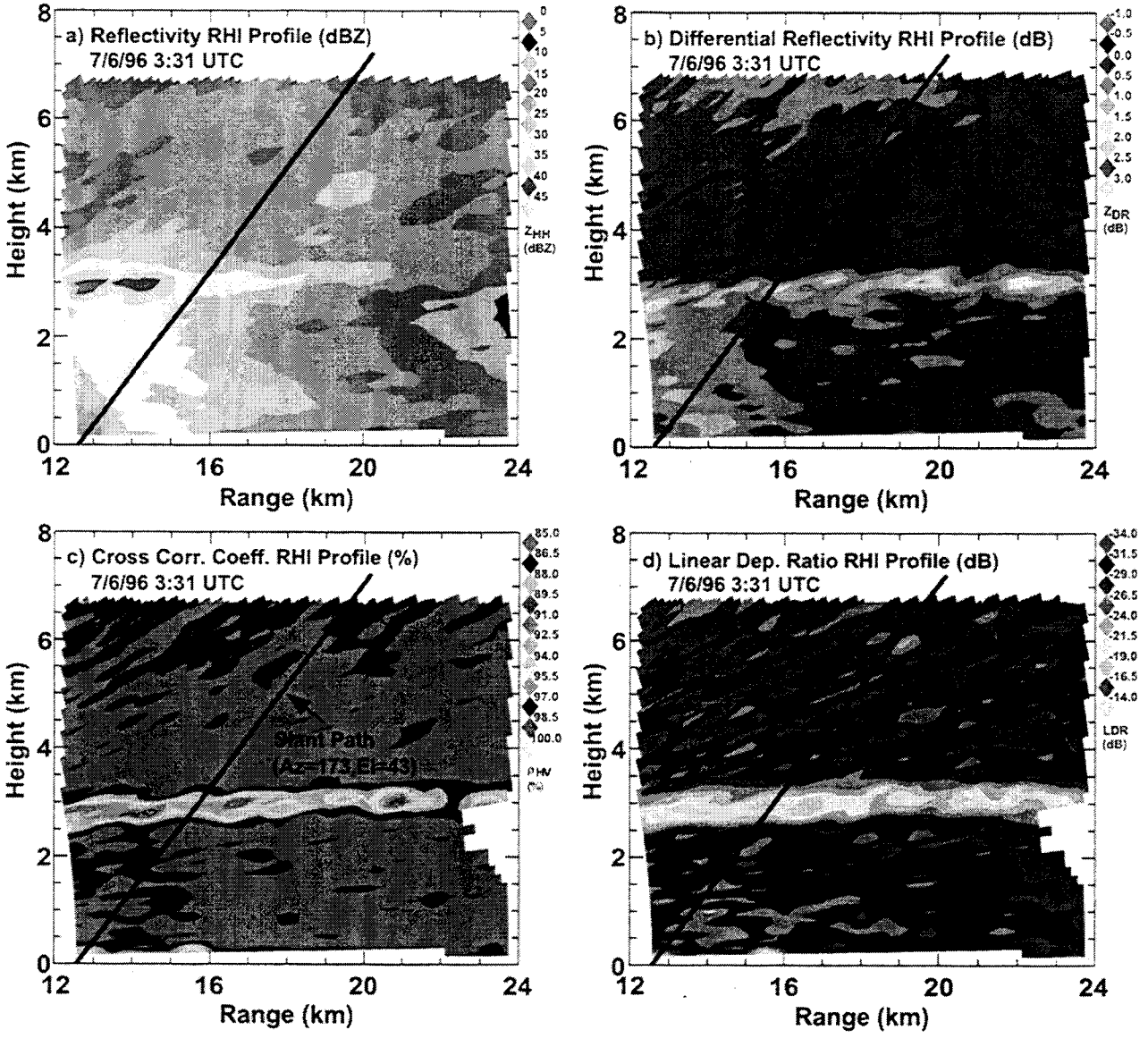
7/6/96 ACTS Propagation Data (CO)



ACTS Data - Convective Case

7/7/96 ACTS Propagation Data (CO)

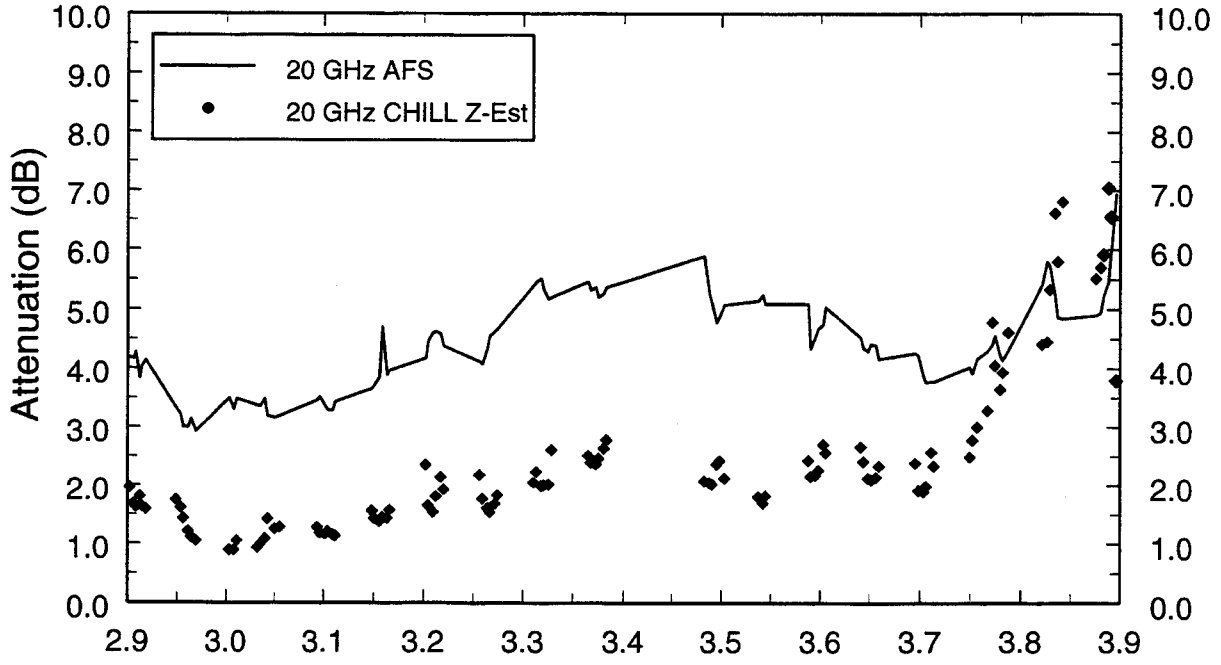


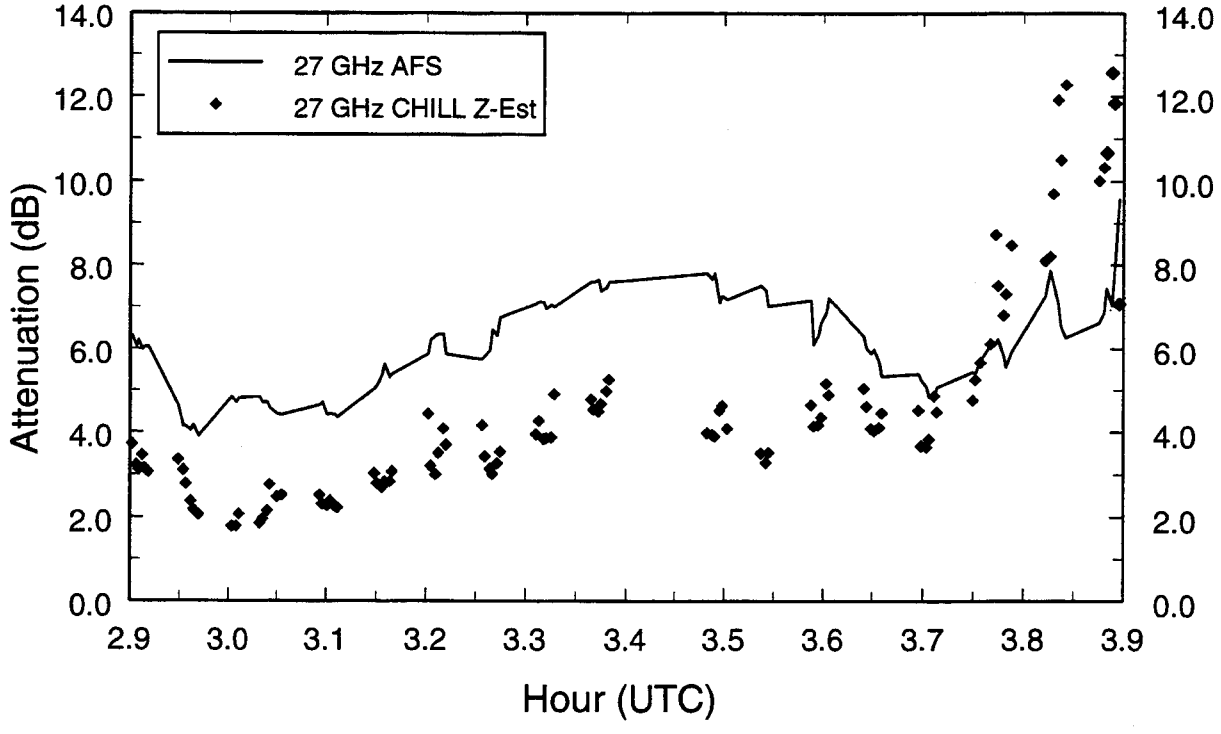


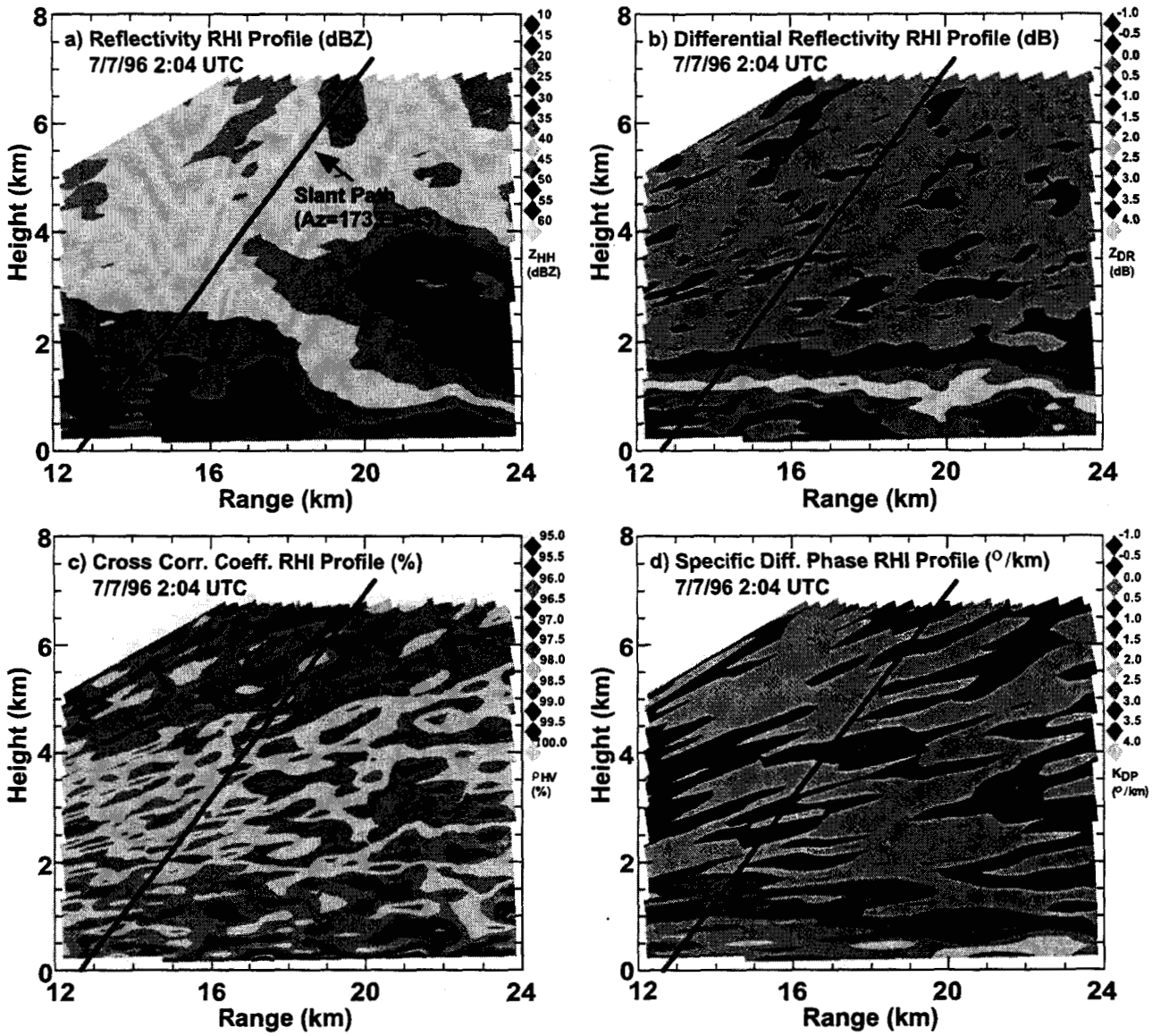
RHI scan for the July 6, 1996 stratiform case. The CSU–APT elevation angle is 43°. The APT is located 13 km south from the radar site. Height in km is along the y–axis. Distance away from the radar is given in km along the x–axis. a) Horizontal reflectivity, Z_{HH} (dBZ). b) Differential reflectivity, Z_{DR} (dB). c) The cross correlation coefficient, ρ_{HV} (given as a percentage). d) The linear depolarization ratio, LDR (dB).

July 6, 1996 Stratiform Case

Comparison of CSU-CHILL and CSU-APT Attenuation Estimates



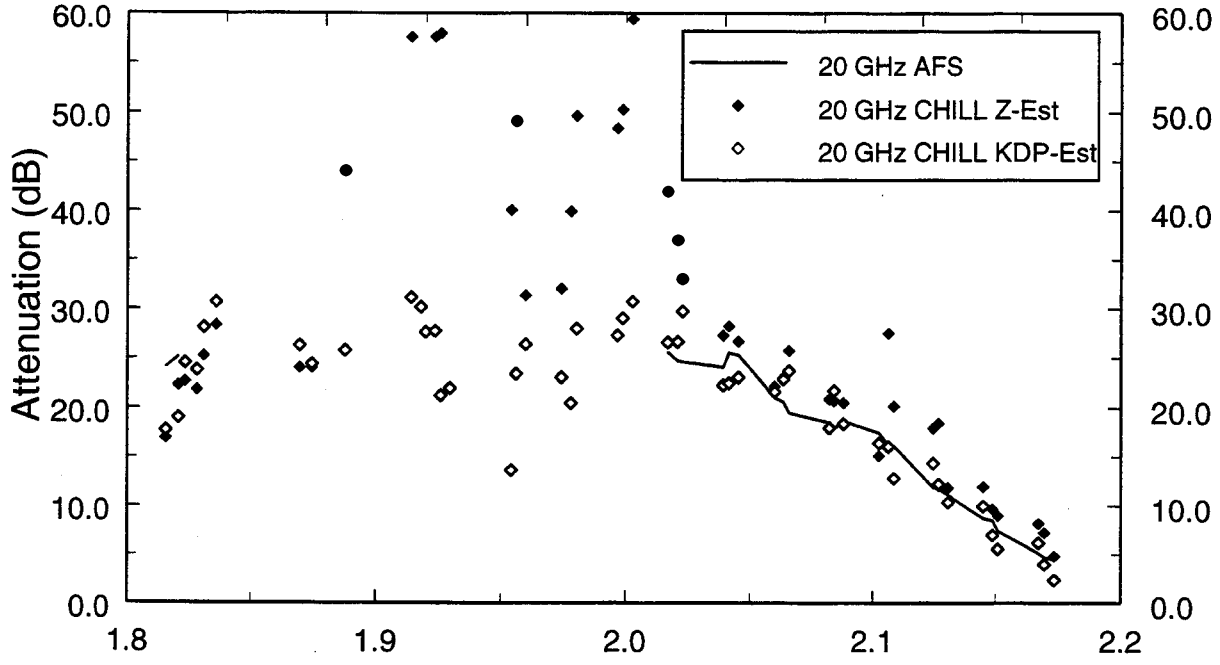


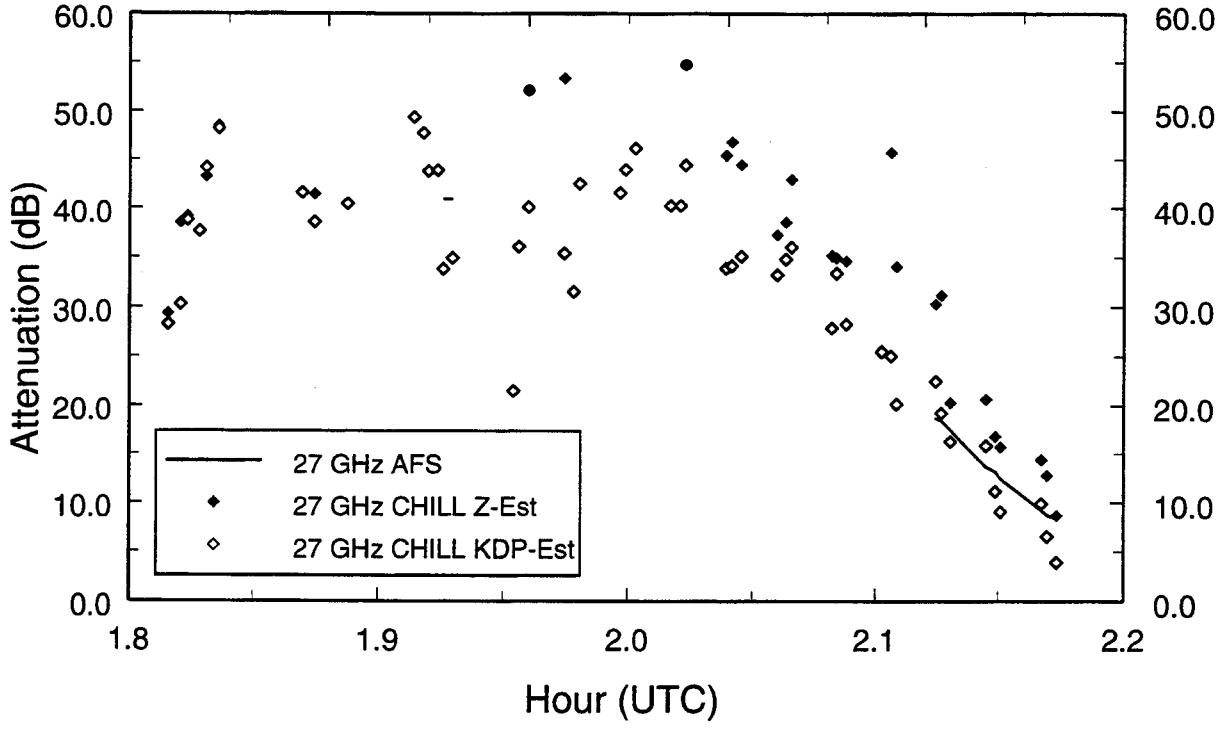


RHI scan for the July 7, 1996 convective case. The CSU–APT elevation angle is 43°. The APT is located 13 km south from the radar site. Height in km is along the y–axis. Distance away from the radar is given in km along the x–axis. a) Horizontal reflectivity, Z_{HH} (dBZ). b) Differential reflectivity, Z_{DR} (dB). c) The cross correlation coefficient, ρ_{HV} (given as a percentage). d) Specific differential phase, K_{DP} (deg/km).

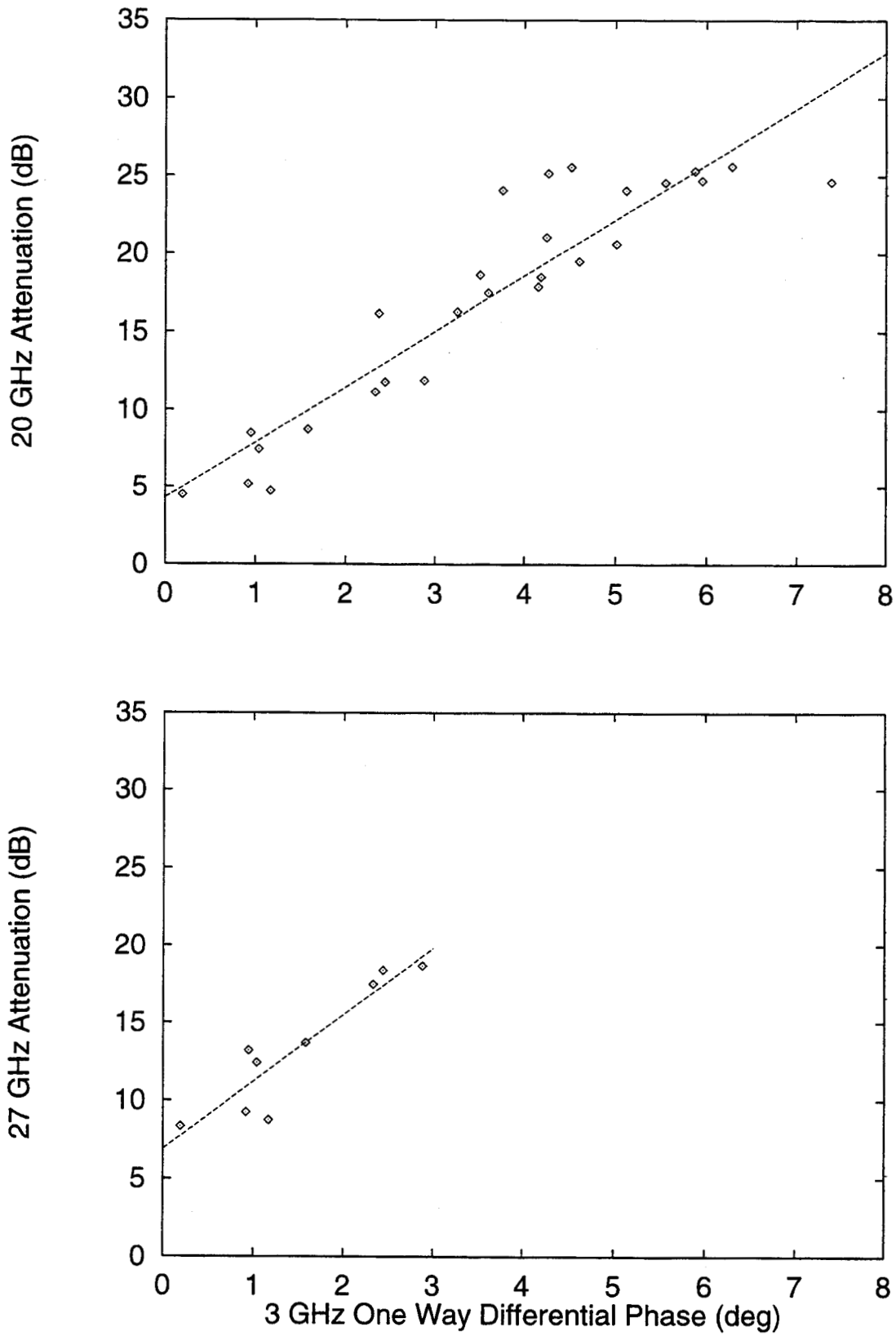
July 7, 1996 Convective Case

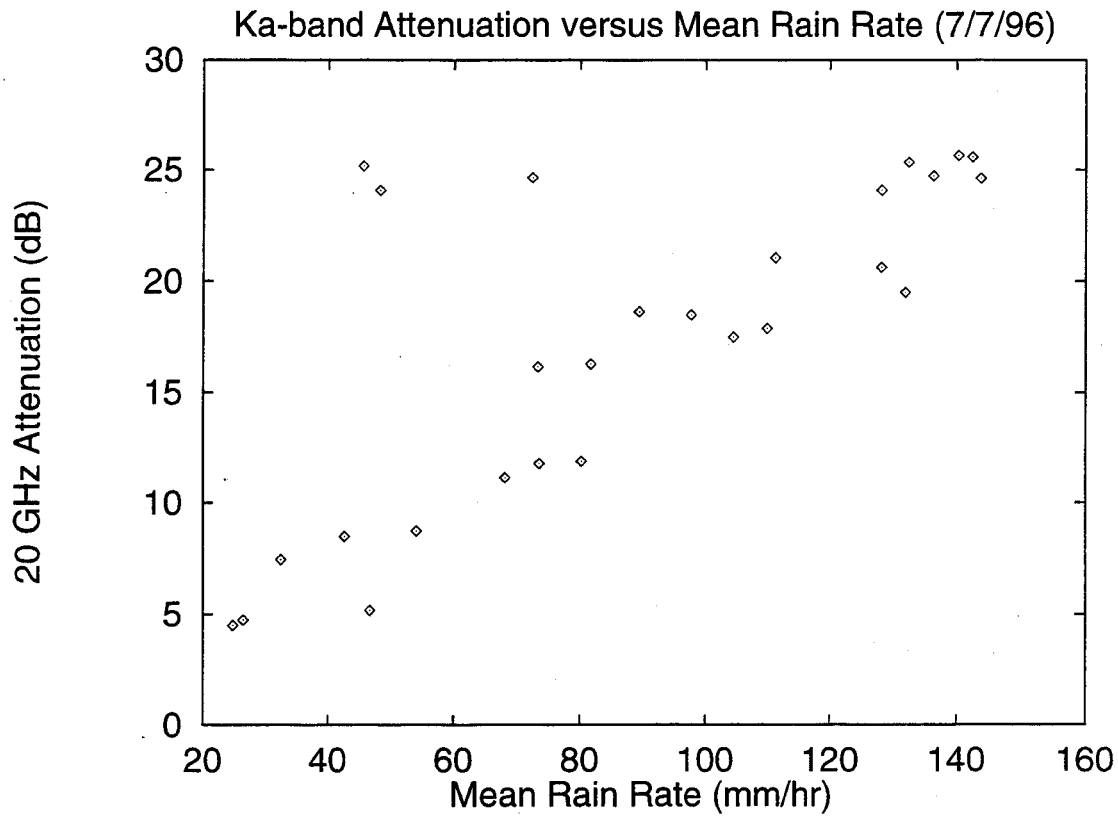
Comparison of CSU-CHILL and CSU-APT Attenuation Estimates

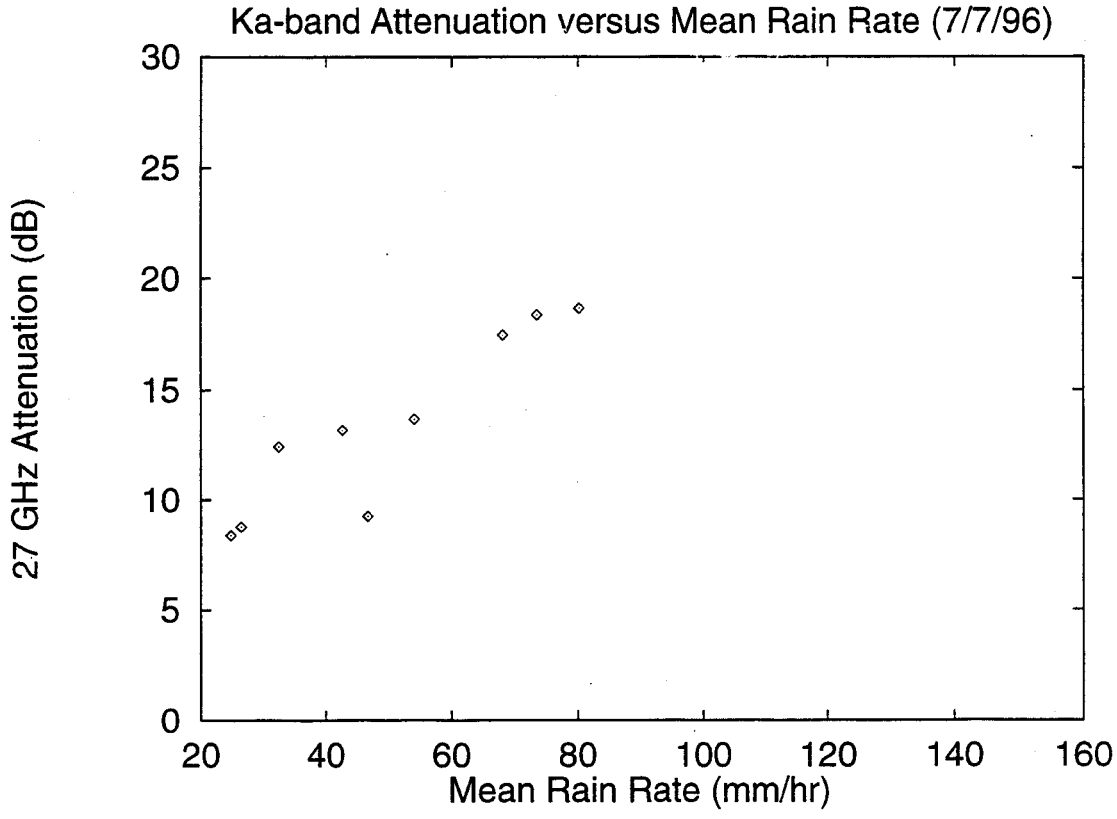


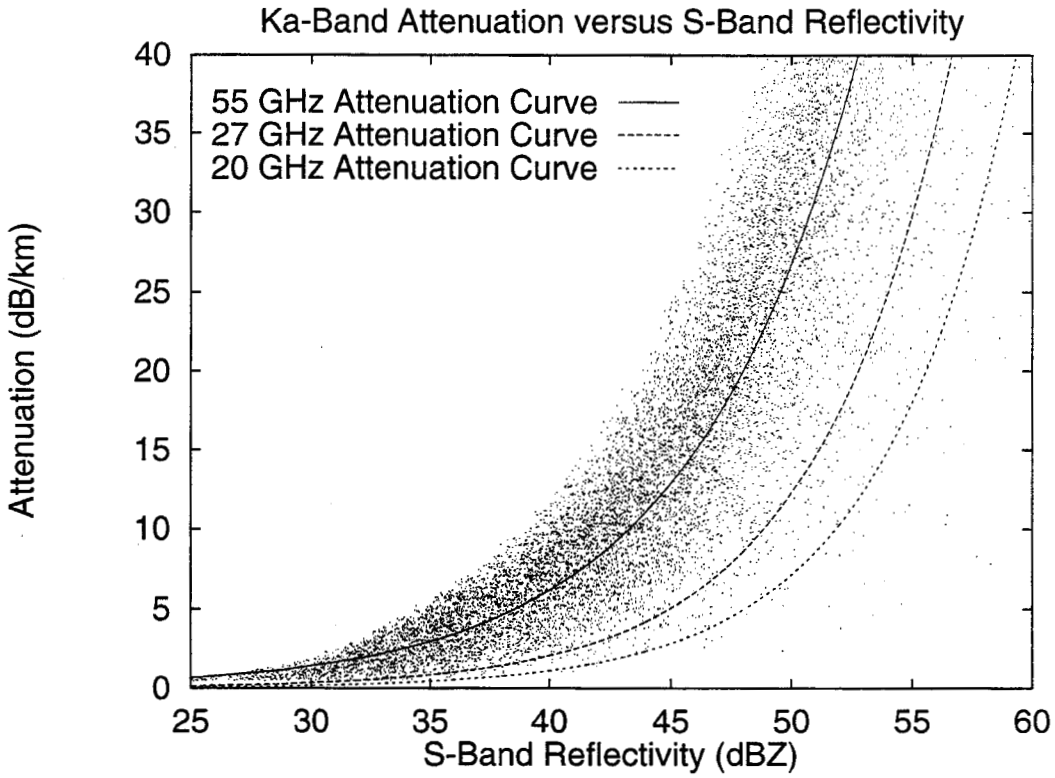


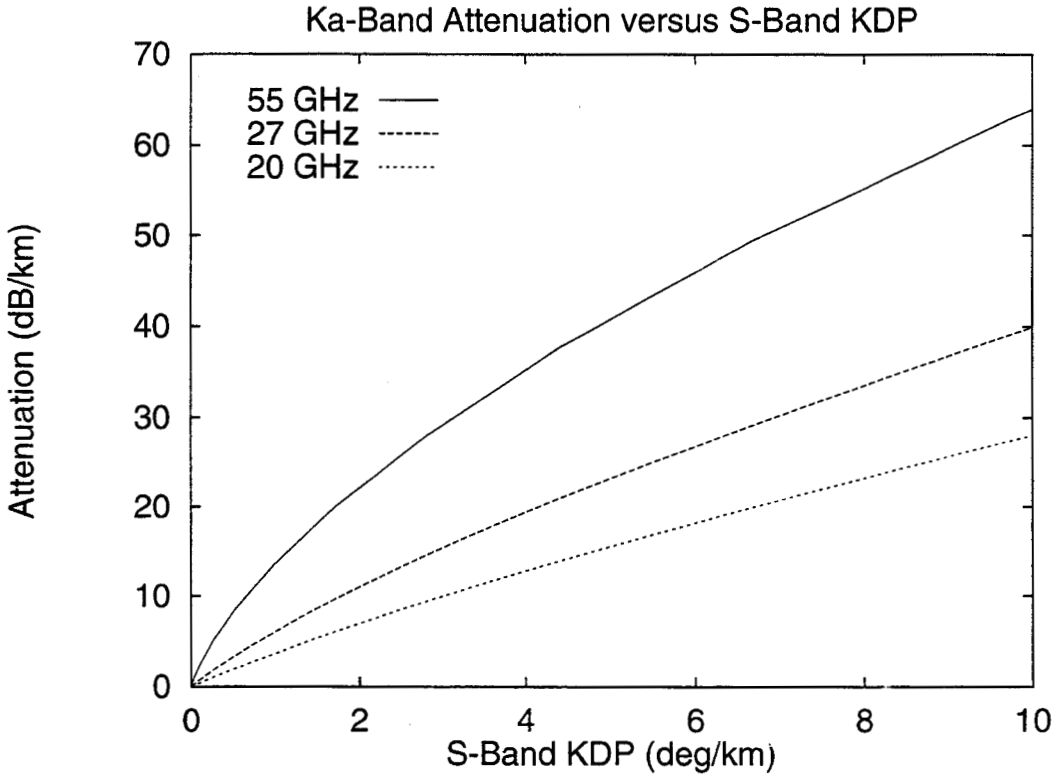
July 7, 1996 One Way Differential Phase




Ka-band Attenuation versus Mean Rain Rate (7/7/96)
20 GHz Attenuation (dB)
Mean Rain Rate (mm/hr)
0
5
10
15
20
25
30
20
40
60
80
100
120
140
160


Ka-band Attenuation versus Mean Rain Rate (7/7/96)
27 GHz Attenuation (dB)
Mean Rain Rate (mm/hr)
0
5
10
15
20
25
30
20
40
60
80
100
120
140
160


Ka-Band Attenuation versus S-Band Reflectivity
55 GHz Attenuation Curve
27 GHz Attenuation Curve
20 GHz Attenuation Curve
Attenuation (dB/km)
S-Band Reflectivity (dBZ)
0
5
10
15
20
25
30
35
40
25
30
35
40
45
50
55
60


Ka-Band Attenuation versus S-Band KDP
55 GHz
27 GHz
20 GHz
Attenuation (dB/km)
S-Band KDP (deg/km)
0
10
20
30
40
50
60
70
0
2
4
6
8
10

Conclusions

- Completed five years of data collection
  - Processed and calibrated all five years
  - Completed statistical analysis of data
  - Compared results with existing models

- Developed a radar-base prediction model
  - Relates Ka-band attenuation to S-band polarimetric radar parameters
  - Completed several case studies for different types of events with excellent results
  - Model can be potentially extended to other frequency bands

- Future Studies
  - Extension of prediction model to V-band (maybe even W-band)
  - Study 0°-isotherm level variation using radar data, and the corresponding impact on LEO systems
  - Potential use of S-band radar/profiler data for optical communications