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Land Mobile Satellite Channel Modeling

Chun Loo
Communications Research Centre Canada
3701 Carling Ave., P.O. Box 11490 Station H
Ottawa Ontario, Canada K2H 8S2
chun.loo@crc.ca

Canada

CRC

Outline

- Introduction
- L Band Channel Model
- Ka Band Channel Model
- Summary

Introduction

- Measurement program
- Measurement procedure
- Channel modeling procedure

L Band Channel Models

- Shadowed Rician Model
- Total Shadowed Model
- Shadowing on both LOS and Multipath Model
- Lognormal Shadowing Model
- Empirical Roadside Shadowing Model and Extension
- High Elevation Angle Model

Shadowed Rician Model

$$r\ exp(j\theta) = z\ exp(j\phi_0) + w\ exp(j\phi)$$

ϕ_0 and ϕ are uniformly distributed

z is lognormal

w is Rayleigh

When z is constant and $z = A$, this is Rician.

$$p_R(r) = r/b_0 \; exp[-(r^2 + A^2)/2b_0] I_0(rA/b_0)$$

When there is shadowing, z, but, no multipath fading, $w = 0$,

$$p(r) = 1/(r\sqrt{2\pi d_0}) \; exp[-(ln\, r - \mu)^2/2d_0]$$

When there is no shadowing and no LOS component, $z = 0$,

$$p(r) = r/b_0 \; exp(-r^2/2b_0)$$

Shadowed Rician Model

$$p(r) = r/(b_0\sqrt{2\pi d_0}\int_0^\infty 1/z$$

$$exp[-(ln\, z - \mu)^2/2d_0$$

$$-(r^2 + z^2)/2b_0]I_0(rz/b_0)dz$$

where μ and d_0 are the mean and variance
b_0 represents the average scattered power
$I_0(\,.\,)$ is the modified Bessel function of zeroth order.

Total Shadowing Model

Let $S = r^2$ and $S_0 = b_0$

$$p_{Rice}(S) = K\, exp\,[-K(S+1)]\, I_0(2K\sqrt{S})$$

where K is the ratio of LOS power to multi-path power

$$p_{Ray}(S/S_0) = \frac{1}{S_0}\, exp\,(-S/S_0)$$

$$p_{LN}(S_0) = \frac{10}{\sqrt{2\pi d_0\, ln\, 10}} \frac{1}{S_0} exp\,[-\frac{(10\, log\, S_0 - \mu)^2}{2d_0}]$$

where μ is the mean and d_0 is the variance due to shadowing.

$$p(S) = (1 - F)p_{Rice}(S) +$$

$$F \cdot \int_0^\infty p_{Ray}(S/S_0)\, p_{LN}(S_0)\, dS_0.$$

The values of F and model parameters are given in their paper.

Lognormal Shadowing Model

$$P(r) = (1 - F)\, P_{Rice}(r) + F\, P_{Loo}(r)$$

where $P_{Rice}(r)$ denotes the Rician model and $P_{Loo}(r)$ denotes the shadowed Rician model. F is the percentage of shadowed conditions.

Shadowing of LOS and Multipath Model

$$p(r) = \int_0^\infty \frac{1}{z}\, p_R(r/z)\, p(z) dz$$

Shadowing Rician Model

$$p(r) = \int_0^\infty p_R(r/z)\, p(z) dz$$

K, μ and $\sqrt{d}$ as a function of α
valid in the range $20° < \alpha < 80°$:

$$K(\alpha) = K_0 + K_1\alpha + K_2\alpha^2$$

$$\mu(\alpha) = \mu_0 + \mu_1\alpha + \mu_2\alpha^2 + \mu_3\alpha^3$$

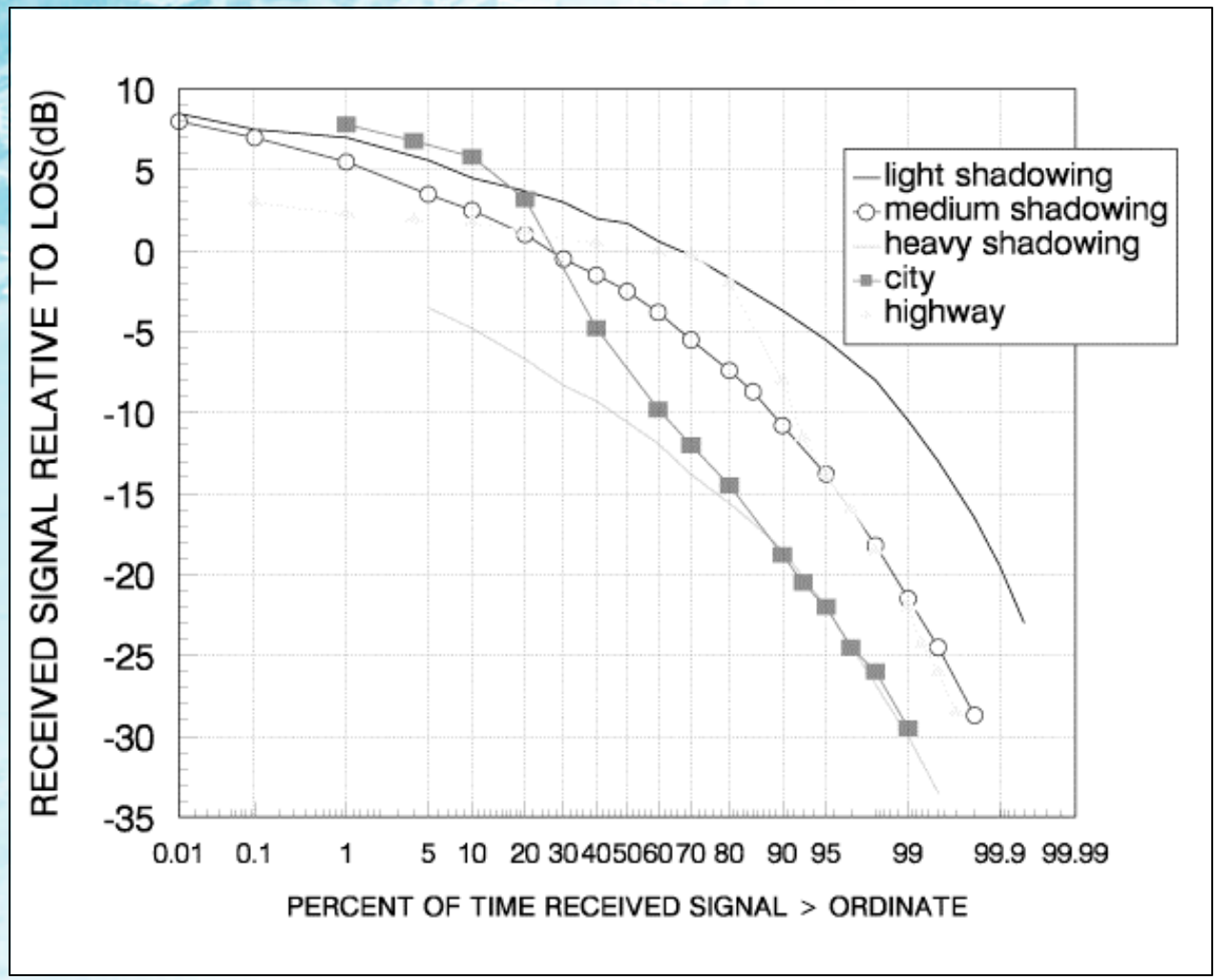
$$\sqrt{d}(\alpha) = \alpha_0 + \sqrt{d_1}\alpha.$$

Conditions of comparison

Model	Frequency(MHz)	Elevation (deg)
Shadowed Rician	870	15
Total shadowing	1540	24

For city $F = 0.79$

For highway $F = .19$


RECEIVED SIGNAL RELATIVE TO LOS(dB)
10
5
0
-5
-10
-15
-20
-25
-30
-35
0.01
0.1
1
5
10
20
30
40
50
60
70
80
90
95
99
99.9
99.99
PERCENT OF TIME RECEIVED SIGNAL > ORDINATE
light shadowing
medium shadowing
heavy shadowing
city
highway

Ka Band Measurement

- Elevation angle to Olympus: 14.2°
- Transmit frequency(GHz): 28.07225
- Receive frequency(GHz): 18.925
- Weather conditions: cloudy with sunny break

Ka Band Channel Models

- Gaussian Model for Fixed Channel (weather conditions)
- Shadowed Rician Model for Mobile Channel

Ka Band Fixed and Mobile Channel Model

$$p(r) = p_w(r) \cdot p_{Loo}(r)$$

$$p_w(r) = \frac{1}{\sqrt{2\pi}\,\sigma_w} exp\,(-\frac{(r-m_w)^2}{2\sigma_w^2}$$

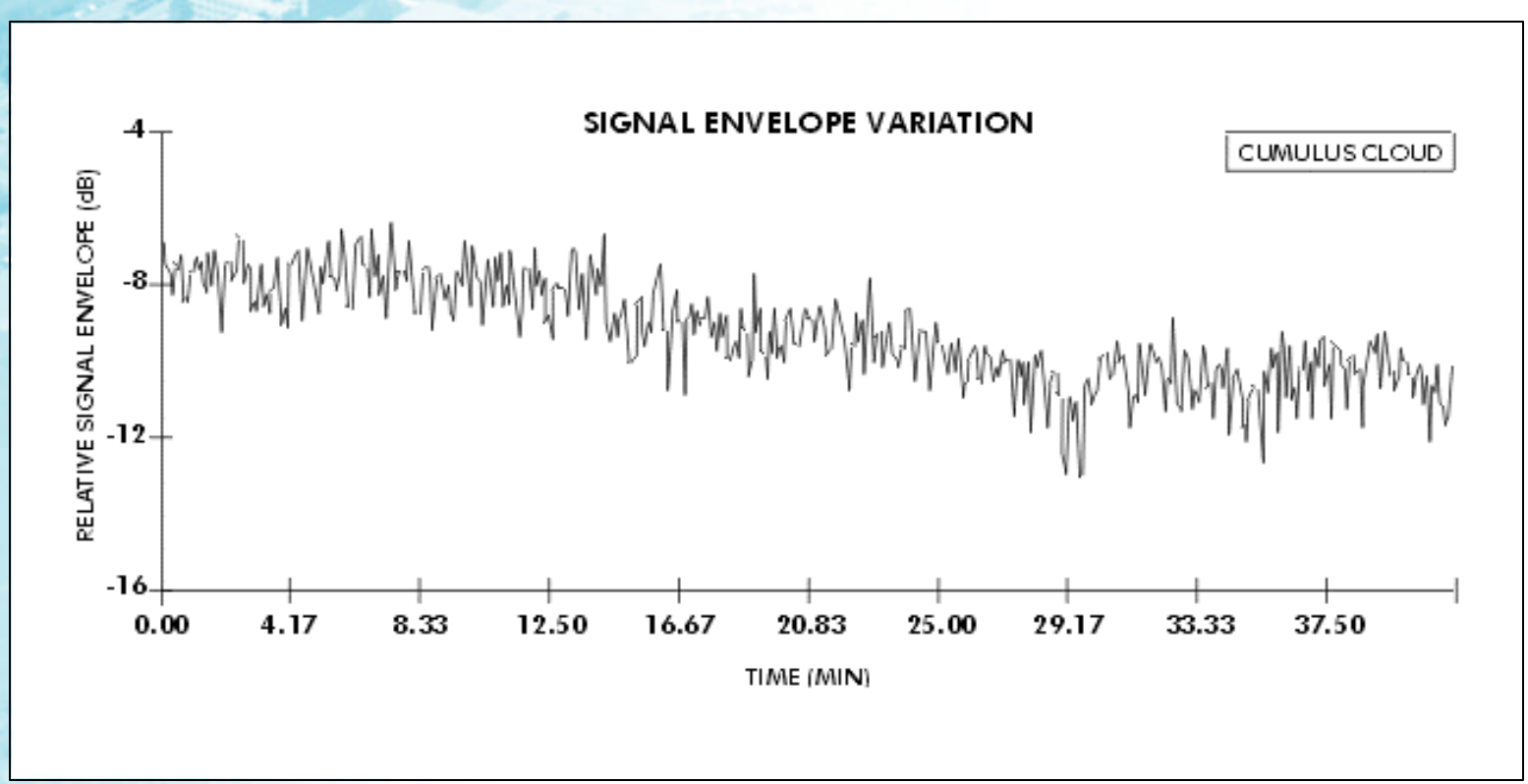
where m_w and σ_w^2 are the mean and variance respectively

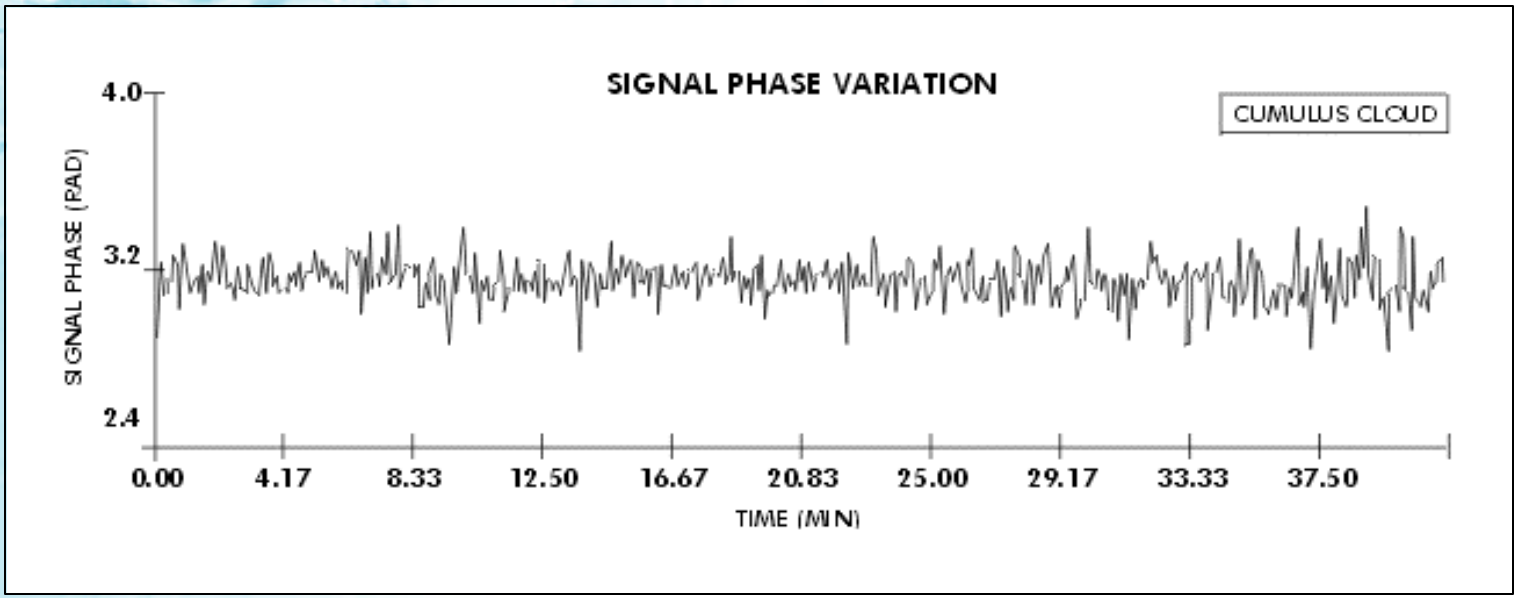
$p_{Loo}(r)$ is the shadowed Rician model

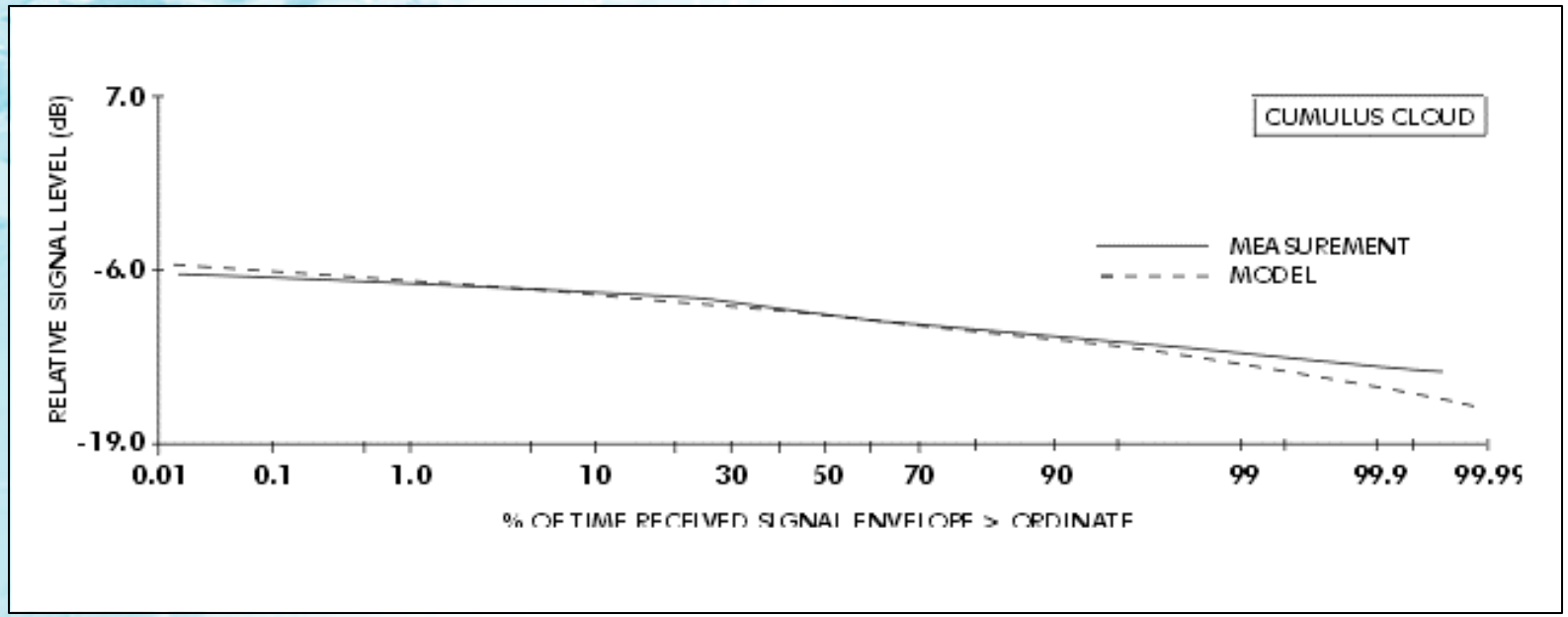
Signal Phase Model for both Fixed and Mobile is Gaussian

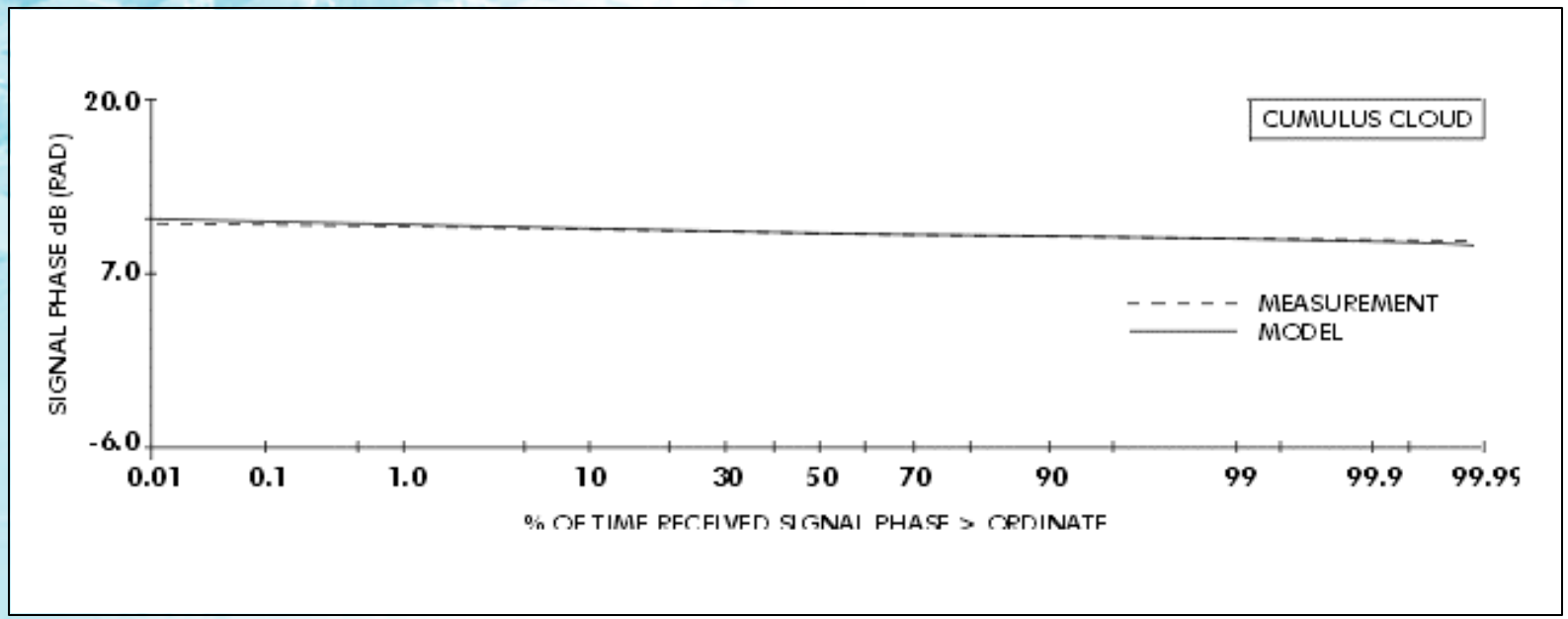
$$p(\phi) = \frac{1}{\sqrt{2\pi}\sigma} exp\,(-\frac{(\phi - m)^2}{2\sigma^2}$$

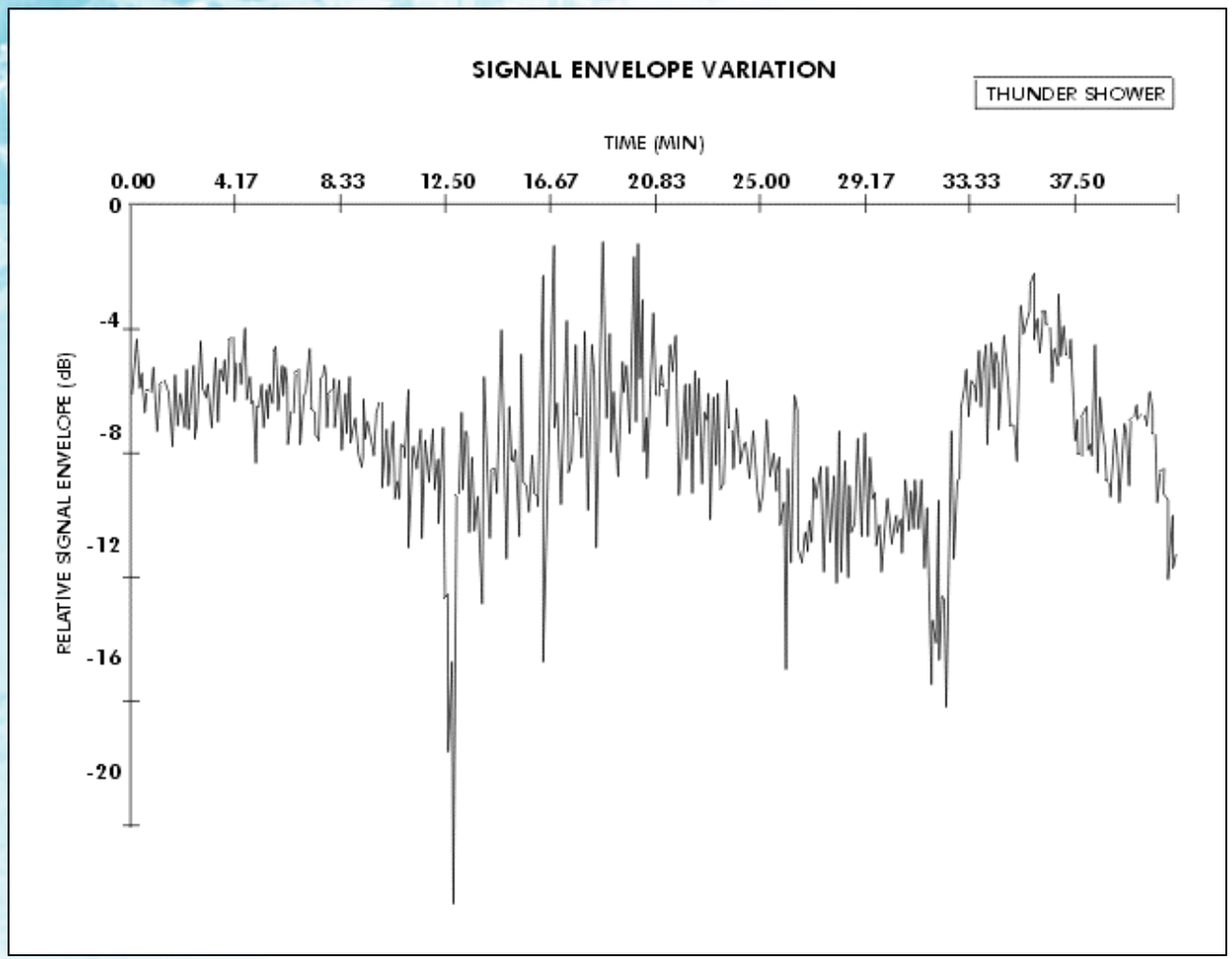
where m and σ^2 are the mean and variance of the signal phase model

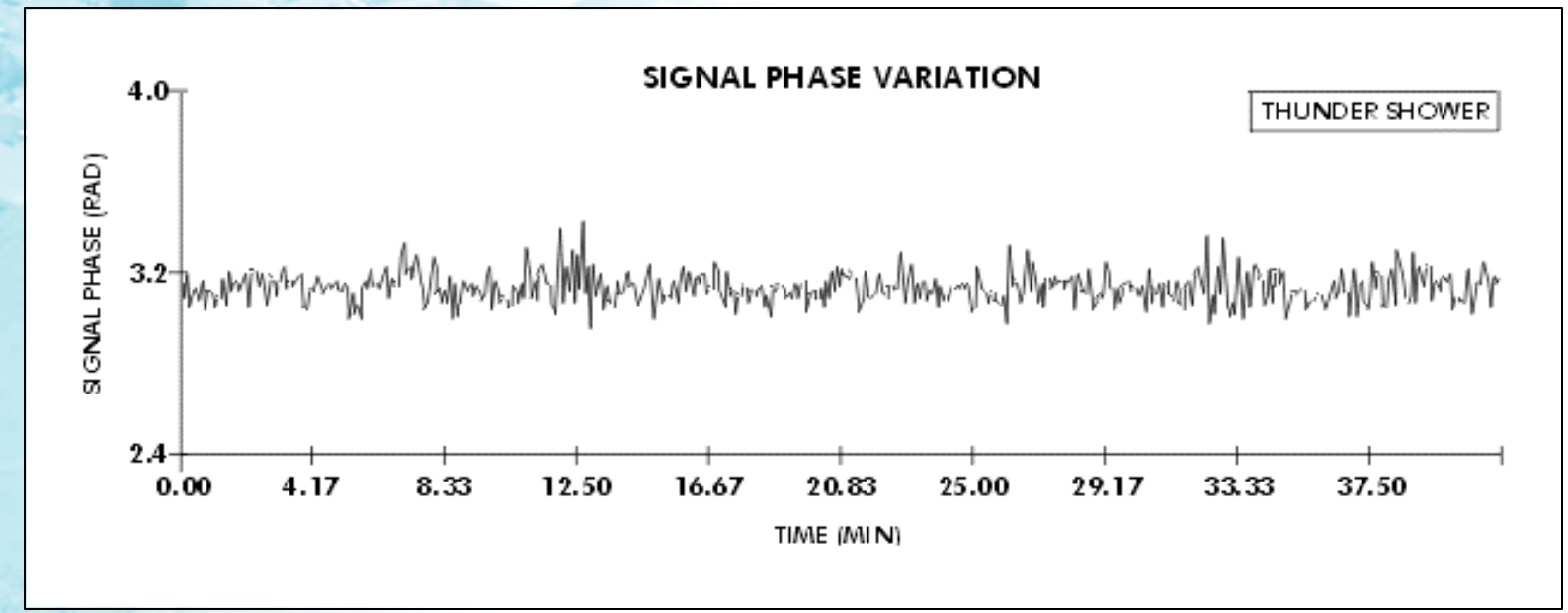

SIGNAL ENVELOPE VARIATION
CUMULUS CLOUD
RELATIVE SIGNAL ENVELOPE (dB)
-4
-8
-12
-16
0.00
4.17
8.33
12.50
16.67
20.83
25.00
29.17
33.33
37.50
TIME (MIN)

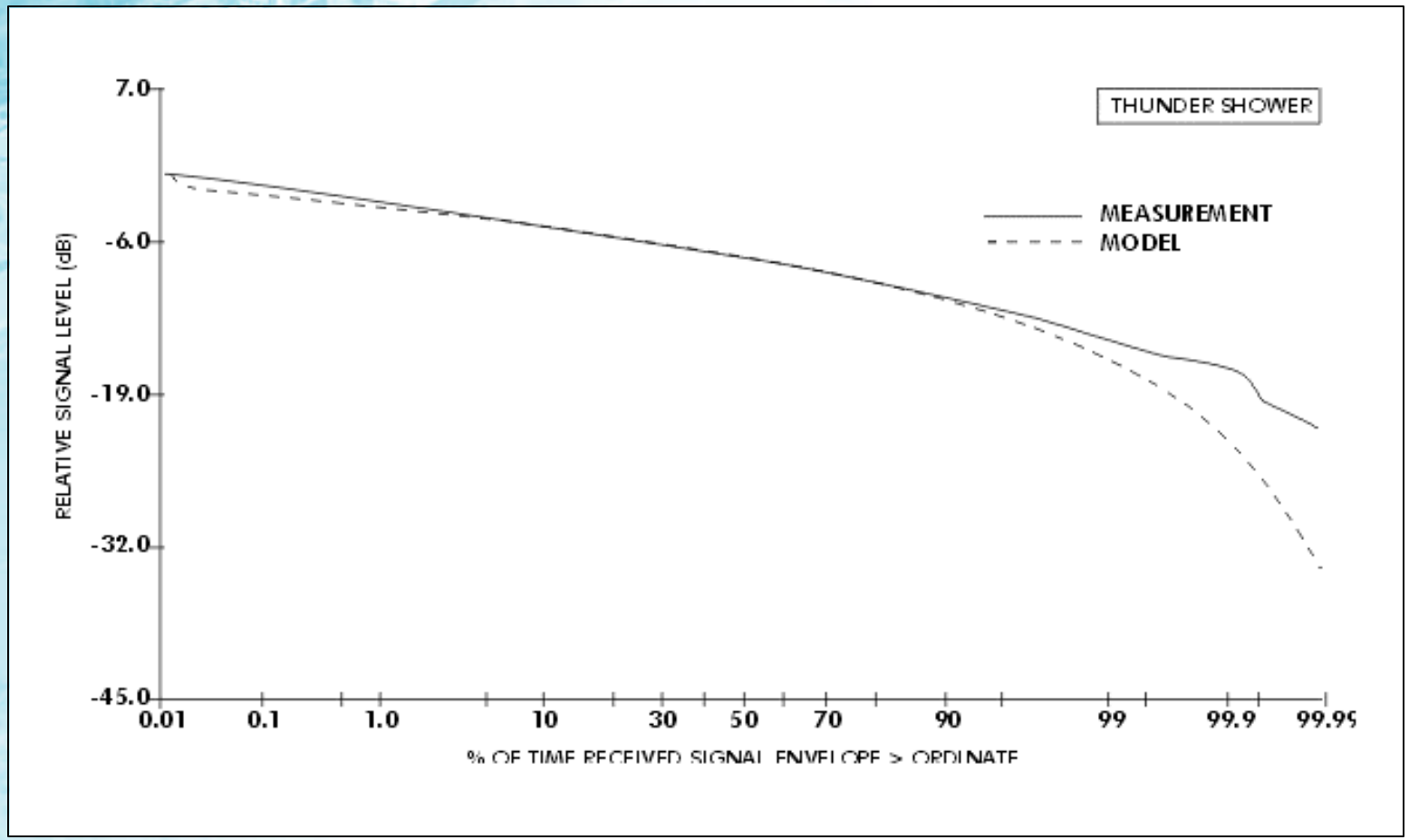

SIGNAL PHASE VARIATION
CUMULUS CLOUD
SIGNAL PHASE (RAD)
4.0
3.2
2.4
0.00
4.17
8.33
12.50
16.67
20.83
25.00
29.17
33.33
37.50
TIME (MIN)

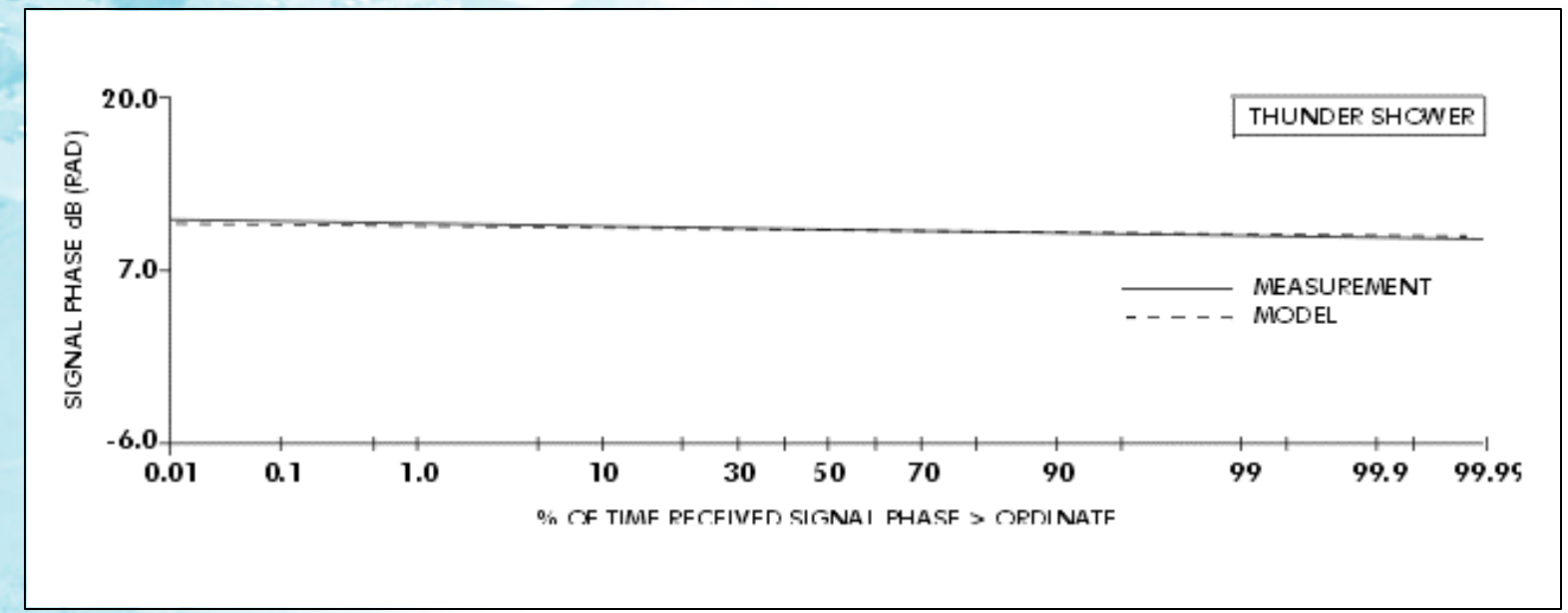

CUMULUS CLOUD
MEASUREMENT
MODEL
RELATIVE SIGNAL LEVEL (dB)
7.0
-6.0
-19.0
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL ENVELOPE > ORDINATE


CUMULUS CLOUD
MEASUREMENT
MODEL
SIGNAL PHASE dB (RAD)
20.0
7.0
-6.0
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL PHASE > ORDINATE


SIGNAL ENVELOPE VARIATION
THUNDER SHOWER
TIME (MIN)
0.00
4.17
8.33
12.50
16.67
20.83
25.00
29.17
33.33
37.50
0
-4
-8
-12
-16
-20
RELATIVE SIGNAL ENVELOPE (dB)


SIGNAL PHASE VARIATION
THUNDER SHOWER
SIGNAL PHASE (RAD)
4.0
3.2
2.4
0.00
4.17
8.33
12.50
16.67
20.83
25.00
29.17
33.33
37.50
TIME (MIN)


THUNDER SHOWER
MEASUREMENT
MODEL
RELATIVE SIGNAL LEVEL (dB)
7.0
-6.0
-19.0
-32.0
-45.0
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL ENVELOPE > ORDINATE


20.0
7.0
-6.0
SIGNAL PHASE dB (RAD)
THUNDER SHOWER
MEASUREMENT
MODEL
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL PHASE > ORDINATE

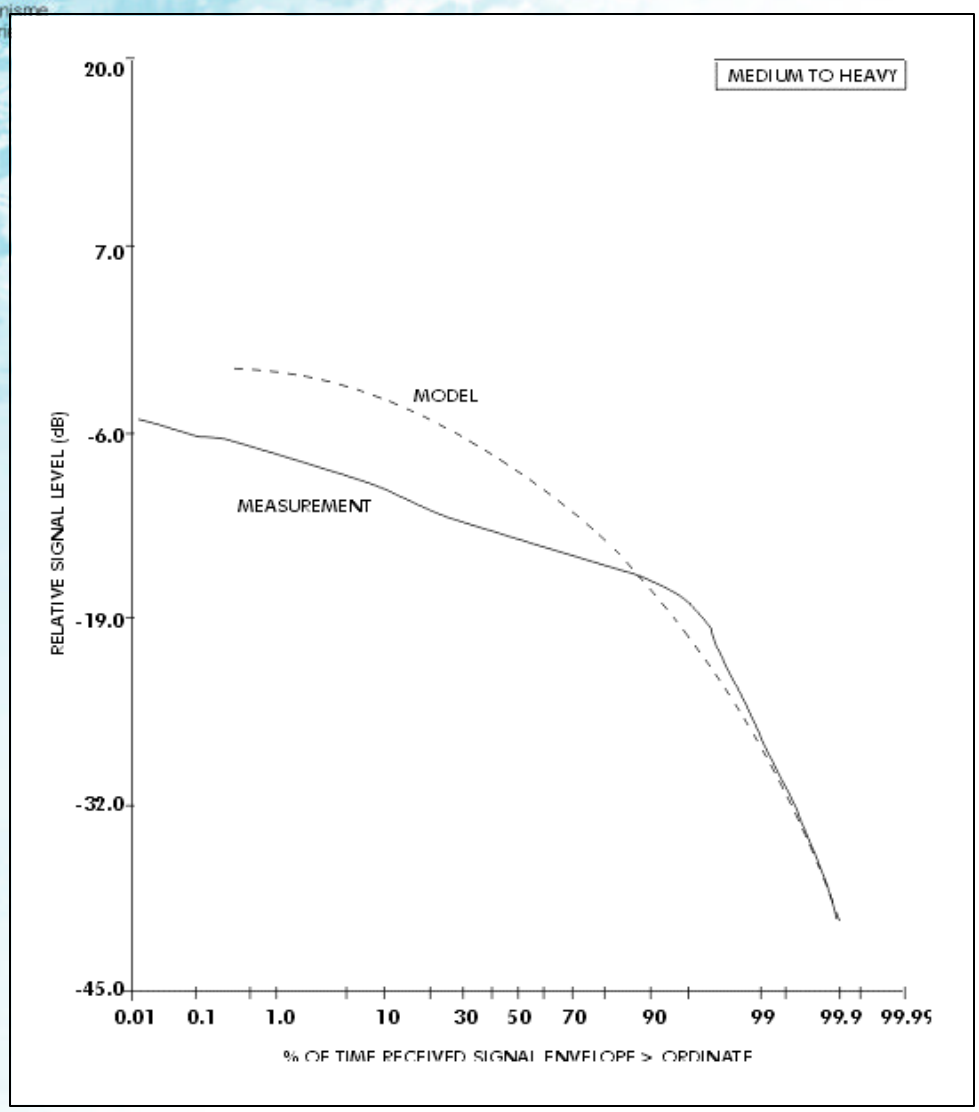
Signal Envelope Model Parameters

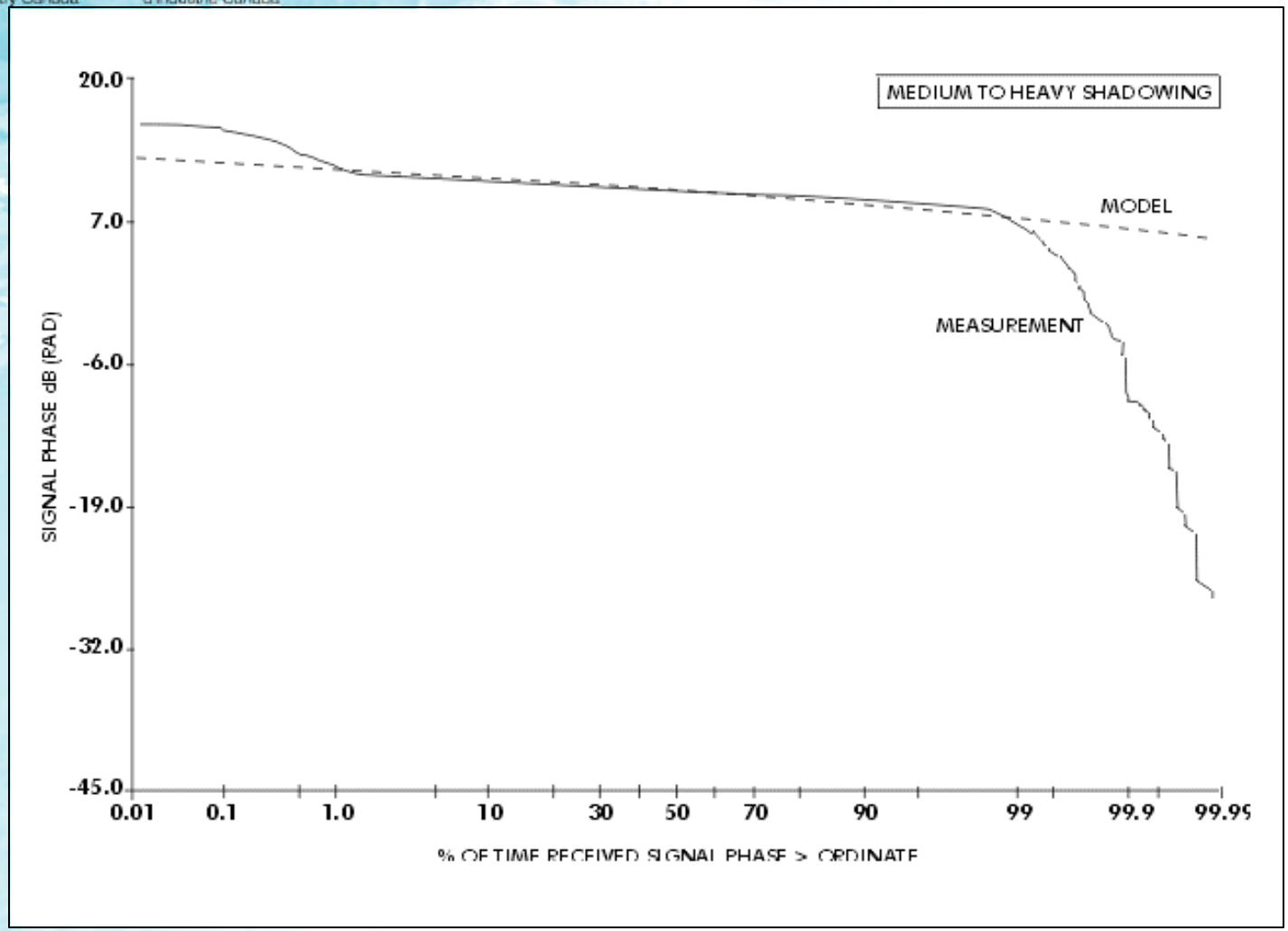
Weather conditions	mean*	variance
Cumulus cloud	0.346	0.00272
Thunder shower	0.436	0.01386
Ice pellets	0.482	0.00062

*nominal signal envelope level is 1. volt

Signal Phase Model Parameters

Weather conditions	mean(rad)	variance(rad^2)
Cumulus cloud	0.0154	0.00864
Thunder shower	0.0068	0.00414
Ice pellets	0.0094	0.00544


MEDIUM TO HEAVY
20.0
7.0
-6.0
-19.0
-32.0
-45.0
MODEL
MEASUREMENT
RELATIVE SIGNAL LEVEL (dB)
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL ENVELOPE > ORDINATE


MEDIUM TO HEAVY SHADOWING
MODEL
MEASUREMENT
20.0
7.0
-6.0
-19.0
-32.0
-45.0
SIGNAL PHASE dB (PAD)
0.01
0.1
1.0
10
30
50
70
90
99
99.9
99.99
% OF TIME RECEIVED SIGNAL PHASE > ORDINATE

Ka Band Mobile Channel

Medium-to-Heavy Shadowing Conditions

Signal Envelope Model Paramters

$\mu = -2.30$ $\sqrt{d_0} = 0.046$ $b_0 = 0.10$

Signal Phase Model Parameters

$m = -0.0144$ $\sigma^2 = 0.1124$

Summary

- Described various channel models
- Compared measured and modeling results
- Provided modeling parameters for the shadowed Rician model and some weather conditions

References

1. C. Loo, "A Statistical model for land mobile satellite link," *IEEE Trans Veh. Technol.*, vol. VT-34, no. 3, pp. 122-127,Aug., 1985

2. C. Loo and J. S. Butterworth, "Land mobile satellite channel measurements and modeling," *Proceedings of the IEEE*, vol. 86, no. 7, pp. 1442-1463, July 1998.

3. J. Goldhirsh and W. Vogel, "Handbook of propagation effects for vehicular and personal mobile satellite systems," *The John Hopkins University and The University of Texas at Austin*, A2A-98-U-0-021(APL) EERL-98-12A(EERL) Dec. 1998