FIVE YEARS OF ACTS PROPAGATION STUDIES IN ALASKA

NAPEX-XXIII
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OUTLINE

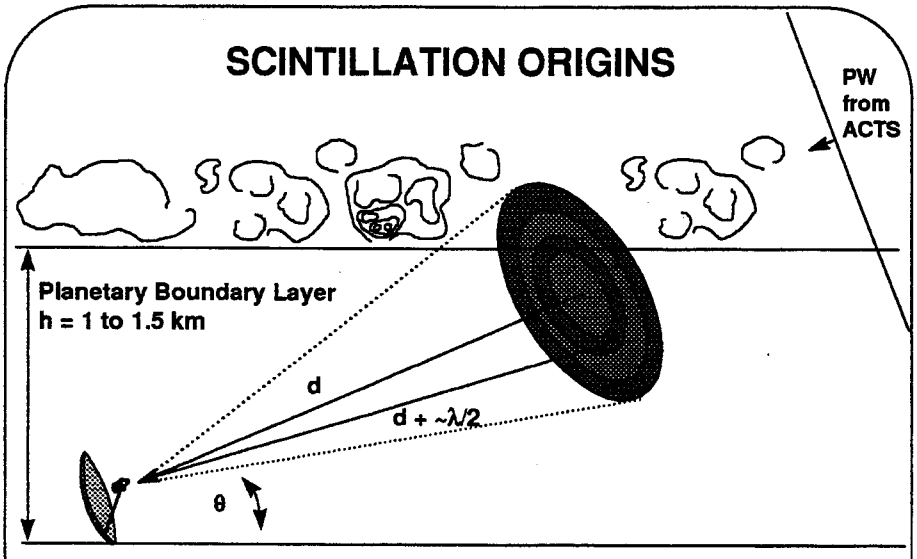
MAYER
- EXPERIMENT OVERVIEW
- YEARLY STATISTICS
- SCINTILLATION STUDIES

JAEGER
- ANALYSIS AND MODELING OF:
  - ATTENUATION
  - FADE SLOPE
  - FADE DURATION
  - ATTENUATION SCALING
  - MEDIUM AND SKY TEMPERATURE

ACTS - UAF LINK BUDGET		
Frequency (GHz)	20.2	27.5
Peak EIRP (dBW)	19.8	17.9
Alaska footprint loss (dB)	-10.3	-7.7
Modulation loss (dB)	-3.2	
Path loss (dB)	-210.7	-213.4
Other losses (dB)	-1.5	-1.7
1.2-m antenna gain (dB)	46.4	49.0
System temp. (NF = 7 dB in dB-K)	-31.3	-31.3
Boltzmann's const. (dBW/K-Hz)	228.6	228.6
C/N_o (dB-Hz)	37.8	41.4
Bandwidth (20 Hz in dB-Hz)	-13.0	-13.0
C/N (dB)	**24.8**	**28.4**

Alaska ACTS Propagation

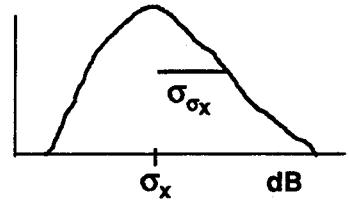
SCINTILLATION ORIGINS



Alaska ACTS Propagation

SCINTILLATION INTRODUCTION

- SCINTILLATION IS A ZERO-MEAN PROCESS
- MAGNITUDE OF SIGNAL FLUCTUATIONS (X in dB) IS REPRESENTED BY THE RMS OR STD. DEV. (since mean = 0) IN SOME TIME PERIOD (1, 2, 10, 60 MINUTES)
- RESULT IS A DISTRIBUTION OF THESE STANDARD DEVIATIONS WITH:
  - A MEAN OF σ_x IN dB
  - A STD. DEV. OF σ_{σ_x}



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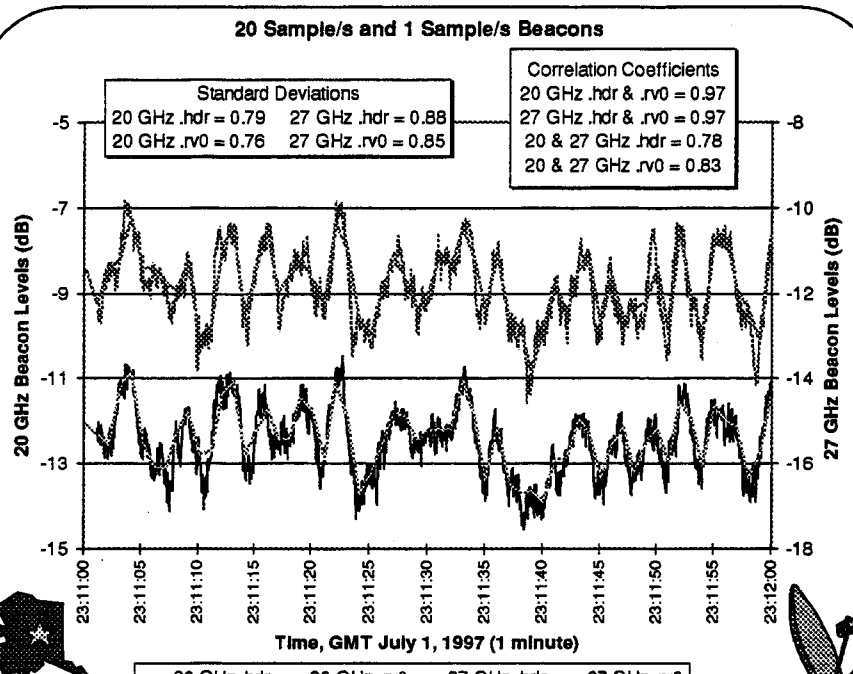
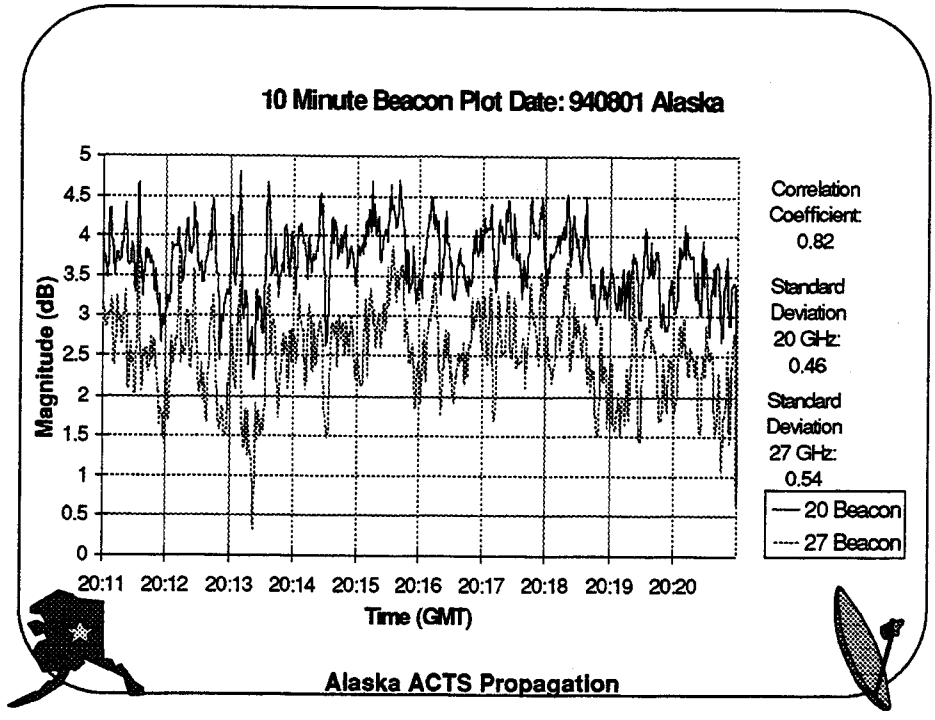
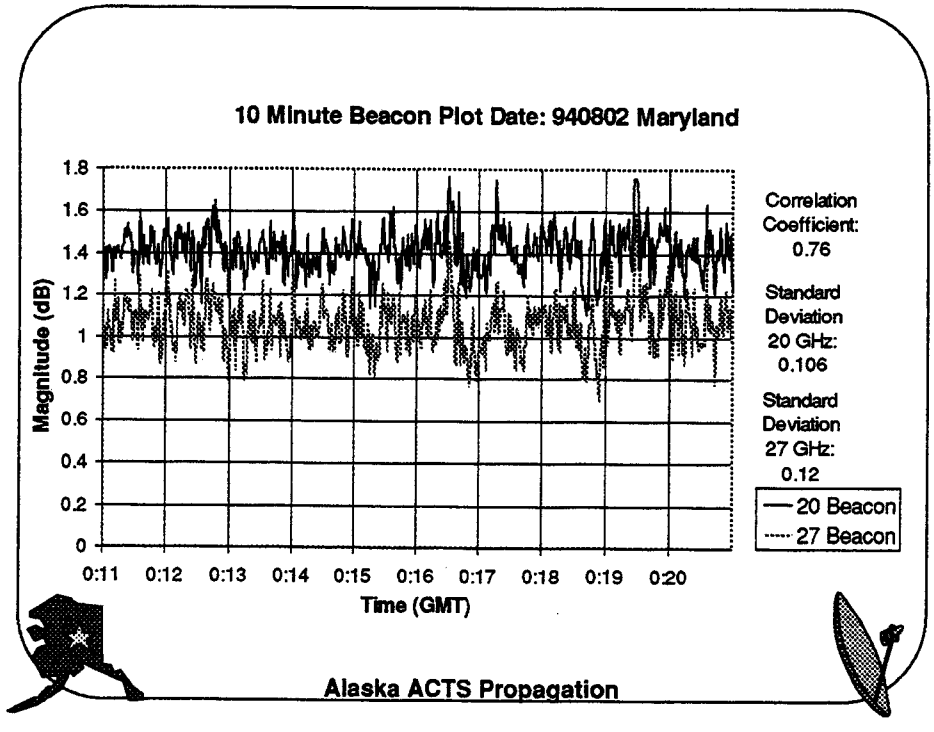
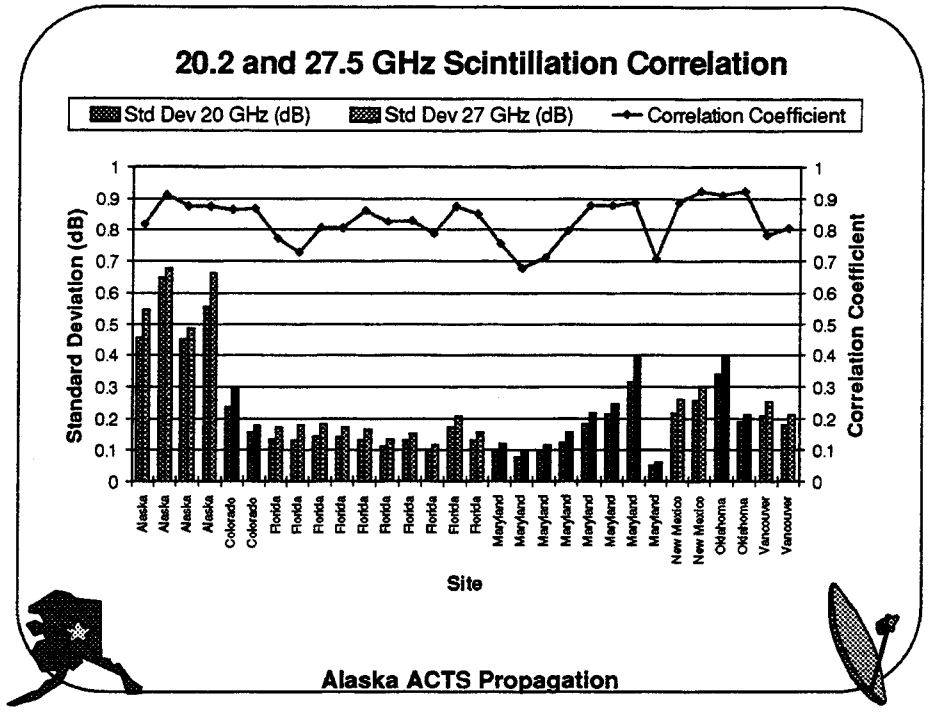
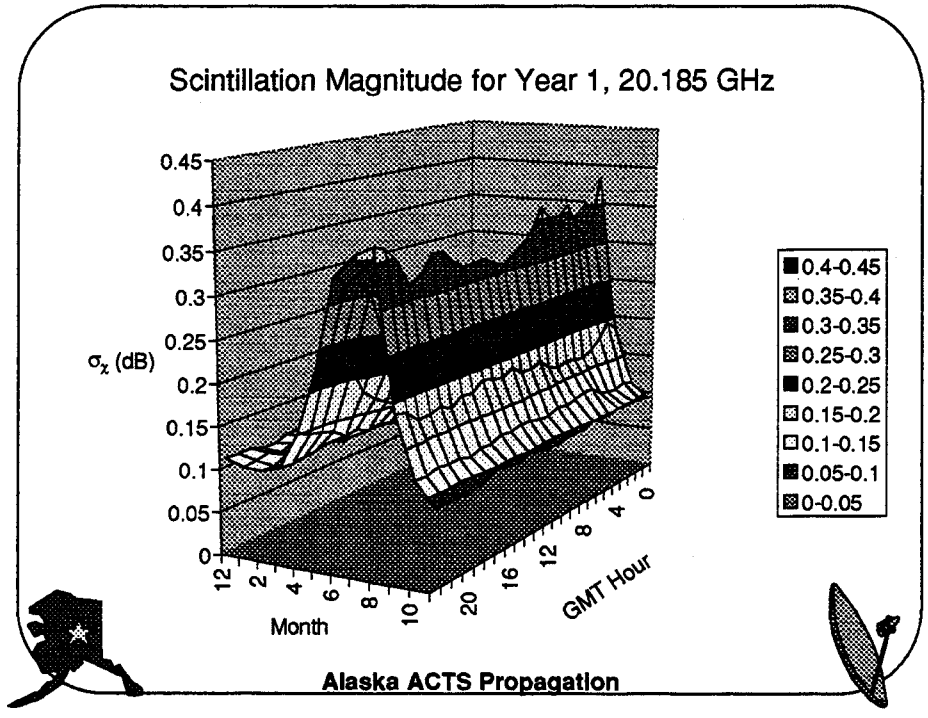
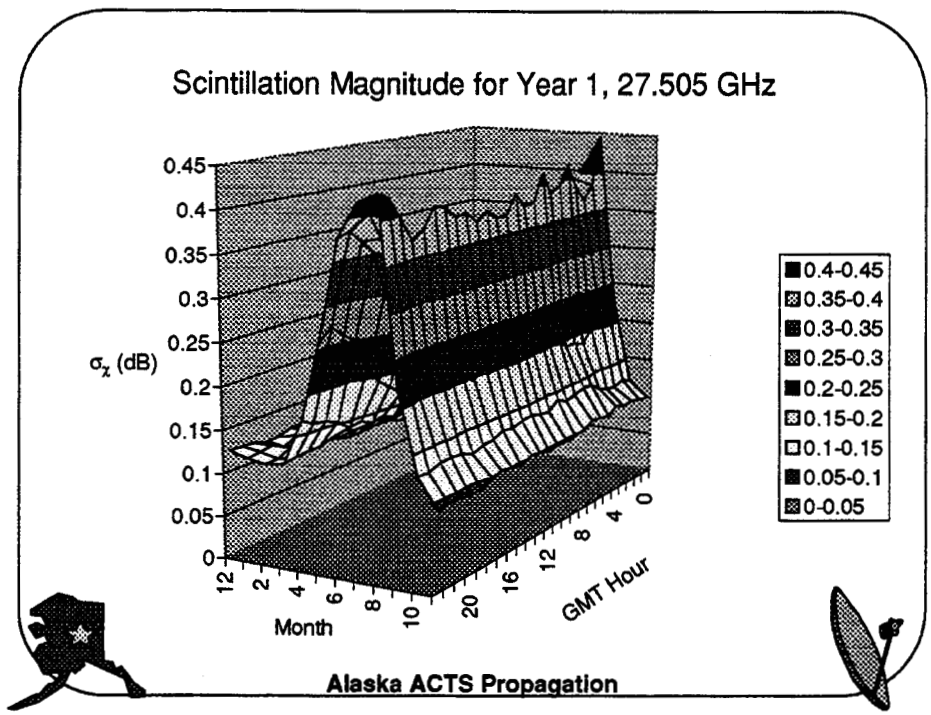


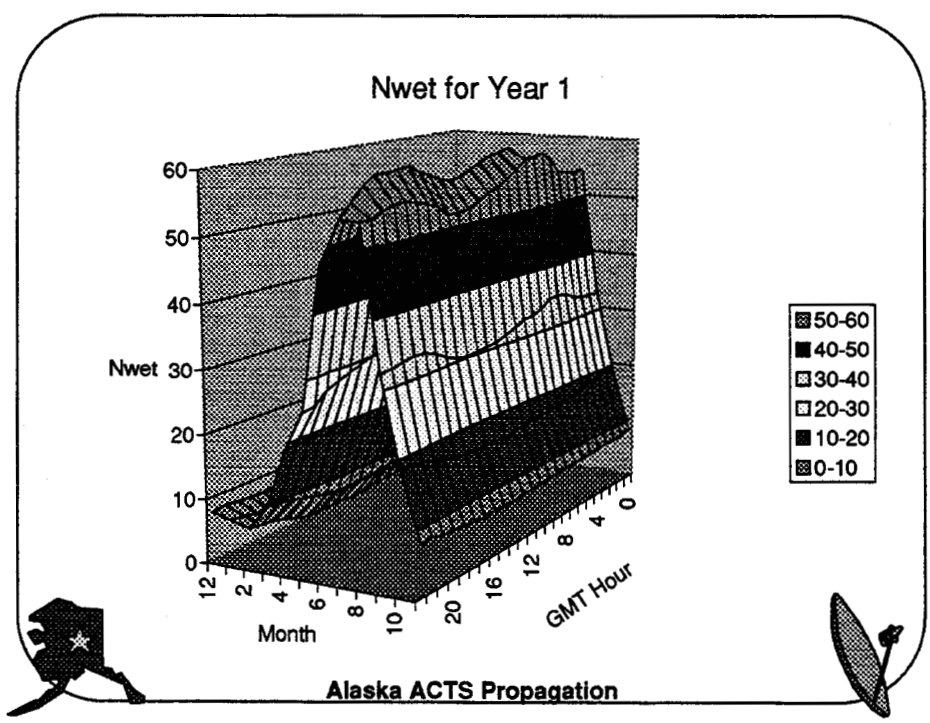

10 Minute Beacon Plot Date: 940801 Alaska
Magnitude (dB)
5
4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
20:11 20:12 20:13 20:14 20:15 20:16 20:17 20:18 20:19 20:20
Time (GMT)
Correlation Coefficient: 0.82
Standard Deviation 20 GHz: 0.46
Standard Deviation 27 GHz: 0.54
20 Beacon
27 Beacon
Alaska ACTS Propagation


10 Minute Beacon Plot Date: 940802 Maryland
Magnitude (dB)
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
0:11 0:12 0:13 0:14 0:15 0:16 0:17 0:18 0:19 0:20
Time (GMT)
Correlation Coefficient: 0.76
Standard Deviation 20 GHz: 0.106
Standard Deviation 27 GHz: 0.12
20 Beacon
27 Beacon
Alaska ACTS Propagation

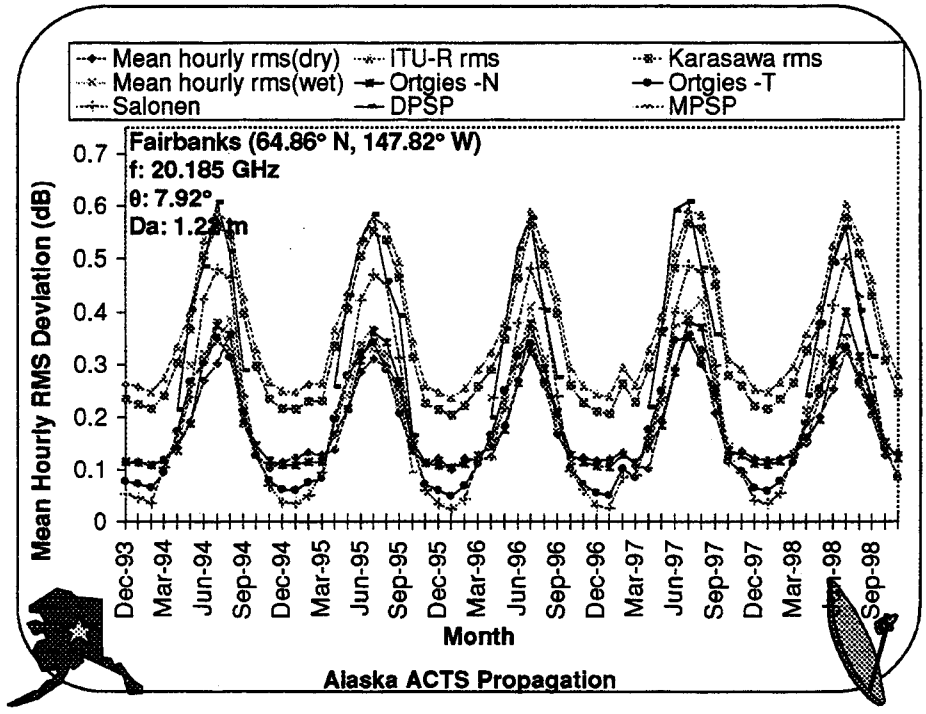

20.2 and 27.5 GHz Scintillation Correlation
Std Dev 20 GHz (dB)
Std Dev 27 GHz (dB)
Correlation Coefficient
Standard Deviation (dB)
Correlation Coefficient
Site
Alaska ACTS Propagation

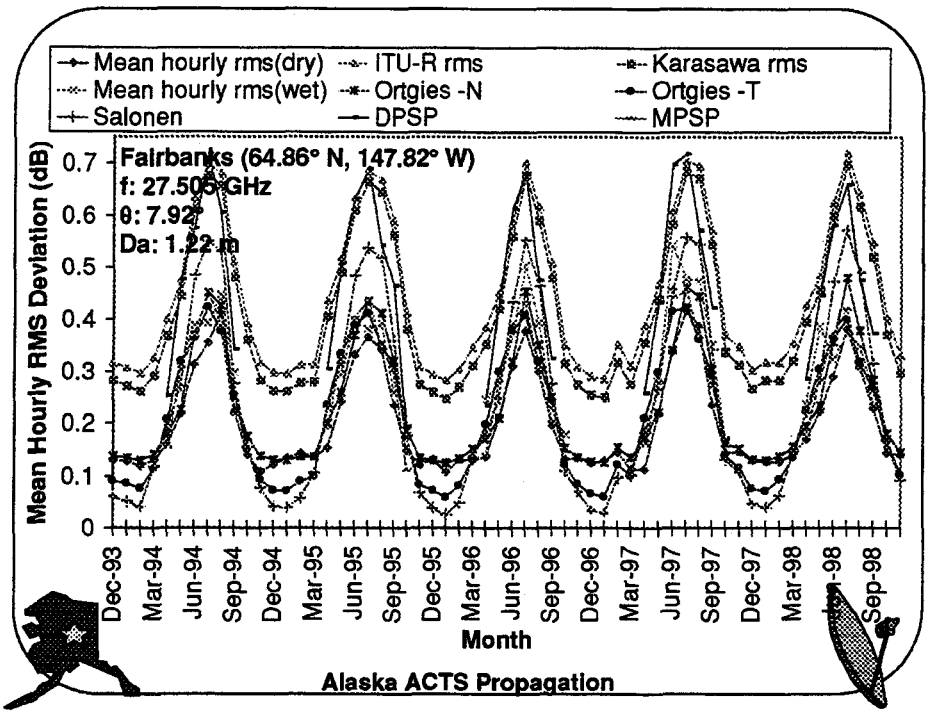

Scintillation Magnitude for Year 1, 20.185 GHz
σχ (dB)
Month
GMT Hour
0.4-0.45
0.35-0.4
0.3-0.35
0.25-0.3
0.2-0.25
0.15-0.2
0.1-0.15
0.05-0.1
0-0.05
Alaska ACTS Propagation

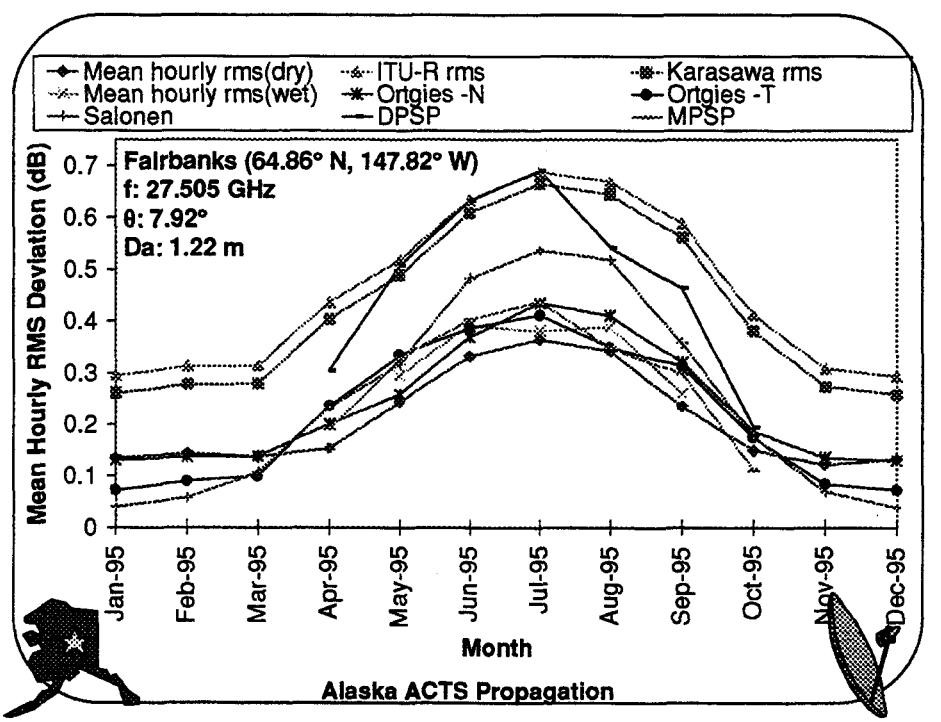

Scintillation Magnitude for Year 1, 27.505 GHz
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
σχ (dB)
12
2
4
6
8
10
Month
20
16
12
8
4
0
GMT Hour
0.4-0.45
0.35-0.4
0.3-0.35
0.25-0.3
0.2-0.25
0.15-0.2
0.1-0.15
0.05-0.1
0-0.05
Alaska ACTS Propagation

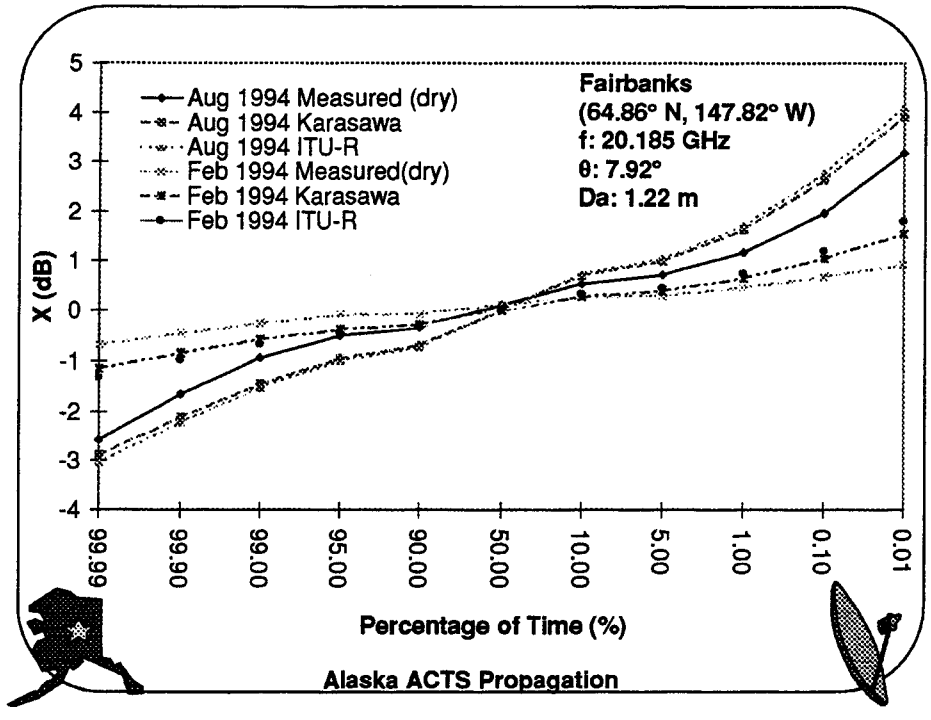

Nwet for Year 1
60
50
40
Nwet 30
20
10
0
12
2
4
6
8
10
Month
20
16
12
8
4
0
GMT Hour
50-60
40-50
30-40
20-30
10-20
0-10
Alaska ACTS Propagation

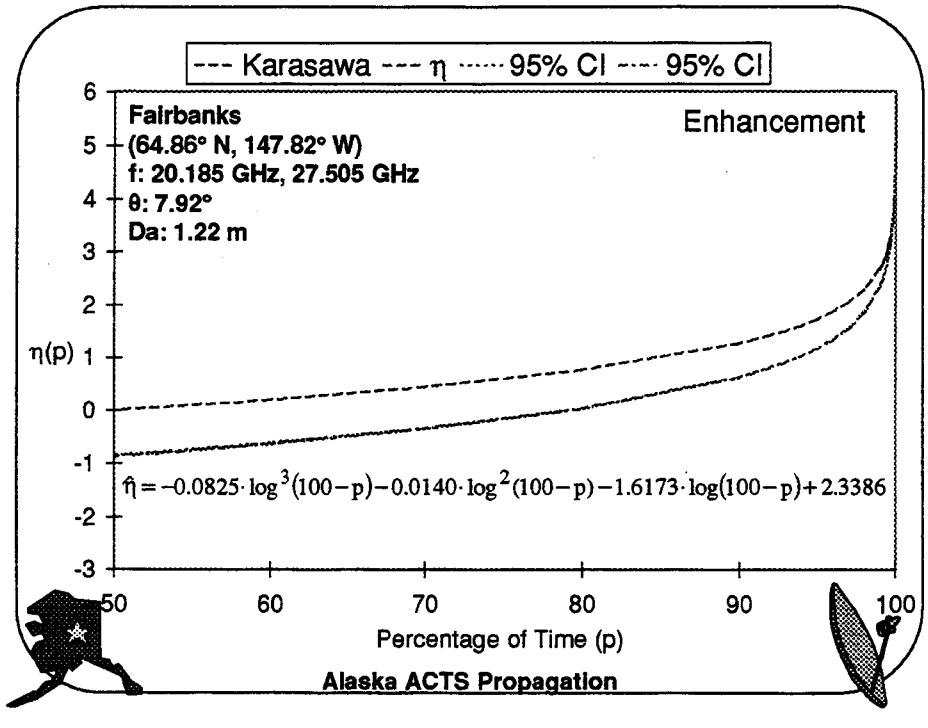
Scintillation Model	Year	freq. dep.	sin θ dep.	Par.	H (m)	Data source (f, θ), Zone	Regression	Model Restrictions	Fade/ Enhan.
Karasawa, Yamada, Allnutt	1988	0.45	-1.3	N_{wet}	2000	Yamaguchi, Jap. (11.45, 4,6.5,9°) M	m vs. N_{wet}	7 - 14 GHz $4 < \theta < 30°$	Regres. m vs. variance
ITU - R	1990	0.583 (7/12)	-1.2	N_{wet}	1000			6 - 20 GHz $4 < \theta < 30°$	Regres.
Ortgies-N	1993	0.605	-1.2	N_{wet}	1000	Darmstadt, Ger. (19.8, 29.7, 27°) E	$\ln(\sigma_x^2)$ vs. N_{wet}	$6.5 < \theta < 30°$	∫ Gauss. (sym.)
Ortgies-T	1993	0.605	-1.2	T	1000	Darmstadt, Ger. (19.8, 29.7, 27°) E	$\ln(\sigma_x^2)$ vs. T	$6.5 < \theta < 30°$	∫ Gauss. (sym.)
DPSP-Direct Physical Statistical Prediction	1997	0.583	-1.2	T	2058 + 94.5 T	Louvain-la-N, Bel. (12.5, 29.7, 28°) E and Milan, It. (19.8, 30°) K	Ver. Refrac. gradient (radiosonde) to give $\ln(\sigma_x^2)$ vs. T	T > -5 C	∫ Gauss. (sym.)
MPSP-Modeled Physical Statistical Prediction	1997	0.583	-.917	T	2058 + 94.5 T	Louvain-la-N, Bel. (12.5, 29.7, 28°) E and Milan, It. (19.8, 30°) K	Ver. Refrac. gradient (radiosonde) to give $\ln(\sigma_x^2)$ vs. T	T > -5 C	∫ Gauss. (sym.)
Tervonen, van de Kamp, Salonen	1998	0.45	-1.3	N_{wet}, P(Cu)	2000	Kirkkonummi, Finland (19.8, 29.7, 13°) E	σ_x vs. N_{wet} & P(Cu)		




Mean hourly rms(dry)
ITU-R rms
Karasawa rms
Mean hourly rms(wet)
Ortgies -N
Ortgies -T
Salonen
DPSP
MPSP
Fairbanks (64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
Mean Hourly RMS Deviation (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Dec-93
Mar-94
Jun-94
Sep-94
Dec-94
Mar-95
Jun-95
Sep-95
Dec-95
Mar-96
Jun-96
Sep-96
Dec-96
Mar-97
Jun-97
Sep-97
Dec-97
Mar-98
Jun-98
Sep-98
Month
Alaska ACTS Propagation


Mean hourly rms(dry)
ITU-R rms
Karasawa rms
Mean hourly rms(wet)
Ortgies -N
Ortgies -T
Salonen
DPSP
MPSP
Fairbanks (64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
Mean Hourly RMS Deviation (dB)
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
Jan-95
Feb-95
Mar-95
Apr-95
May-95
Jun-95
Jul-95
Aug-95
Sep-95
Oct-95
Nov-95
Dec-95
Month
Alaska ACTS Propagation


Aug 1994 Measured (dry)
Aug 1994 Karasawa
Aug 1994 ITU-R
Feb 1994 Measured(dry)
Feb 1994 Karasawa
Feb 1994 ITU-R
Fairbanks
(64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
X (dB)
5
4
3
2
1
0
-1
-2
-3
-4
99.99
99.90
99.00
95.00
90.00
50.00
10.00
5.00
1.00
0.10
0.01
Percentage of Time (%)
Alaska ACTS Propagation

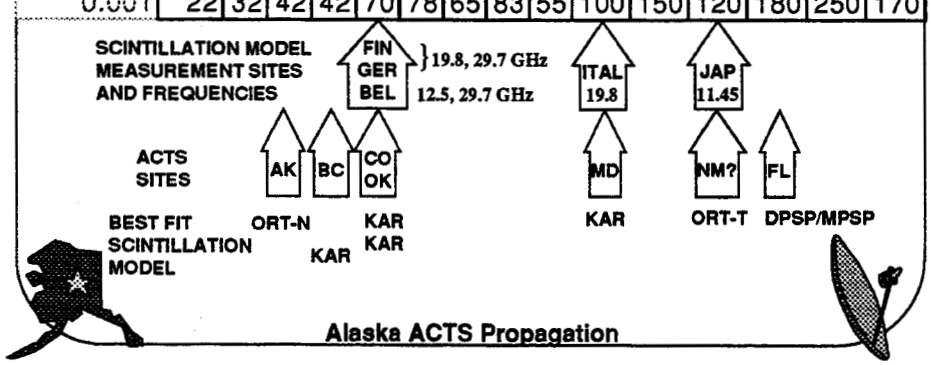

--- Karasawa --- η ····· 95% CI ---- 95% CI
Fairbanks
(64.86° N, 147.82° W)
f: 20.185 GHz, 27.505 GHz
θ: 7.92°
Da: 1.22 m
Enhancement
η(p)
6
5
4
3
2
1
0
-1
-2
-3
$\hat{\eta} = -0.0825 \cdot \log^3(100-p) - 0.0140 \cdot \log^2(100-p) - 1.6173 \cdot \log(100-p) + 2.3386$
50
60
70
80
90
100
Percentage of Time (p)
Alaska ACTS Propagation

7 SITE SCINTILLATION MODEL COMPARISON (RMSD)

Site	Freq. (GHz)	Karasawa	ITU-R	Ortgies-N	Ortgies-T	DPSP	MPSP	Tervonen
AK	20.2	.1731	.2018	.0267	.0431	.1881	.0422	.0892
	27.5	.2228	.2516	.0390	.0515	.2293	.0545	.0993
BC	20.2	.0081	.0307	.0198	.0278	.0177	.0203	.0126
	27.5							
CO	20.2	.0051	.0171	.0133	.0132	.0135	.0133	.0132
	27.5							
FL	20.2	.0210	.0193	.0411	.0374	.0148	.0149	.0175
	27.5							
MD	20.2	.0101	.0179	.0194	.0257	.0144	.0139	.0187
	27.5							
NM	20.2	.0139	.0100	.0210	.0081	.0342	.0328	.0194
	27.5							
OK	20.2	.0068	.0211	.0217	.0146	.0186	.0172	.0093
	27.5							
AVERAGE(7)		.0576	.0712	.0253	.0277	.0663	.0261	.0349
AVERAGE(6)		.0108	.0194	.0227	.0211	.0189	.0187	.0151

ITU-R Rainfall Rate Climatic Zones (mm/hr)

% of time	A	B	C	D	E	F	G	H	J	K	L	M	N	P	Q
1.000	<0.1	1	1	2	1	2	3	2	8	1.5	2	4	5	12	24
0.300	0.8	2	3	5	2	5	7	4	13	4.2	7	11	15	34	49
0.100	2	3	5	8	6	8	12	10	20	12	15	22	35	65	72
0.030	5	6	9	13	12	15	20	18	28	23	33	40	65	105	96
0.010	8	12	15	19	22	28	30	32	35	42	60	63	95	145	115
0.003	14	21	26	29	41	54	45	55	45	70	105	95	140	200	142
0.001	22	32	42	42	70	78	65	83	55	100	150	120	180	250	170

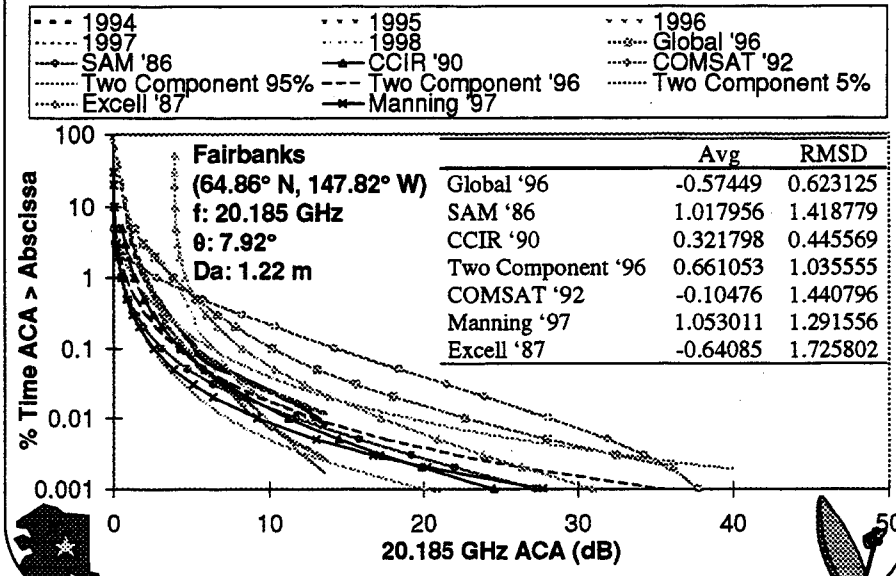


CONCLUSIONS

- SCINTILLATIONS ARE IMPORTANT IN LOW ELEVATION ANGLE, LOW MARGIN LINKS
  - LEO SYSTEMS
  - INTERCONTINENTAL GEO SYSTEMS
  - HIGH LATITUDE GEO
- SCINTILLATIONS INCREASE AS:
  - ELEVATION ANGLE DECREASES
  - HUMIDITY INCREASES
  - TEMPERATURE INCREASES
  - FREQUENCY INCREASES
  - ANTENNA APERTURE DECREASES
- SCINTILLATIONS ARE WELL CORRELATED BETWEEN 20 AND 27 GHz (UL AND DL FREQUENCIES)
- ORTGIES-N MODEL BEST PREDICTS MAGNITUDE OF SCINTILLATION FOR FAIRBANKS
- KARASAWA MODEL BEST PREDICTS MAGNITUDE OF SCINTILLATION FOR 4 OF 6 LOWER 48 SITES
  - LOWEST RMSD FOR ALL 6 LOWER 48 SITES

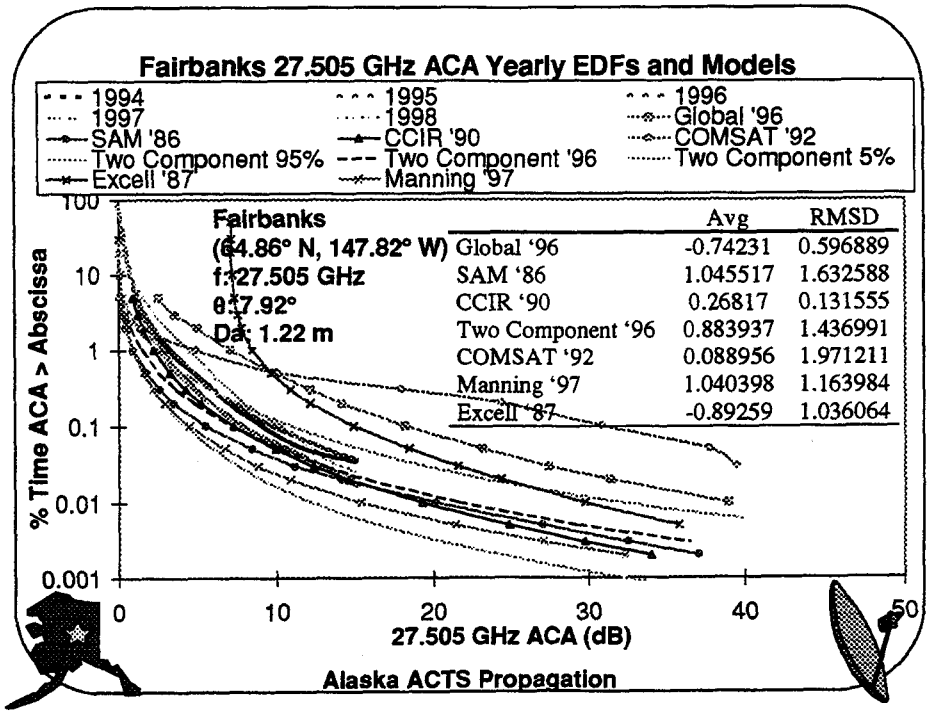
Alaska ACTS Propagation

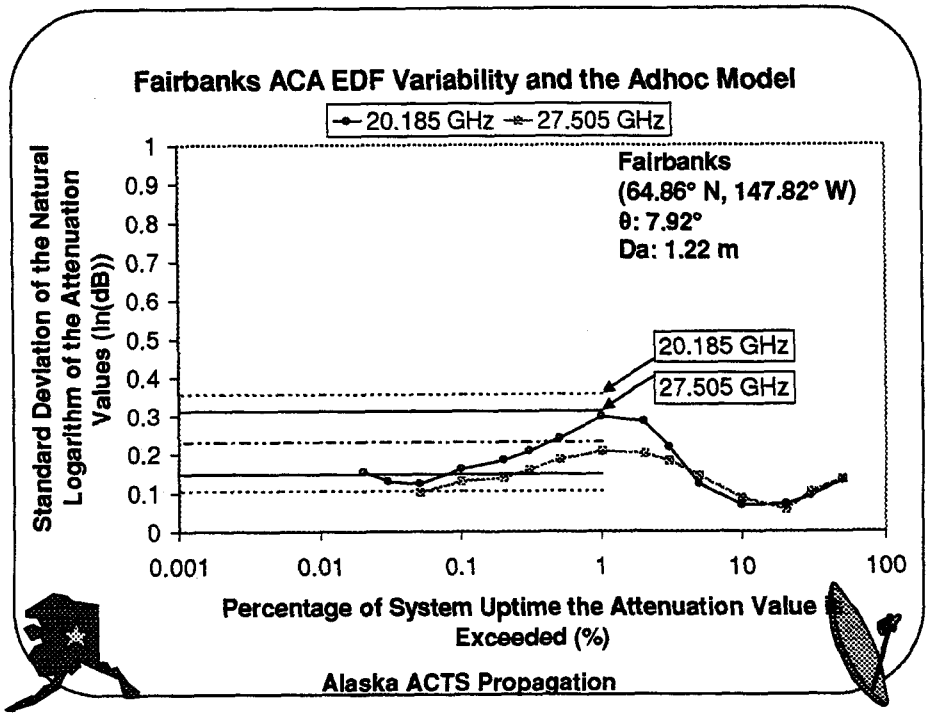
Fairbanks 20.185 GHz ACA Yearly EDFs and Models

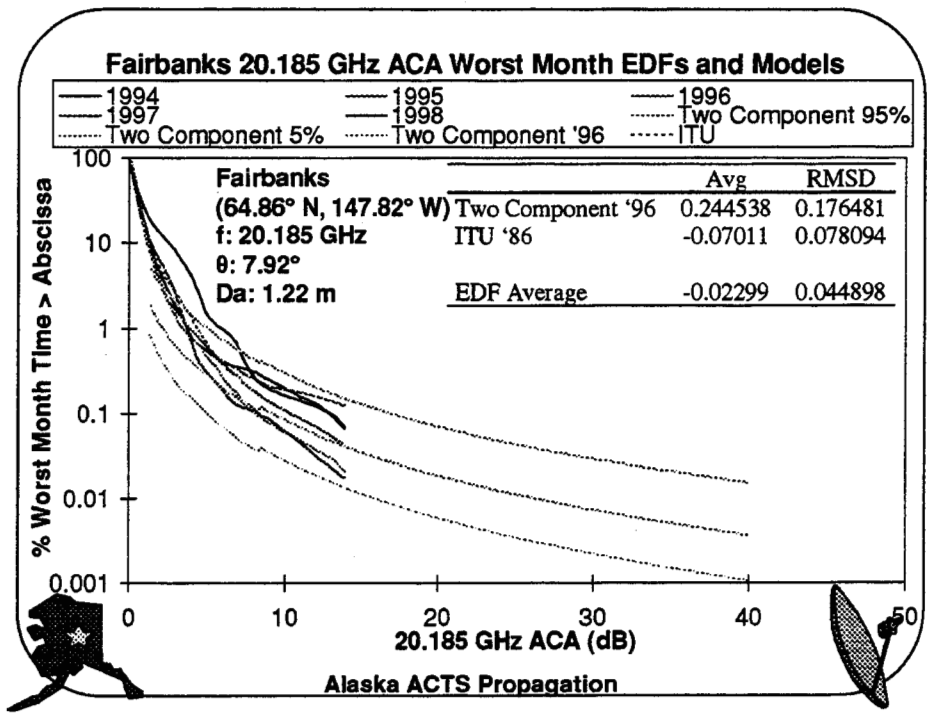


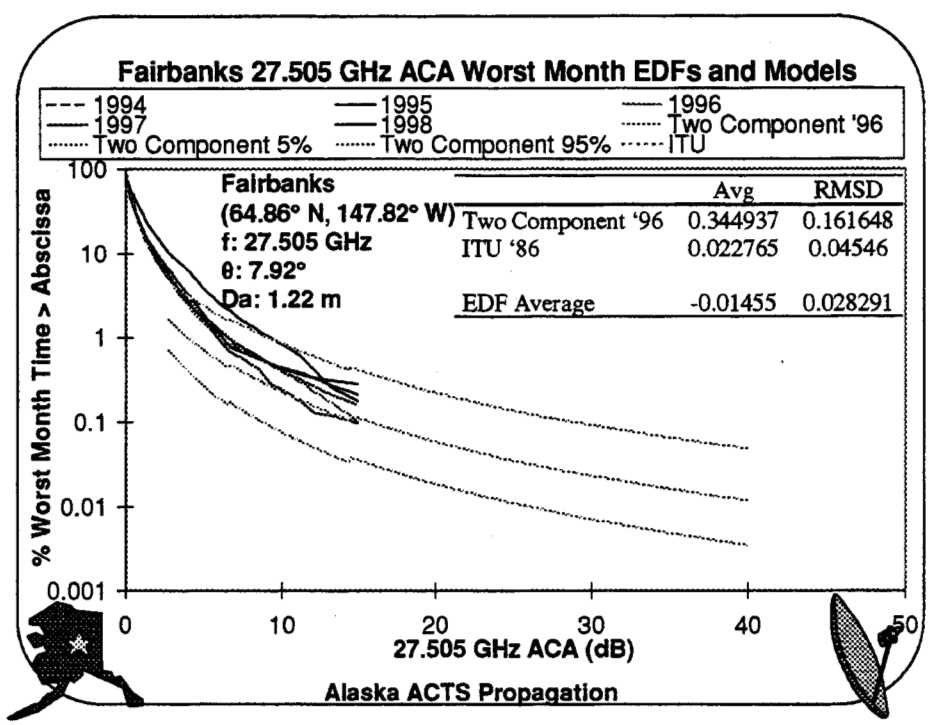
	Avg	RMSD
Global '96	-0.57449	0.623125
SAM '86	1.017956	1.418779
CCIR '90	0.321798	0.445569
Two Component '96	0.661053	1.035555
COMSAT '92	-0.10476	1.440796
Manning '97	1.053011	1.291556
Excell '87	-0.64085	1.725802

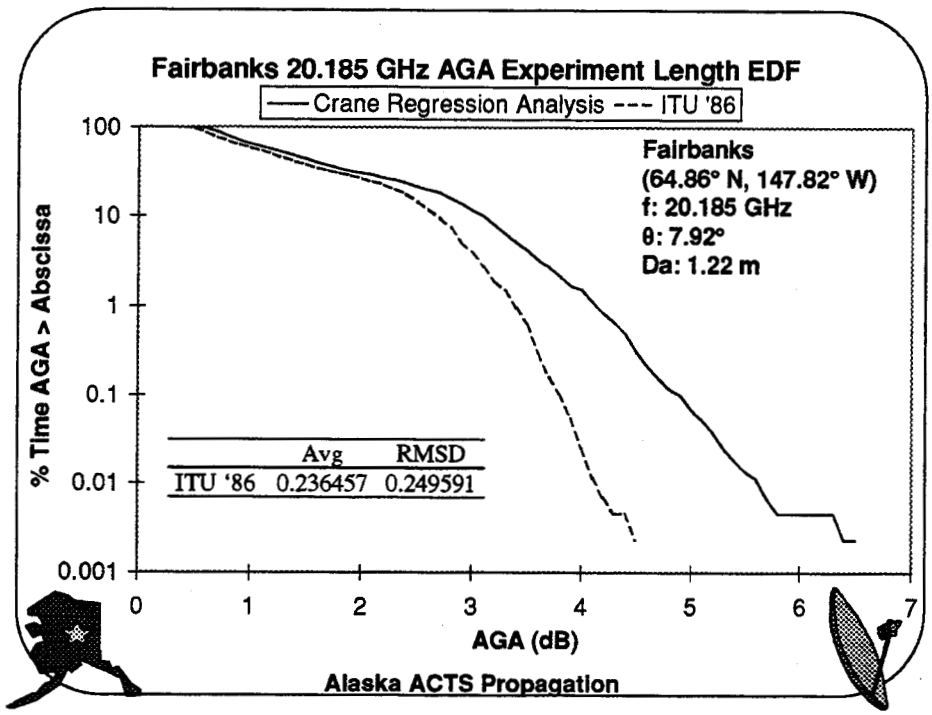
Alaska ACTS Propagation

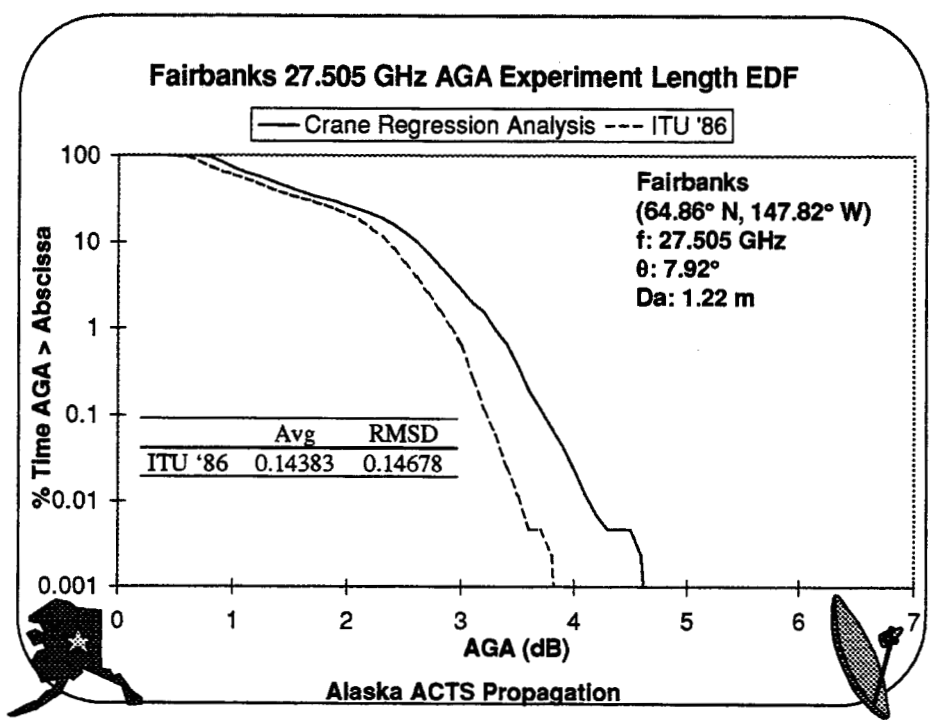

Fairbanks 27.505 GHz ACA Yearly EDFs and Models
1994
1995
1996
1997
1998
Global '96
SAM '86
CCIR '90
COMSAT '92
Two Component 95%
Two Component '96
Two Component 5%
Excell '87
Manning '97
Fairbanks
(64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
Avg RMSD
Global '96 -0.74231 0.596889
SAM '86 1.045517 1.632588
CCIR '90 0.26817 0.131555
Two Component '96 0.883937 1.436991
COMSAT '92 0.088956 1.971211
Manning '97 1.040398 1.163984
Excell '87 -0.89259 1.036064
% Time ACA > Abscissa
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
27.505 GHz ACA (dB)
Alaska ACTS Propagation

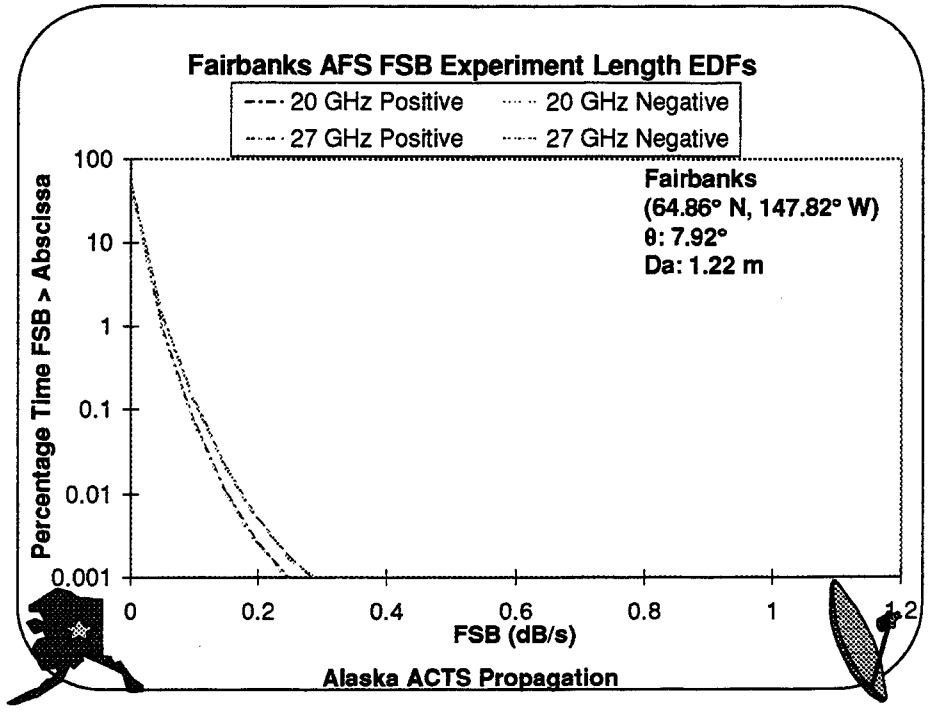

Fairbanks ACA EDF Variability and the Adhoc Model
20.185 GHz
27.505 GHz
Fairbanks
(64.86° N, 147.82° W)
θ: 7.92°
Da: 1.22 m
20.185 GHz
27.505 GHz
Standard Deviation of the Natural Logarithm of the Attenuation Values (ln(dB))
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.001
0.01
0.1
1
10
100
Percentage of System Uptime the Attenuation Value Is Exceeded (%)
Alaska ACTS Propagation

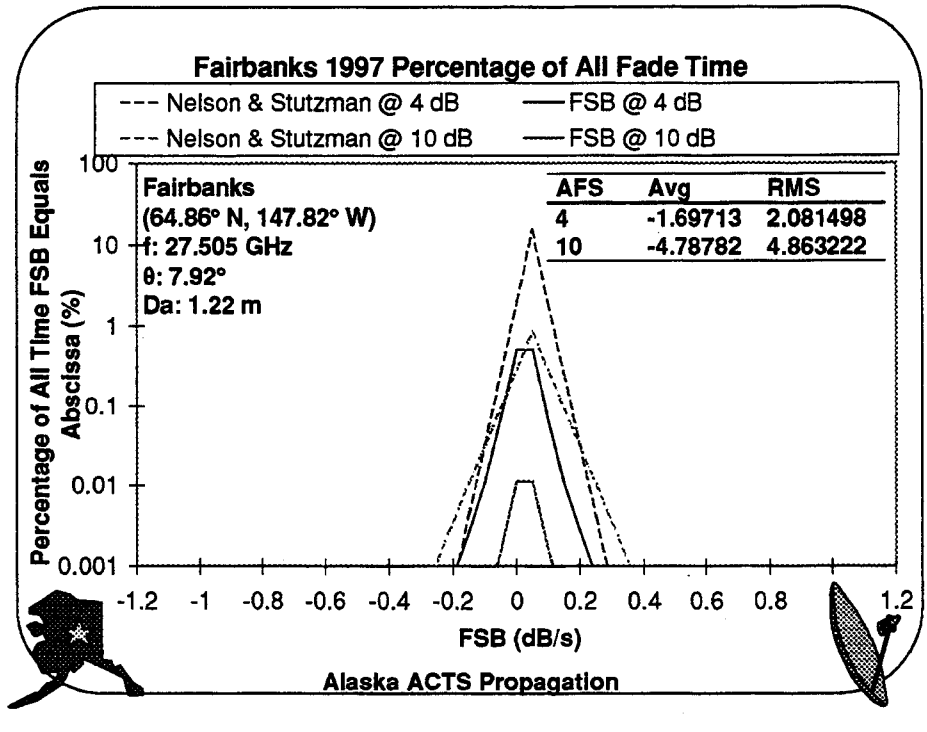

Fairbanks 20.185 GHz ACA Worst Month EDFs and Models
1994
1995
1996
1997
1998
Two Component 95%
Two Component 5%
Two Component '96
ITU
Fairbanks
(64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
Avg RMSD
Two Component '96 0.244538 0.176481
ITU '86 -0.07011 0.078094
EDF Average -0.02299 0.044898
% Worst Month Time > Abscissa
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
20.185 GHz ACA (dB)
Alaska ACTS Propagation

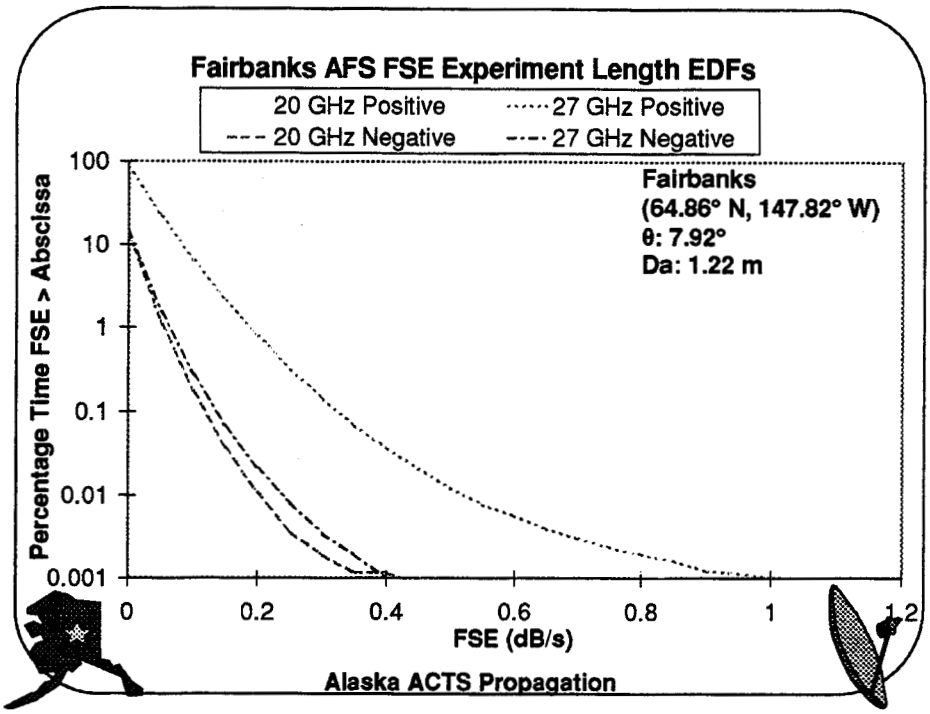

Fairbanks 27.505 GHz ACA Worst Month EDFs and Models
1994
1995
1996
1997
1998
Two Component '96
Two Component 5%
Two Component 95%
ITU
Fairbanks
(64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
Avg RMSD
Two Component '96 0.344937 0.161648
ITU '86 0.022765 0.04546
EDF Average -0.01455 0.028291
% Worst Month Time > Abscissa
100
10
1
0.1
0.01
0.001
0
10
20
30
40
50
27.505 GHz ACA (dB)
Alaska ACTS Propagation

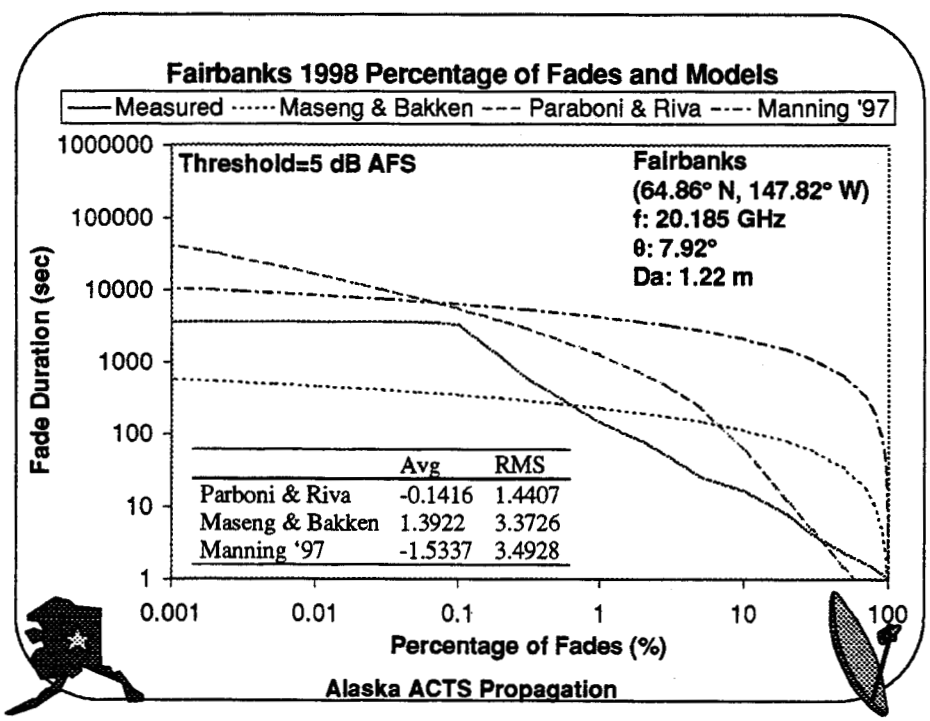

Fairbanks 20.185 GHz AGA Experiment Length EDF
Crane Regression Analysis --- ITU '86
Fairbanks
(64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
% Time AGA > Abscissa
100
10
1
0.1
0.01
0.001
Avg RMSD
ITU '86 0.236457 0.249591
0 1 2 3 4 5 6 7
AGA (dB)
Alaska ACTS Propagation


Fairbanks 27.505 GHz AGA Experiment Length EDF
Crane Regression Analysis --- ITU '86
Fairbanks
(64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
% Time AGA > Abscissa
100
10
1
0.1
0.01
0.001
Avg RMSD
ITU '86 0.14383 0.14678
0 1 2 3 4 5 6 7
AGA (dB)
Alaska ACTS Propagation


Fairbanks AFS FSB Experiment Length EDFs
20 GHz Positive
20 GHz Negative
27 GHz Positive
27 GHz Negative
Fairbanks
(64.86° N, 147.82° W)
θ: 7.92°
Da: 1.22 m
Percentage Time FSB > Abscissa
100
10
1
0.1
0.01
0.001
0
0.2
0.4
0.6
0.8
1
1.2
FSB (dB/s)
Alaska ACTS Propagation


Fairbanks 1997 Percentage of All Fade Time
Nelson & Stutzman @ 4 dB
FSB @ 4 dB
Nelson & Stutzman @ 10 dB
FSB @ 10 dB
Fairbanks
(64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
AFS Avg RMS
4 -1.69713 2.081498
10 -4.78782 4.863222
Percentage of All Time FSB Equals Abscissa (%)
100
10
1
0.1
0.01
0.001
-1.2
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1.2
FSB (dB/s)
Alaska ACTS Propagation


Fairbanks AFS FSE Experiment Length EDFs
20 GHz Positive
27 GHz Positive
20 GHz Negative
27 GHz Negative
Fairbanks
(64.86° N, 147.82° W)
θ: 7.92°
Da: 1.22 m
Percentage Time FSE > Abscissa
100
10
1
0.1
0.01
0.001
0
0.2
0.4
0.6
0.8
1
1.2
FSE (dB/s)
Alaska ACTS Propagation


Fairbanks 1998 Percentage of Fades and Models
Measured
Maseng & Bakken
Paraboni & Riva
Manning '97
Threshold=5 dB AFS
Fairbanks
(64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
Avg RMS
Parboni & Riva -0.1416 1.4407
Maseng & Bakken 1.3922 3.3726
Manning '97 -1.5337 3.4928
Fade Duration (sec)
1000000
100000
10000
1000
100
10
1
0.001
0.01
0.1
1
10
100
Percentage of Fades (%)
Alaska ACTS Propagation

Paraboni & Riva Model

Lognormal Distribution

$$p(D) = \frac{1}{(D-\theta)\cdot\sqrt{2\cdot\pi}\cdot\sigma}\cdot\exp\left[\frac{-1}{2}\cdot\frac{\{\log(D-\theta)-\zeta\}^2}{\sigma^2}\right]$$

Slow Phenomena Fade Durations

$$N_s(D) = N_{tot}\cdot\eta\cdot Q\left(\frac{D}{D_0}\right) \qquad D \geq Dt$$

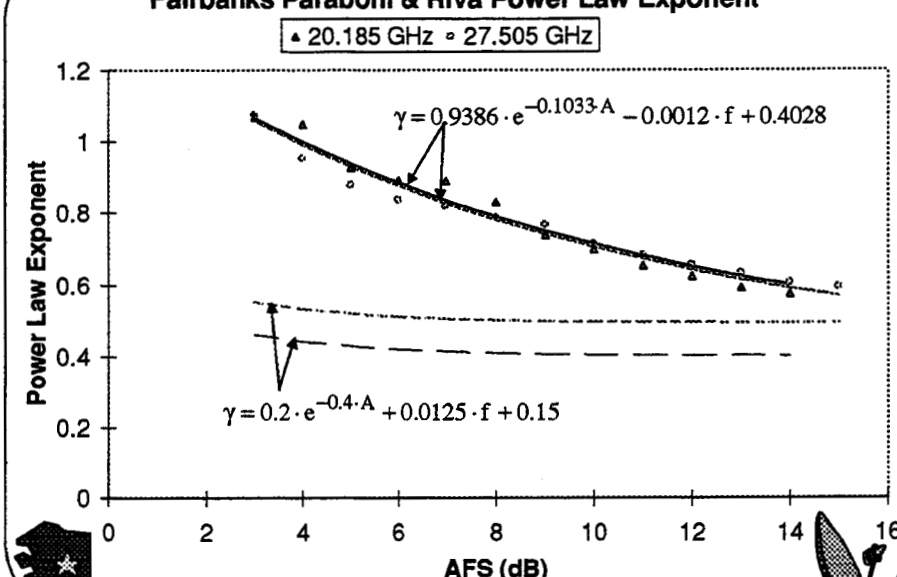
$$Q(z) = \frac{1}{\sqrt{2\cdot\pi}}\cdot\int_{\ln(z)/\sigma}^{\infty} e^{-\frac{1}{2}x^2}\,dx$$

Fast Phenomena Fade Durations

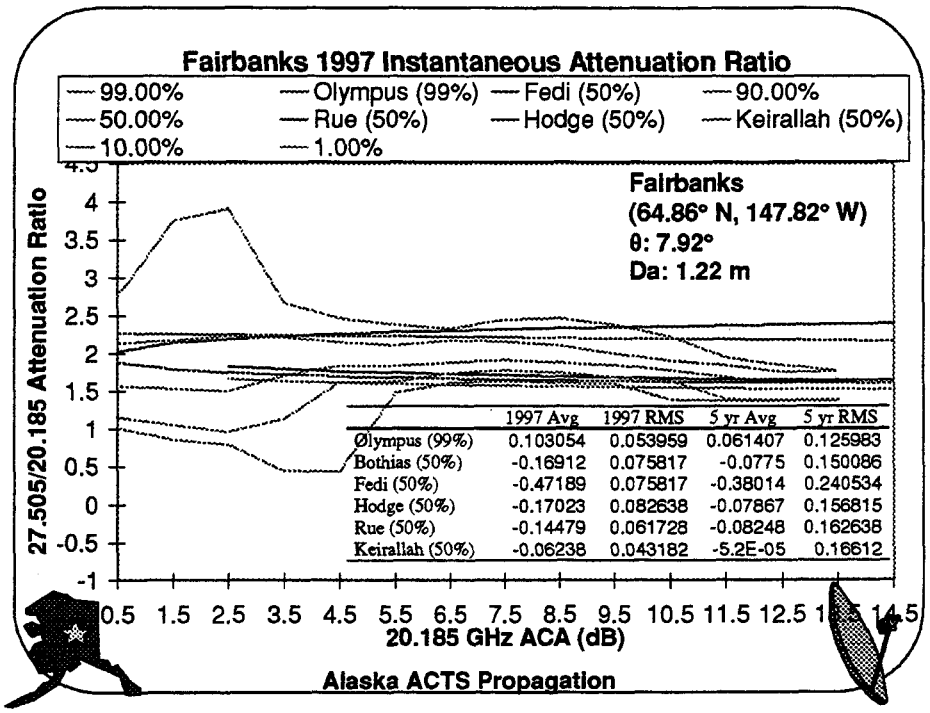
$$N_d(D) = \frac{N_{tot}}{D_1}\cdot\eta\cdot Q\left(\frac{D_t}{D_2}\right)\cdot\left(\frac{D}{D_t}\right)^{-\gamma}$$

Alaska ACTS Propagation

Fairbanks Paraboni & Riva Power Law Exponent



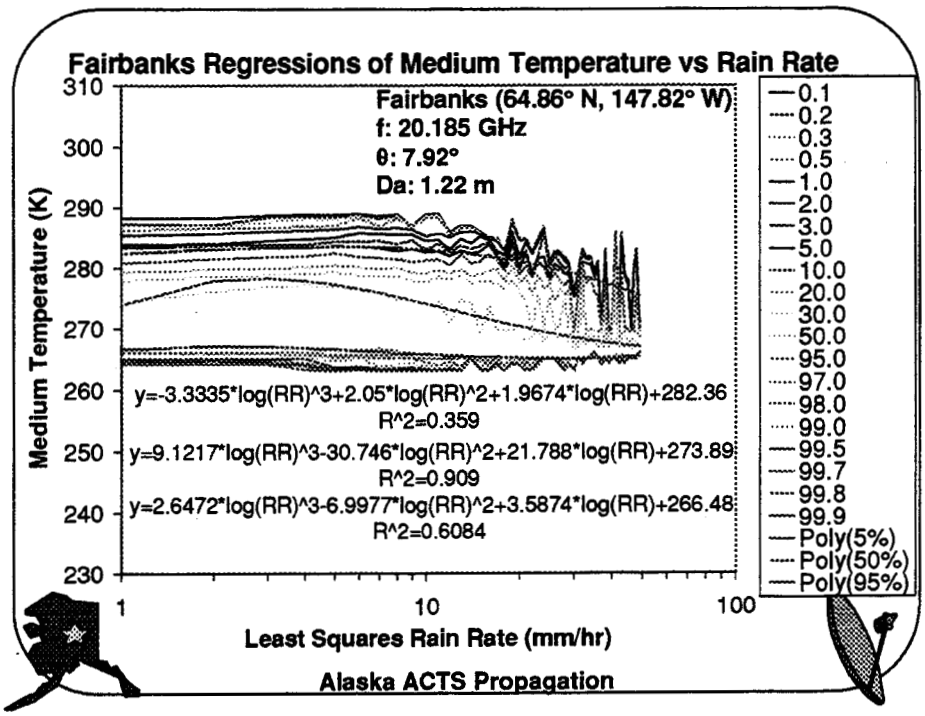
Alaska ACTS Propagation

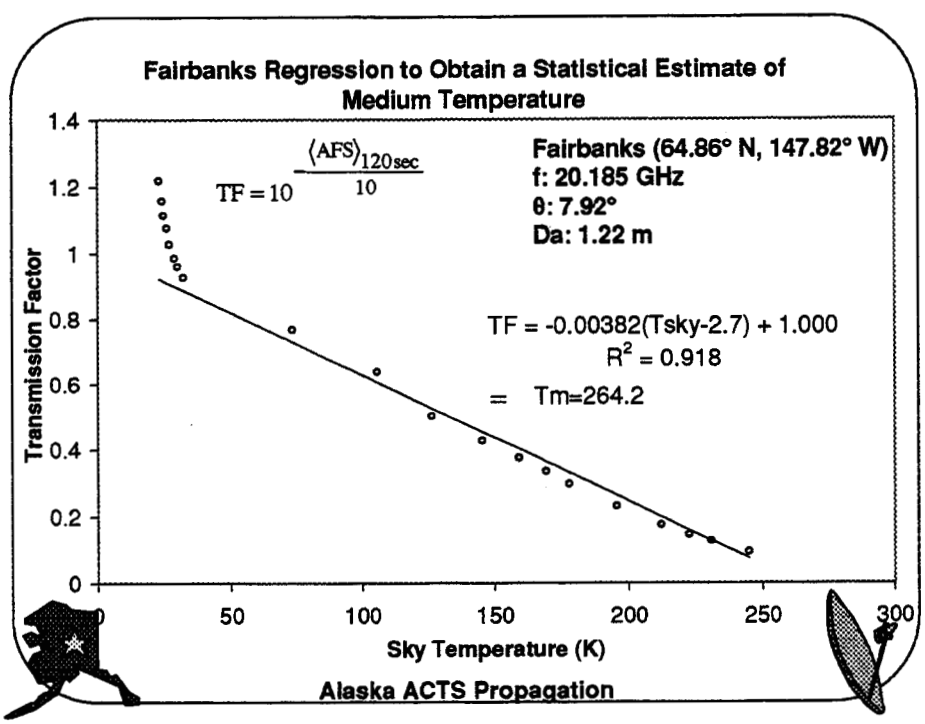


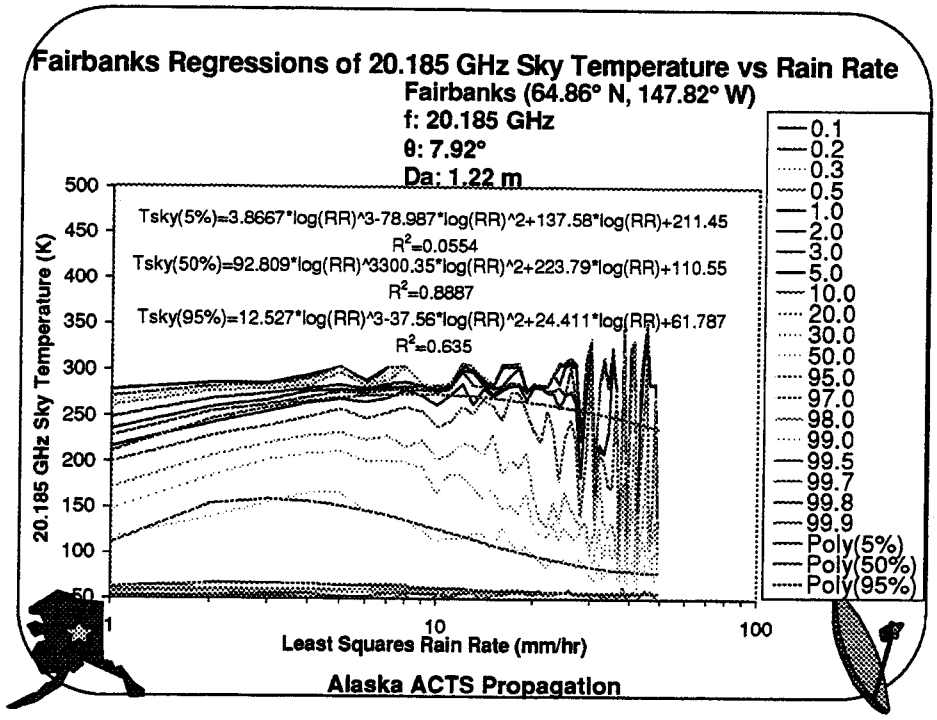
	1997 Avg	1997 RMS	5 yr Avg	5 yr RMS
Olympus (99%)	0.103054	0.053959	0.061407	0.125983
Bothias (50%)	-0.16912	0.075817	-0.0775	0.150086
Fedi (50%)	-0.47189	0.075817	-0.38014	0.240534
Hodge (50%)	-0.17023	0.082638	-0.07867	0.156815
Rue (50%)	-0.14479	0.061728	-0.08248	0.162638
Keirallah (50%)	-0.06238	0.043182	-5.2E-05	0.16612

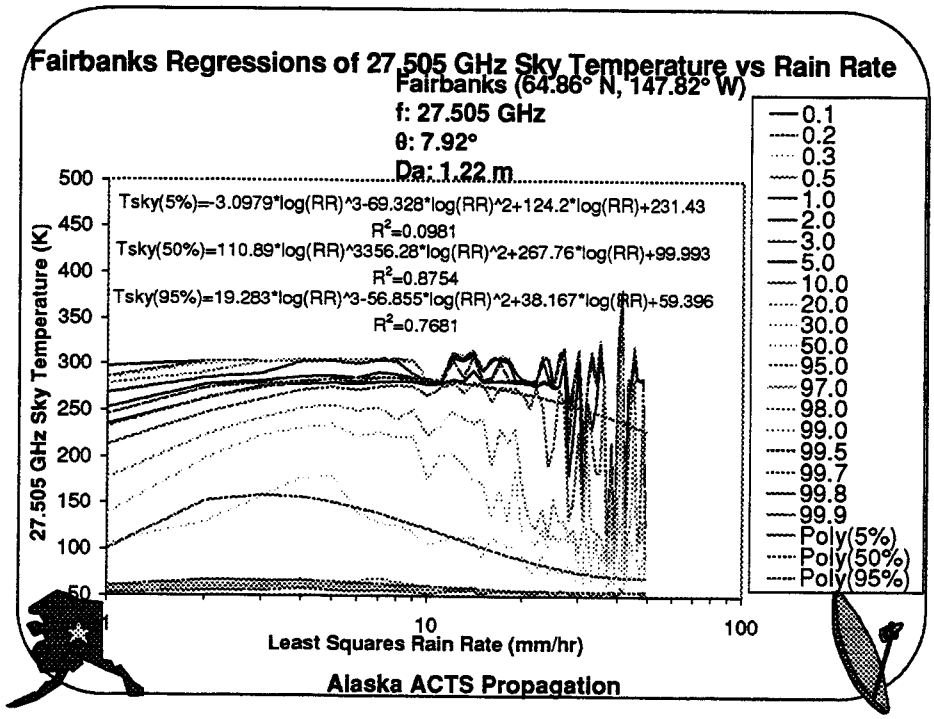
DIFFERENCE ERRORS FOR INSTANTANEOUS ATTENUATION RATIO MODELS

	1994		1995		1996		1997		1998		5 year	
	avg	rms	avg	rms	avg	rms	avg	rms	avg	rms	avg	rms
Olympus (99%)	0.11	0.21	-0.07	0.12	0.01	0.11	0.10	0.05	0.14	0.05	0.06	0.12
Bothias (50%)	0.11	0.15	0.02	0.05	0.04	0.10	-0.16	0.07	-0.39	0.26	-0.07	0.15
Fedi (50%)	-0.18	0.20	-0.28	0.29	-0.26	0.28	-0.47	0.07	-0.68	0.26	-0.38	0.24
Hodge (50%)	0.10	0.15	0.01	0.07	0.04	0.11	-0.17	0.08	-0.39	0.26	-0.07	0.15
Rue (50%)	0.10	0.14	0.00	0.04	0.03	0.10	-0.14	0.06	-0.41	0.30	-0.08	0.16
Keirallah (50%)	0.18	0.21	0.08	0.10	0.11	0.15	-0.06	0.04	-0.32	0.24	0.00	0.16
5 Year Average											-0.004	0.010


Fairbanks Regressions of Medium Temperature vs Rain Rate
Fairbanks (64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
y=-3.3335*log(RR)^3+2.05*log(RR)^2+1.9674*log(RR)+282.36
R^2=0.359
y=9.1217*log(RR)^3-30.746*log(RR)^2+21.788*log(RR)+273.89
R^2=0.909
y=2.6472*log(RR)^3-6.9977*log(RR)^2+3.5874*log(RR)+266.48
R^2=0.6084
Medium Temperature (K)
310
300
290
280
270
260
250
240
230
1
10
100
Least Squares Rain Rate (mm/hr)
0.1
0.2
0.3
0.5
1.0
2.0
3.0
5.0
10.0
20.0
30.0
50.0
95.0
97.0
98.0
99.0
99.5
99.7
99.8
99.9
Poly(5%)
Poly(50%)
Poly(95%)
Alaska ACTS Propagation


Fairbanks Regression to Obtain a Statistical Estimate of Medium Temperature
$TF = 10^{\frac{\langle AFS \rangle_{120sec}}{10}}$
Fairbanks (64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
TF = -0.00382(Tsky-2.7) + 1.000
R^2 = 0.918
= Tm=264.2
Transmission Factor
1.4
1.2
1
0.8
0.6
0.4
0.2
0
50
100
150
200
250
300
Sky Temperature (K)
Alaska ACTS Propagation


Fairbanks Regressions of 20.185 GHz Sky Temperature vs Rain Rate
Fairbanks (64.86° N, 147.82° W)
f: 20.185 GHz
θ: 7.92°
Da: 1.22 m
Tsky(5%)=3.8667*log(RR)^3-78.987*log(RR)^2+137.58*log(RR)+211.45
R²=0.0554
Tsky(50%)=92.809*log(RR)^3300.35*log(RR)^2+223.79*log(RR)+110.55
R²=0.8887
Tsky(95%)=12.527*log(RR)^3-37.56*log(RR)^2+24.411*log(RR)+61.787
R²=0.635
20.185 GHz Sky Temperature (K)
500
450
400
350
300
250
200
150
100
50
1
10
100
Least Squares Rain Rate (mm/hr)
Alaska ACTS Propagation
0.1
0.2
0.3
0.5
1.0
2.0
3.0
5.0
10.0
20.0
30.0
50.0
95.0
97.0
98.0
99.0
99.5
99.7
99.8
99.9
Poly(5%)
Poly(50%)
Poly(95%)


Fairbanks Regressions of 27.505 GHz Sky Temperature vs Rain Rate
Fairbanks (64.86° N, 147.82° W)
f: 27.505 GHz
θ: 7.92°
Da: 1.22 m
Tsky(5%)=-3.0979*log(RR)^3-69.328*log(RR)^2+124.2*log(RR)+231.43
R²=0.0981
Tsky(50%)=110.89*log(RR)^3356.28*log(RR)^2+267.76*log(RR)+99.993
R²=0.8754
Tsky(95%)=19.283*log(RR)^3-56.855*log(RR)^2+38.167*log(RR)+59.396
R²=0.7681
27.505 GHz Sky Temperature (K)
500
450
400
350
300
250
200
150
100
50
1
10
100
Least Squares Rain Rate (mm/hr)
Alaska ACTS Propagation
0.1
0.2
0.3
0.5
1.0
2.0
3.0
5.0
10.0
20.0
30.0
50.0
95.0
97.0
98.0
99.0
99.5
99.7
99.8
99.9
Poly(5%)
Poly(50%)
Poly(95%)

Conclusions

- The CCIR '90 model had the lowest rms bias for Fairbanks among the attenuation models examined.
- Variability of attenuation edfs was accounted for by the Ad Hoc model within the dynamic range.
- Gaseous attenuation (AGA) was under-estimated by the ITU '86 model.
- The Nelson and Stutzman model over-estimated P(FSB) for Fairbanks.
- The Paraboni & Riva model had the lowest rms bias for AFS fades less than 4 dB.
- The power law for exponent for fast phenomena fade durations seems to be above that given by Paraboni & Riva.
- Bothias, Hodge, Rue, and Keirallah models for ART perform about equally well at Fairbanks.
- Regression equations were presented for predicting Fairbanks medium temperature and sky temperatures from rain rate.