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VHF AND UHF PROPAGATION STUDIES IN THE CANADIAN ARCTIC

by

F.H. PALMER

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ABSTRACT

50// A series of measurements of VHF and UHF radiowave path loss were carried out near Inuvik and Resolute, N.W.T., during 1976 and 1977. Transmitter sites were chosen to be fairly representative of those that would be selected for actual communications facilities. Measurements of path-loss, for various frequencies, polarizations, and transmitting and receiving antenna heights, were made at a number of receiving sites along several radials from each transmitter. Path lengths ranged from 1 to 100 km and covered land, water, and mixed types of terrain. The measurements have been used to construct empirical models of path loss for these areas, and to form a data base with which to compare the predictions of the CRC VHF/UHF propagation prediction computer program.// This report describes the measurement program and the empirical models which have been derived from the results.

1. INTRODUCTION

Although VHF/UHF communication systems are widely used in Northern and Arctic Canada, there is a scarcity of basic propagation information upon which to base the designs of such systems. To fill part of this need, VHF/UHF propagation measurements were carried out near Inuvik and Resolute, N.W.T., during 1976 and 1977.

The measurements have been used to construct empirical models of path-loss in these areas, and to form a data base with which to compare the predictions of the CRC VHF/UHF propagation prediction computer program. This report describes the measurements and the empirical models which have been constructed from them.

The types of terrain found near Inuvik range from flat to hilly with a ground cover of grass or moss and/or relatively sparse, mostly coniferous, trees. These conditions are representative, except for mountainous regions*, of those found over wide areas of northern Canada bounded in the west by the Mackenzie Delta and northern Alberta and by central Quebec in the east.

The terrain found in the Resolute area consists, for the most part, of relatively steep-sided, flat-topped, hills and islands. The ground surface consists of solid or broken rock. It is devoid of vegetation. These conditions are representative, again excepting mountainous regions, of the more northerly areas of Canada which extend to the pole.

2. THE MEASUREMENTS

2.1 MEASUREMENT LOCATIONS

One transmitter site was established at Inuvik and one at Resolute. Transmitter sites were chosen to be fairly representative of those that would be selected for actual communications facilities. The Inuvik site was located upon the highest local point of land (elevation 92 m a.s.l.) and can be considered to be an example of a well sited installation. The Resolute transmitter was sited at an elevation of 30 m a.s.l. with hills, in some directions, rising to 100-200 m within 5 km of the site. For this reason, this site must be considered less than ideal when compared to the Inuvik site. It is however, a good example of the type of site which must be chosen in many northern areas, for logistical reasons. Measurements of path-loss, for various frequencies, polarizations, and transmitting and receiving antenna heights, were made at a number of sites along several radials from each transmitter. These receiving sites were generally chosen to have foregrounds relatively uncluttered by trees (at Inuvik); otherwise little regard was taken of the local terrain. At some sites measurements of transmitting and receiving antenna height gain, location variability, excess attenuation due to trees, and cross-polarization losses were made. Path lengths ranged from 1 to 100 km. Land, water (fresh and salt) or ice, and 'mixed' paths were selected. Figures 1 and 2 indicate the measurement sites at Inuvik and Resolute Bay respectively.

Two sets of measurements were made at different seasons at the two locations. Measurements at Inuvik in September and at Resolute Bay in August were taken as representative of summer conditions since snow cover was thin

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* *Measurements were not made in the Richardson Mountains to the west of the Mackenzie Delta.*

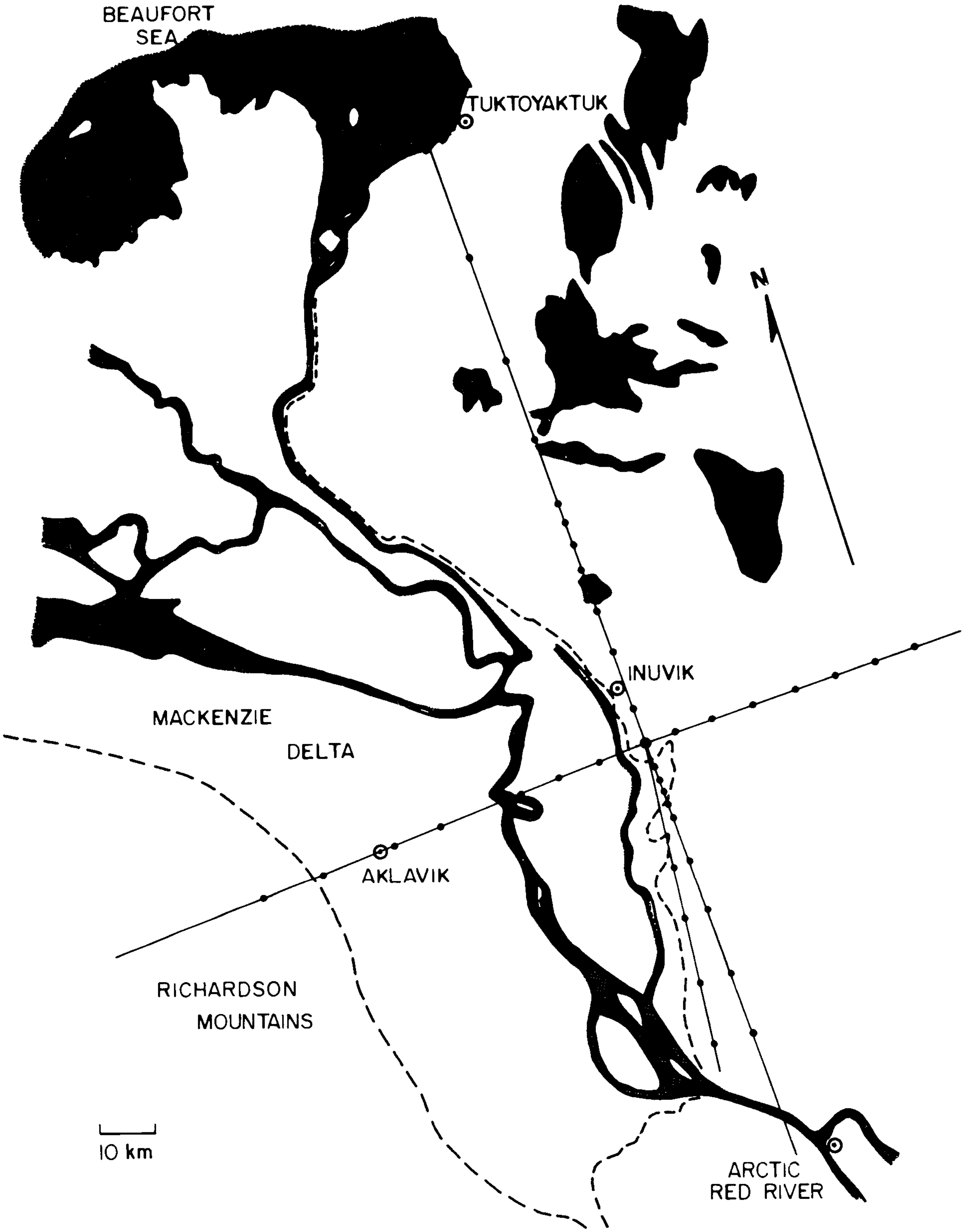

Figure 1. Map of the area around Inuvik, N.W.T., showing measurement radials and sites

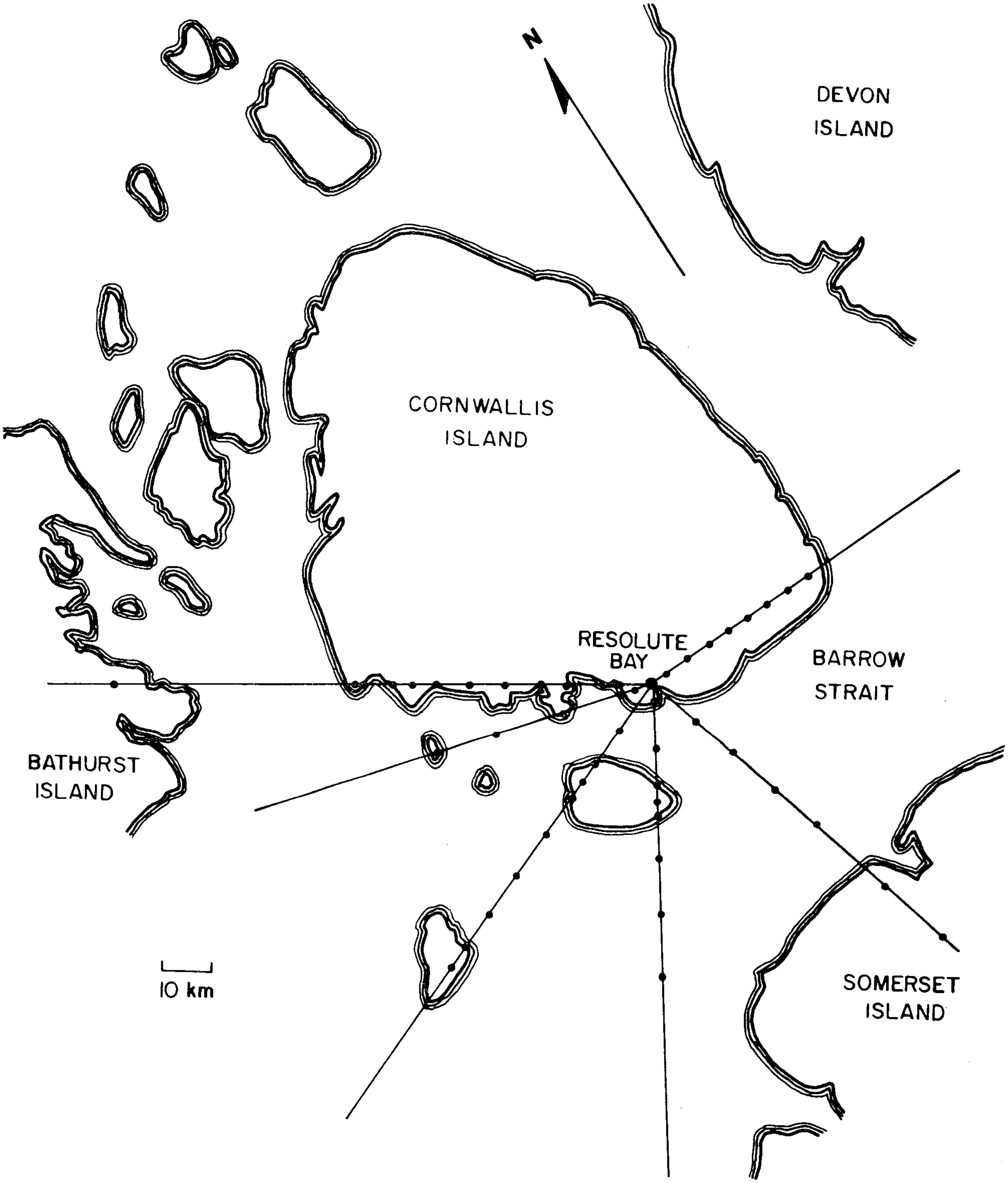

Figure 2. Map of the area around Resolute, N.W.T., showing measurement radials and sites

or absent and large bodies of water were, for the most part, ice-free. Measurements at Inuvik in March and at Resolute in May were taken as representative of winter conditions. Bodies of both fresh and salt water were at that time covered with 1-2 metres of ice and a snow cover was present at both locations. Measurements were made using receiving sites on sea ice near Resolute at this time.

2.2 MEASUREMENT PROCEDURE

At each receiving site measurements of received power were made for the sixteen combinations of:

Transmitter frequency	148 and 450 MHz
Polarization	Vertical and Horizontal
Transmitting Antenna Height	7.2 and 16.5 metres
Receiving Antenna Height	1.5 and 3.0 metres

Received power was measured using a Singer NM 37/57 Field Intensity meter. Transmitter power, line losses, and antenna gains were known, permitting the values of received power to be converted to equivalent values of path-loss.

At a number of sites 'small-scale' location variability studies were made by repeating the measurement sequence several times; the receiving antenna being moved 10-20 metres between each set of measurements. At several other sites, receiving and transmitting antenna height-gain profiles were determined in detail by recording received power levels over a range of transmitting or receiving antenna height rather than at just the two heights normally used. At a number of sites, measurements of path-loss were also carried out using orthogonally polarized transmitting and receiving antennas in order to estimate the amount of depolarization of the received signals.

2.3 SYSTEM CALIBRATION

The effective isotropic radiated power (EIRP), P_t, of a transmitter is given by

$$P_t = P'_t + G_t - L_t \qquad \text{dBm}$$

where P'_t is the actual transmitter output power in dBm, G_t is the transmitting antenna gain above isotropic in dB, and L_t is the transmitter-antenna line loss in dB. The power, P_r, received by an omnidirectional receiving antenna, at the same location as the actual receiving antenna, is related to the power measured at the receiver input in the actual system by

$$P_r = P'_r - G_r + L_r \qquad \text{dBm}$$

where P'_r is the power measured at the receiver input in dBm, G_r is the receiving antenna gain over isotropic in dB, and L_r is the antenna - receiver line loss in dB.

The path-loss between transmitter and receiver is then defined as

$$L_p = P_t - P_r \qquad \text{dB},$$

or as

$$L_p = S - P'_r \qquad \text{dB}$$

where $S = P'_t + G_t + G_r - L_t - L_r$ dB. For a given system, S is usually a constant. In the present measurement program, however, cable lengths and transmitters were changed during the course of the experiment. Due to environmental conditions, the transmitter output power levels varied with time. Values of S, and of its variation, were carefully monitored and appropriate values were used in all calculations.

3. EMPIRICAL DESCRIPTIONS OF PATH-LOSS

Many empirical path-loss models are of the form

$$L_p = a_1 + a_2 \log f + a_3 \log d + a_4 \log h_t + a_5 \log h_r \qquad \text{(dB)}$$

where the frequency, f, is given in MHz; the path-length, d, is given in kilometres; and transmitting and receiving antenna heights h_t and h_r are given in metres. For example, in the Egli (1) model, widely used for calculating path-loss in urban areas, the coefficients a_i take the values

$$a_1 = 85.9;\ a_2 = 20.0;\ a_3 = 40.0;\ a_4 = -20.0;\ a_5 = -20.0 \qquad \text{for } h \geq 10 \text{ m.}$$

$$a_1 = 76.3;\ a_2 = 20.0;\ a_3 = 40.0;\ a_4 = -20.0;\ a_5 = -10.0 \qquad \text{for } h < 10 \text{ m.}$$

In the model due to Murphy (2), for paths in rural areas, the a_i take the values

$$a_1 = 21.4;\ a_2 = 39.4;\ a_3 = 40.0;\ a_4 = -20.0;\ a_5 = -5.3$$

The analytic expressions for free-space and plane-earth path-loss are also of the form given above, with coefficients

$$a_1 = 32.4;\ a_2 = 20.0;\ a_3 = 20.0;\ a_4 = 0.0;\ a_5 = 0.0 \qquad \text{(free-space)}$$

$$a_1 = 120.;\ a_2 = 0.0;\ a_3 = 40.0;\ a_4 = -20.0;\ a_5 = -20.0 \qquad \text{(plane-earth)}$$

3.1 DETERMINATION OF LOSS COEFFICIENTS

It was assumed in the present experiment that path-loss could be represented by an expression of the form given above. Implicit in this model is the assumption that the magnitudes of the a_i are independent of the actual values of the parameters f, d, h_t, and h_r.

3.1.1 The Coefficients a_2, a_4, and a_5

a_2 was determined for each combination of system parameters as follows. For fixed polarization, transmitting antenna height, and receiving antenna height, the path-loss measured at 148 MHz at each site was plotted, as illustrated in Figure 3, against the corresponding path-loss at 450 MHz. This procedure was repeated using data from each receiving site. A straight line was fitted through the data points. The deviation of this line, in dB, from a line at 45° passing through the origin is equal to a log(450 MHz/148 MHz) = $0.4829a_2$. This immediately enables a_2 to be determined for the polarization and antenna heights chosen.

Repeating this procedure for the other transmitting and receiving antenna heights gives a total of four estimates of a_2 for each polarization. Mean values and (approximate) standard deviations, s, of the four estimates of a_2 can be derived from these estimates.

Mean values and standard deviations of the coefficients a_4 and a_5 were derived in a similar manner. Actual antenna heights above the ground surface were used in the derivations of a_4 and a_5 (see Section 6).

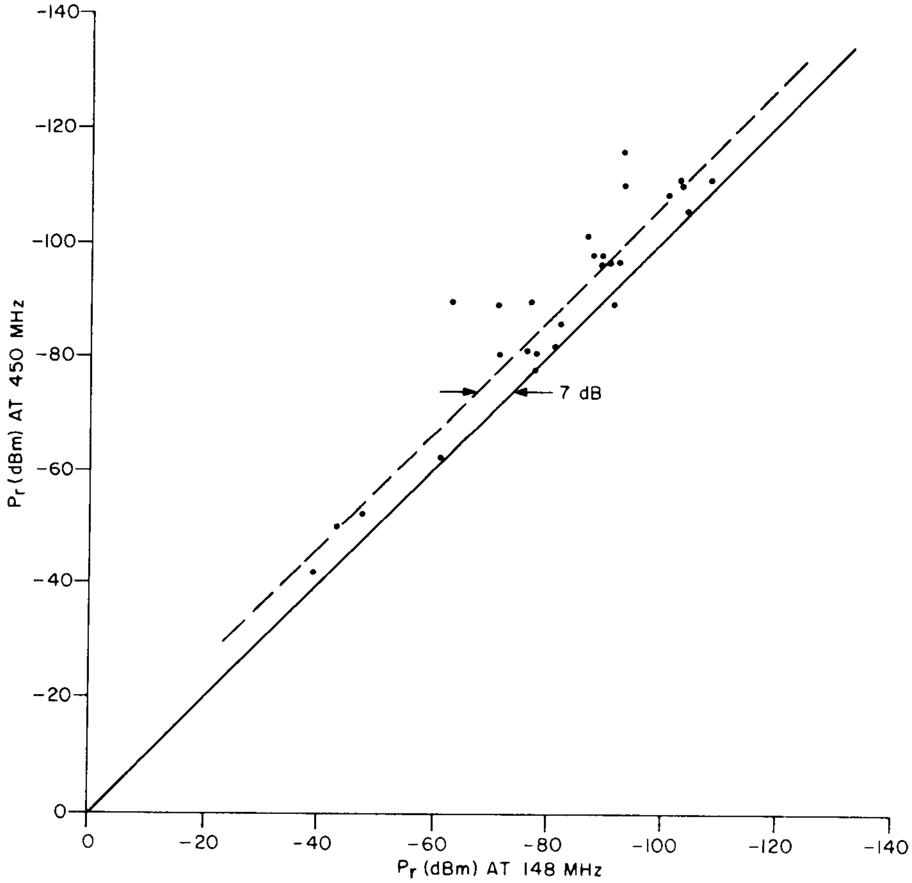

Figure 3. Plot of received power at 450 MHz as a function of power received at 148 MHz. Resolute Bay, August 1976. The coefficient a_2 is derived from the difference, in this case 7 dB, between the best fit straight line through the data and a line at 45° passing through the origin. HTX = 16 m, HRX = 1.5 m, Vertical polarization.

3.1.2 The Coefficients a_1 and a_3

The expression for path-loss may be rewritten in the form

$$L_P - a_2 \log f - a_4 \log h_t - a_5 \log h_r = x = a_1 + a_3 \log d$$

If x, determined using the previously derived values of a_2, a_4, and a_5, is plotted as a function of log d, the x - intercept and slope of the best-fit straight line give the values of a_1 and a_3 respectively. An example of such a plot is shown in Figure 4.

The experimentally determined values of the a_i for Inuvik and Resolute, for both summer and winter conditions and for vertical and horizontal polarization, are given, together with the corresponding values of the standard deviations, in Table 1.

TABLE 1

Measured values of the coefficients a_i, and corresponding standard deviations s, of the empirical path-loss expression, $L_P = a_1 + a_2 \log f + a_3 \log d + a_4 \log h_t + a_5 \log h_r$.

	Vertical Polarization				**Horizontal Polarization**			
	Summer		**Winter**		**Summer**		**Winter**	
	a_i	s	a_i	s	a_i	s	a_i	s
INUVIK								
1)	74.0	6.48	71.9	5.57	67.9	7.44	65.7	5.74
2)	5.69	2.33	6.72	4.37	7.39	1.71	9.22	3.72
3)	45.9	4.37	41.8	3.74	45.9	5.01	45.4	3.85
4)	-5.79	0.93	-7.06	3.00	-5.44	1.24	-7.97	4.10
5)	-9.88	1.37	-16.78	1.83	-14.20	3.49	-15.70	2.02
RESOLUTE								
1)	90.1	7.38	94.8	6.74	87.4	8.70	97.7	7.04
2)	8.07	5.30	9.11	1.89	9.32	4.95	6.42	1.81
3)	32.2	5.92	29.8	4.73	32.7	6.09	30.4	4.94
4)	-7.12	1.97	-6.78	3.95	-6.56	4.55	-5.52	2.69
5)	-8.55	1.28	-16.86	1.85	-13.29	3.83	-17.03	2.33

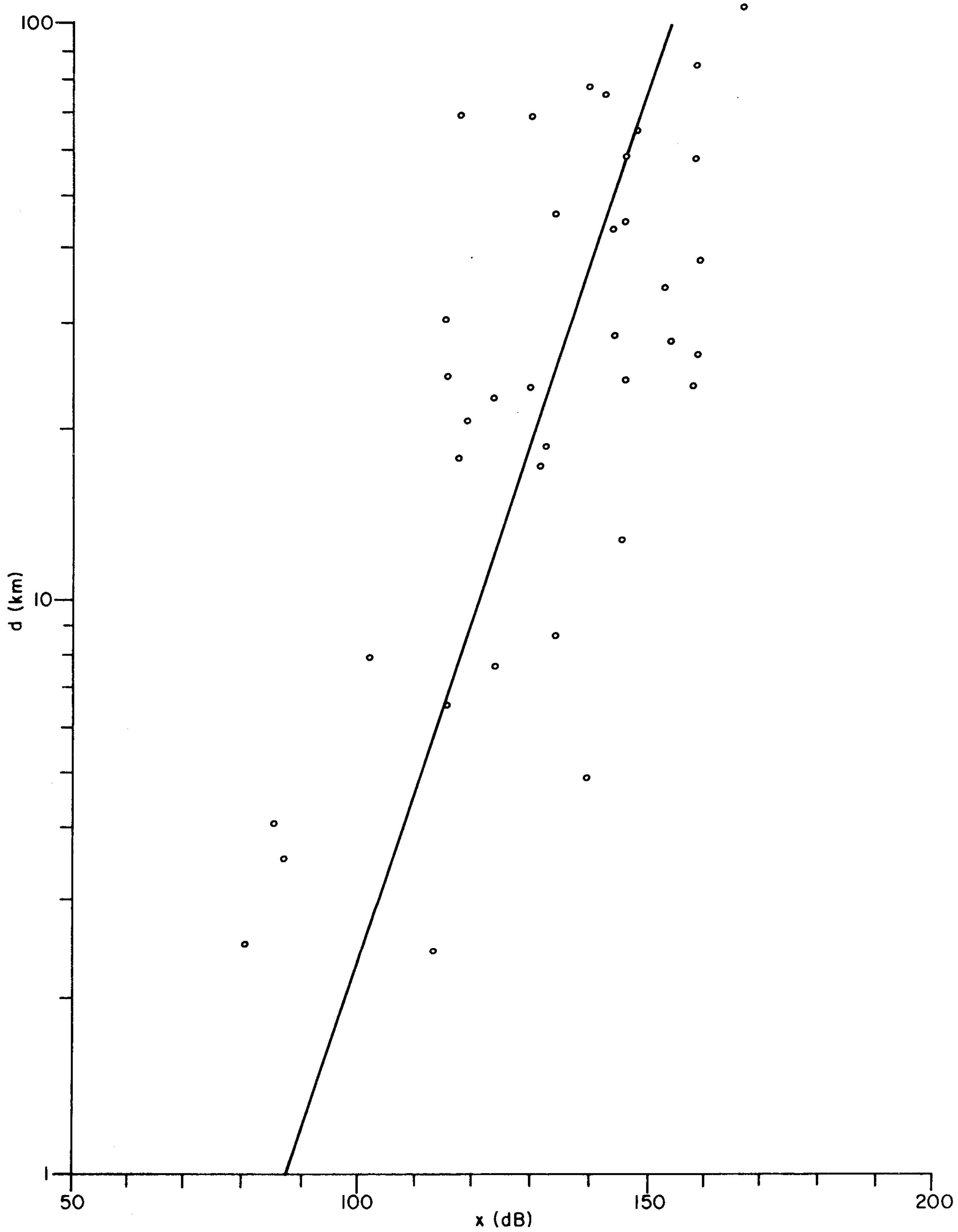

Figure 4. Plot of the value of the parameter x as a function of path-length. In this case, the circles represent the median values of the 16 measurements made at each site.

3.2 DISCUSSION OF RESULTS

3.2.1 Inuvik

The mean value of the coefficient a_1 is 72.9 for vertically polarized signals and 66.8 for horizontally polarized signals. The difference between the two cases is barely significant in light of the magnitudes of the corresponding values of s. If real, the difference can probably be attributed to the differing effects of vegetation, especially trees, at the two polarizations. This will be further discussed in Section 4.

The mean of the four determinations of a_2 is 7.26. This value is within the standard deviation calculated for the four individual values of a_2. A value of 7.3 will thus be taken as representative both of summer and winter and of vertically and horizontally polarized signals.

The mean of the four determinations of a_3 is 44.8 with a standard deviation of 2.0. There is no evident dependence upon season or polarization.

The mean value of a_4 is 6.57. This is within one standard deviation of the four individual values of a_4. A value of $a_4 = 6.6$ will be taken as representative of all conditions.

Three of the four determinations of a_5 are mutually consistent. i.e., $a_5 = 15.56 \pm 1.30$. The fourth value (summer, vertical polarization) is 9.88. This difference can probably be attributed to the differing effects of wet (summer) and dry (winter) ground on horizontally and vertically polarized signals received by the low (1.5 and 3.0 metres) receiving antennas. This point will be discussed in detail in Section 6. There it will be shown that $a_5 = 15.56$, rounded off to 15.6, is appropriate when h_r is taken to be the effective antenna height h_{eff} rather than the actual antenna height h_r. Such an effect was not noted in the case of a_4 since the transmitting antenna height was at all times greater than the minimum effective antenna height h_{min}.

3.2.2 Resolute

The mean of the four determinations of a_1 is 92.5 ± 4.6. There is essentially no difference between the values derived for the horizontally and vertically polarized cases (92.6 and 92.5 respectively). This is consistent with the total lack of ground surface cover at this location. Winter values of a_1 are, however, higher than the summer values, i.e., a_1 (summer) = 88.8, a_1 (winter) = 96.3. The difference between these two values is barely significant in light of the corresponding values of s. There is in any case no obvious physical explanation for this difference as there was in the case of the Inuvik results for horizontal and vertical polarization.

The mean of the four determinations of a_2 is 8.23. This value is within one standard deviation of the four individual values of a_2. A value of 8.2 will be taken as representative both of summer and winter and of vertically and horizontally polarized signals.

The mean value of a_3 is 31.3 with no evident dependance on season or polarization.

The mean value of a_4 is 6.50. This is within one standard deviation of the four individual values of a_4. A value of $a_4 = 6.5$ will be taken as representative of all conditions.

As was the case for Inuvik, three of the four determinations of a_5 are mutually consistent, i.e., $a_5 = 15.73$ with a standard deviation of 2.11. The fourth value (summer, vertical polarization) is 8.55. For reasons that will be discussed in Section 6, a_5 will be taken as 15.7 where the effective antenna heights above ground are used in the calculations.

3.2.3 Intercomparisons of Inuvik and Resolute Results

Results discussed in the previous section may be summarized in the following path-loss expressions:

Inuvik

a. Vertical Polarization

$$L_P = 72.9 + 7.3\log(f) + 44.8\log(d) - 6.6\log(h_t) - 15.6\log(h_r) \quad \text{dB}$$

b. Horizontal Polarization

$$L_P = 66.8 + 7.3\log(f) + 44.8\log(d) - 6.6\log(h_t) - 15.6\log(h_r) \quad \text{dB}$$

Resolute

a. Summer

$$L_P = 88.7 + 8.2\log(f) + 31.3\log(d) - 6.5\log(h_t) - 15.7\log(h_r) \quad \text{dB}$$

b. Winter

$$L_P = 96.3 + 8.2\log(f) + 31.3\log(d) - 6.5\log(h_t) - 15.7\log(h_r) \quad \text{dB}$$

where h_r is the *effective* receiving antenna height above ground.

In view of the closeness of the values of a_2, a_4, and a_5 for both Inuvik and Resolute, the following values will be taken as representative of both locations:

$$a_2 = 7.7; \; a_4 = -6.5; \; a_5 = -15.6$$

For Inuvik then;

$$L_P = \begin{matrix} 72.9 \text{ (V. Pol.)} \\ 66.8 \text{ (H. Pol.)} \end{matrix} + 7.7\log f + 44.8\log d - 6.5\log h_t - 15.6\log h_r \quad \text{(dB)}$$

and for Resolute:

$$L_P = \begin{matrix} 88.7 \text{ (Summer)} \\ 96.3 \text{ (Winter)} \end{matrix} + 7.71\log f + 31.3\log d - 6.5\log h_t - 15.6\log h_r \qquad \text{(dB)}$$

The magnitudes of a_4 and of a_5 are essentially identical at the two locations. It is of some interest, however, that a_4 and a_5 are not equal at a given location. The experimental values of the coefficients show that path loss decreases rapidly as an antenna is raised through the height range 1.5 to 3.0 metres, but more slowly when raised through the range 7.2 to 16.5 metres. This is not entirely unexpected, however, since the shadowing effects of local terrain (trees, boulders, etc.) become less important as antenna height increases, and also, in the limit of free-space propagation, there is no height dependence of path-loss. It is probable that for transmitting or receiving antenna heights less than about 5 m, that both a_4 and a_5 have values near 15.6, while for transmitting and receiving antenna heights greater than about 5 m, both a_4 and a_5 have values near 6.5. In reality, the magnitudes of a_4 and a_5 are probably smoothly varying functions of height.

Large differences in path-loss exist between the Inuvik and Resolute predictions for path-lengths in the 1-10 km range. At Inuvik, path-losses are essentially equal to free-space losses at distances of less than about 2 km. At Resolute, path-losses average about 20 dB higher than free-space at 2 km. The difference between the two locations can probably be attributed to the difference in the sitings of the transmitting antennas with respect to the local terrain. At Resolute, many receiving sites at distances of between 1 and 10 km were shadowed by local terrain, whereas at Inuvik most short paths were unobstructed due to the 'favourable' siting of the transmitting antenna.

At distances between about 10 and 100 km, the predictions of the two path-loss expressions merge, indicating that for the longer paths the nature of the terrain in the immediate vicinity (1-10 km) of the transmitter is of diminishing importance.

4. TERRAIN COVER EFFECTS

There is no vegetative ground surface cover at Resolute. At Inuvik, however, much of the surrounding areas are sparsely to moderately densely covered with coniferous trees with maximum heights near 5 m. Horizontal branch lengths are typically 1m or less. A number of measurements were carried out in order to investigate path-loss variations in and near such treed areas.

As a control, sets of path-loss measurements, separated by about 20m perpendicular to the propagation path, were made at sites devoid of tree cover. The underlying terrain in these areas was smooth on a scale of 20m. The differences between the sixteen corresponding sets of individual measurements ranged from -1 to +2 dB, with a mean difference of 0.6 dB. These small differences appeared random with no clear dependence upon either frequency or polarization.

Measurements made using vertically polarized signals at sites within or behind treed areas showed higher losses than did similar measurements in nearby areas clear of trees. The average excess loss, at both 148 and 450 MHz was about 5 dB for sites situated within treed areas. The equivalent excess loss for horizontal polarization was near 1 dB. This is close to the noise level of the individual measurements. The results of several sets of measurements are shown in Figure 5 where path-loss relative to unobstructed sites is plotted as a function of the distance, along the propagation path, between the treed areas and the measurement sites. The standard deviation of the path-loss within treed areas is seen to be about 3 dB.

These results show the magnitude of the additional path-loss caused by trees in the immediate vicinity of the receiving site. These losses are in addition to those predicted using the expressions derived in Section 3.1 for randomly sites antennas. The expressions of Section 3.1 show that path-losses for vertically polarized signals are generally higher, at Inuvik, than for horizontally polarized signals - even for clear receiving sites. For non-

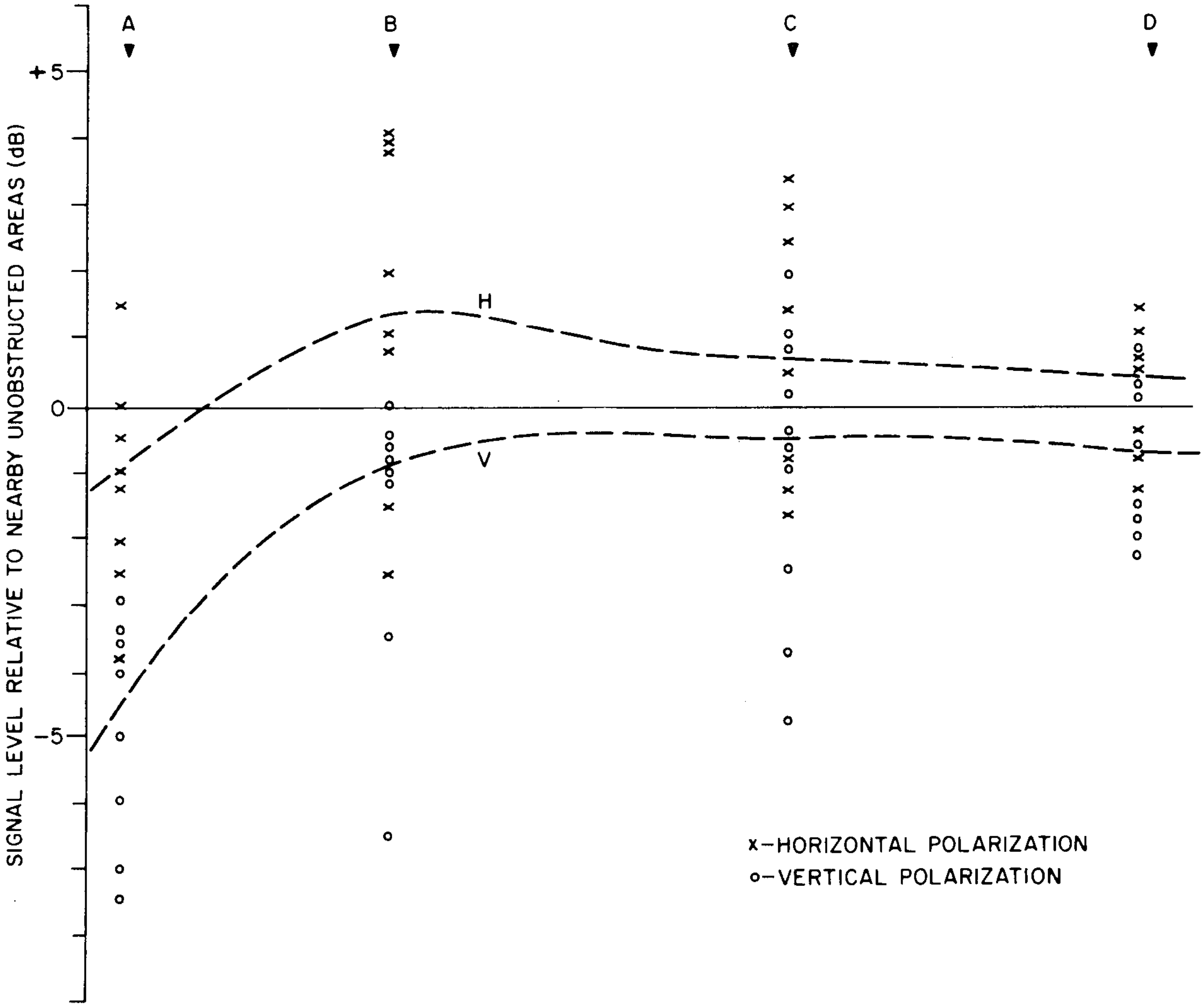

Figure 5. Signal levels, received at various distances behind treed areas, relative to the signal levels received in nearby open areas. A – receiving site in treed areas; B – site 50 ft. behind treed areas; C – site 100 ft. behind treed area; D – site 200 ft. behind treed area. The 'H' indicates fit to data using horizontal polarization, the 'V' to vertical polarization.

line-of-sight paths the excess loss probably occurs when the signal propagates through the tree cover on the crests of the obstructing hills. This is consistent with the Resolute data in which there is essentially no difference between the losses at vertical or horizontal polarization, and where there is no terrain cover on the obstructing hills. Unobstructed, line-of-sight paths at Inuvik show essentially identical losses at the two polarizations.

5. LOCATION VARIABILITY

5.1 SMALL-SCALE VARIABILITY

5.1.1 Treed Areas

In the previous section it was shown that in moving a receiver from an area with a clear foreground to an areas within or immediately behind a treed area an increase in path-loss of about 5 dB will be encountered when using vertically polarized signals. In these treed areas, the standard deviation of any one of the sixteen measurements made was about 3 dB.

5.1.2 Open Areas

Measurements made in open areas (smooth, uncluttered ground surface for at least several hundred metres in front of receiving antenna) show that variations in path-loss occur when the receiving antennas are moved over distances of 10 to 20 m. These variations are small and show no clear dependence upon polarization or frequency. The observed variability for three separate groups of measurements is shown in Figure 6. For all ranges of parameters the standard deviations of the variations of path-loss are 1 to 1.5 dB, with maximum variation in the median received power of about 1 dB. There was no evident difference between the results of measurements made in open areas at Inuvik or Resolute Bay.

5.2 LARGE-SCALE VARIABILITY

The large-scale (distances of 1 to 10 km) variability of path-loss can be determined by comparing measured values of path-loss at each receiving site to the values predicted by the expressions of Section 3.1. The standard deviations of the differences between measured and calculated path-losses (all data) are 10.3 dB at Inuvik and 14.9 dB at Resolute. The frequency dependence of the standard deviations is less than 1 dB..

6. EFFECT OF GROUND SURFACE CONDITIONS ON MEASURED HEIGHT-GAIN

The coefficients a_2, a_4, and a_5 shown in Table 1 for Inuvik and Resolute, and for summer and winter conditions, do not differ significantly with the exception of the values of a_5 for vertically polarized signals under summer conditions. These values of a_5 are significantly lower than those obtained using horizontal polarization, summer or winter, or vertical

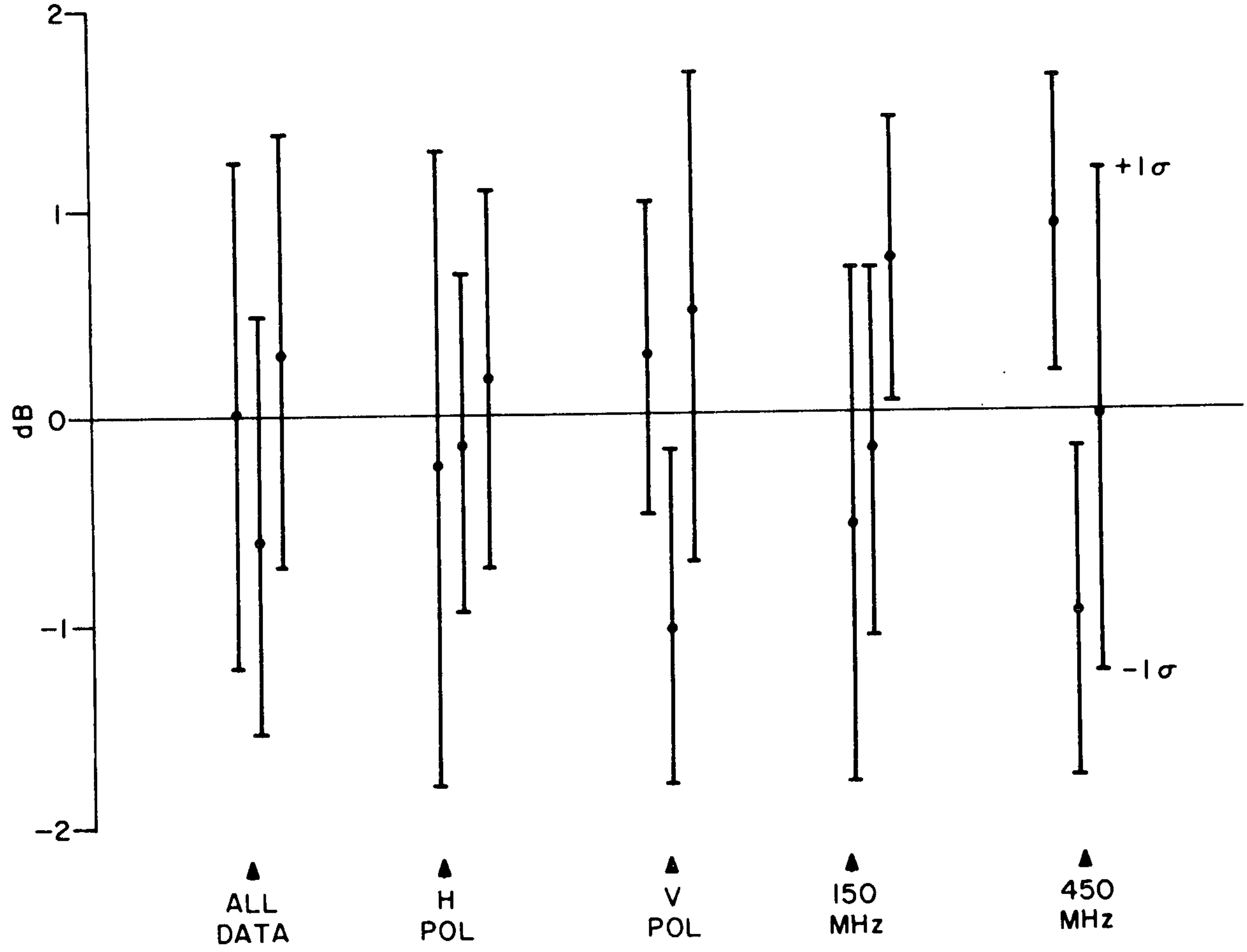

Figure 6. Changes in signal level over 100 ft. distances for open sites. The three sets of data correspond to three separate sets of measurements. "all" represents combined data using both polarizations and both frequencies.

polarization in the winter. It will be shown that this effect probably results from using actual receiving antenna heights in the derivations of a_5 when in fact, the effective antenna heights should have been used. Measurements made in summer using vertical polarization represent the only cases in which the actual antenna heights used are less than the minimum effective antenna height defined as (4):

$$h^V_{min} = \frac{\lambda}{2\pi}\left[(\varepsilon + 1)^2 + (60\ \lambda\sigma)^2\right]^{\frac{1}{4}} \qquad \text{for vertical polarization}$$

$$h^H_{min} = \frac{\lambda}{2\pi}\left[(\varepsilon - 1)^2 + (60\ \lambda\sigma)^2\right]^{-\frac{1}{4}} \qquad \text{for horizontal polarization}$$

where σ and ε are ground conductivity and permittivity respectively.

The effective antenna height is given by

$$h_{eff} = \left[(h^{V}_{min} \text{ or } h^{H}_{min})^2 + h^2_{actual} \right]^{\frac{1}{2}}$$

When the actual antenna height is greater than about 2.2 times the minimum effective height, the effective height and the actual antenna height differ by less than 10%. In the present experiment, h^{H}_{min} is less than 0.12m under all conditions, and the effective antenna heights, for horizontal polarization, may be considered equal to the actual antenna heights.

Under winter conditions, the ground surfaces at both Inuvik and Resolute may be considered dry, and to have relatively low values of σ and ε. If σ and ε are assumed to be those of dry rock, the effective antenna heights for vertically polarized antennas are essentially equal to the actual heights. The situation is otherwise for vertically polarized signals under summer conditions.

In summer the ground surfaces at Inuvik and Resolute are generally quite wet. At Inuvik, the ground surface in many places approximates swampland and values of σ = .01 mho/m and ε = 10. could be assumed, using values given in reference 5. It must be noted however that these values of σ and ε are those derived for use in medium and long-wave propagation. Because of the much smaller skin depths associated with VHF and UHF waves (0.4 m @ 148 MHz and 0.2m @ 450 MHz), it is to be expected that the relevant ground constants are more nearly those of the actual ground surface than is the case for medium or long-waves. Since the ground surface contains a high percentage of water during the summer, an upper limit to the possible values of σ and ε are .01 and 80 respectively, the values for fresh water. Two cases will be considered:

case a. σ = .01 and ε = 10.

and case b. σ = .01 and ε = 80.

In the absence of information concerning the magnitudes of the ground constants at Resolute, the same values of σ and ε will be assumed for that location, although it is realized that the surface water content at Resolute is less than at Inuvik. The above values of σ and ε lead to the following estimates of effective antenna heights for vertical polarization.

		148 MHz		450 MHz	
	h_{actual} =	1.5m	3.0m	1.5m	3.0m
Case a.	h_{eff} =	1.8m	3.2m	1.5m	3.0m
Case b.	h_{eff} =	3.2m	4.1m	1.8m	3.2m

Using these values of effective antenna height and the experimentally determined values of path-loss at the two receiving antenna heights, the following corresponding estimates were derived for a_5, using the techniques described in Section 3.1.1. Also shown, in case (c) below, are the average values of a_5 derived earlier for vertical polarization, winter, and horizontal polarization, summer and winter.

	Inuvik	Resolute
Case a.	11.5	9.7
Case b.	20.5	17.3
Case c.	15.6	15.7

The values of a_5 determined for the cases a) and b) are seen to bracket the values of a_5 shown in c). This indicates that the appropriate values of the ground constants at each location fall between the values chosen in a) and b) above; say $\sigma = .01$ and $\varepsilon = 45$. It is also clear that if the appropriate effective antenna heights are used, the values of a_5 of 15.6 or 15.7 may be taken to hold under all conditions.

7. PATHS OVER ICE-COVERED FRESH WATER

It is well-known that bodies of smooth fresh water can be efficient reflectors of VHF and UHF waves. It might be expected that ice-covered fresh water has essentially the same properties since fresh-water ice has low conductivity and should be almost transparent at VHF and UHF.

Transmitting antenna height-gain measurements were carried out at Resolute over a relatively short (3.5 km) path which included Resolute Lake. This path satisfied the geometrical requirements for the production of an interference pattern at the receiver as a result of reflections from the lake surface. Plots of received power are shown in Figures 7a and 7b as a function of transmitter height for 148 and 450 MHz and for both horizontally and vertically polarized signals. Also shown are calculated curves, assuming reflections from open fresh water, for the same path. The agreement is striking with the exception that the measured null depths for horizontally polarized signals are lower than the computed depths. The most likely reason for this is that the limited extent of the lake along the propagation path results in its not being fully illuminated by the first Fresnel zone of the incident (reflected) ray. It appears that an ice cover has little effect on VHF/UHF waves reflected from fresh water.

8. PATHS OVER ICE-COVERED SALT WATER

Calculated curves showing path-loss as a function of distance have been prepared by the CCIR (3) for VHF signals propagating over smooth salt (sea) water. In the present work it was not possible to carry out comparisons of measured and theoretically predicted losses over open sea water. In any case, these types of measurements have been carried out previously and are of minimal interest in the present context. However, a number of measurements were made at Resolute of path-loss at 148 MHz as a function of distance over ice-covered sea water. The ice surface was, for the most part, smooth with very few ridges.

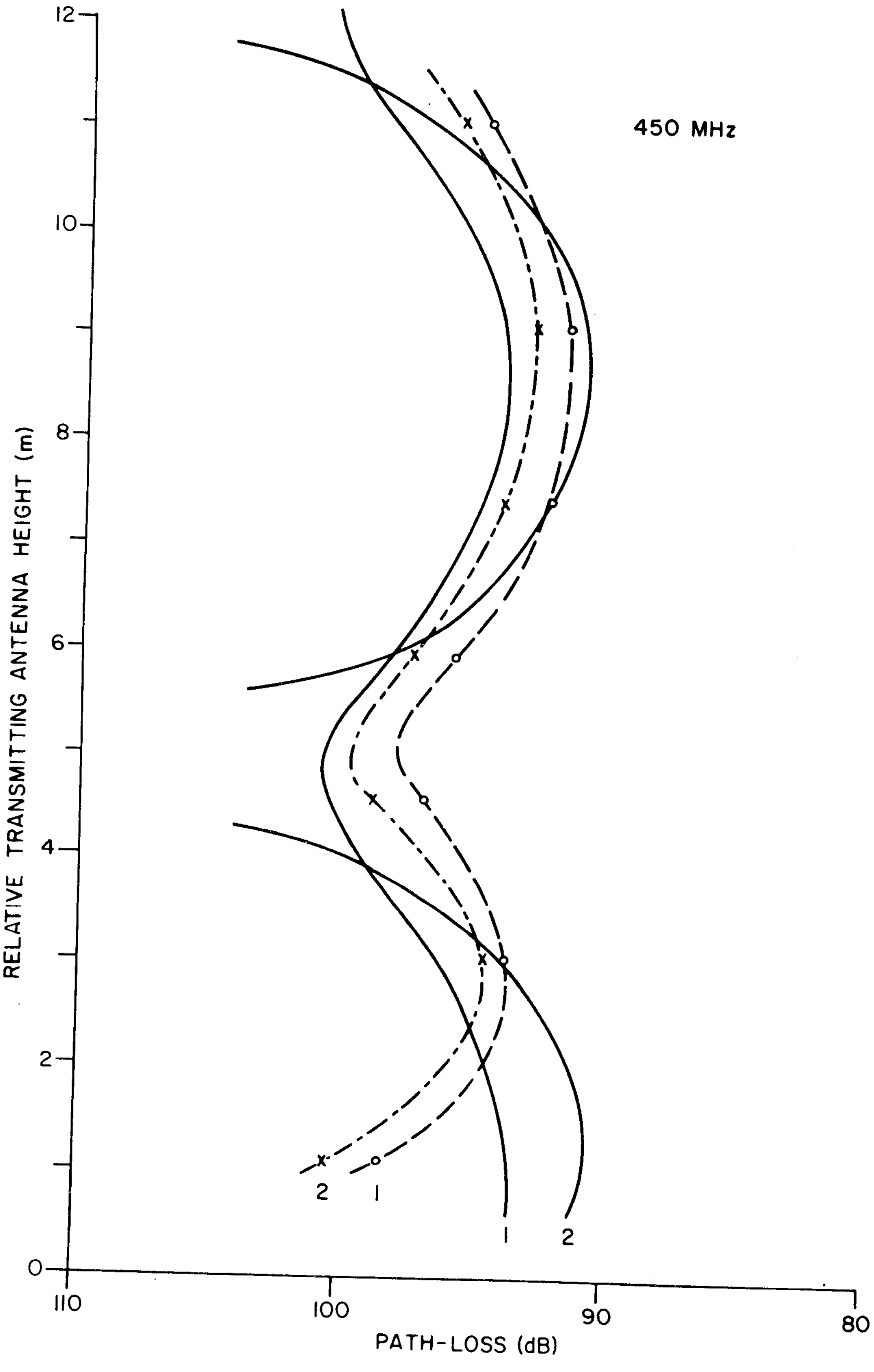

Figure 7a. Measured and predicted 450 MHz path-losses, for the path over Resolute Lake, as a function of transmitting antenna height. Solid lines represent predicted values while the dashed lines are fitted to the measured data points. '1' – vertical polarization; '2' – horizontal polarization.

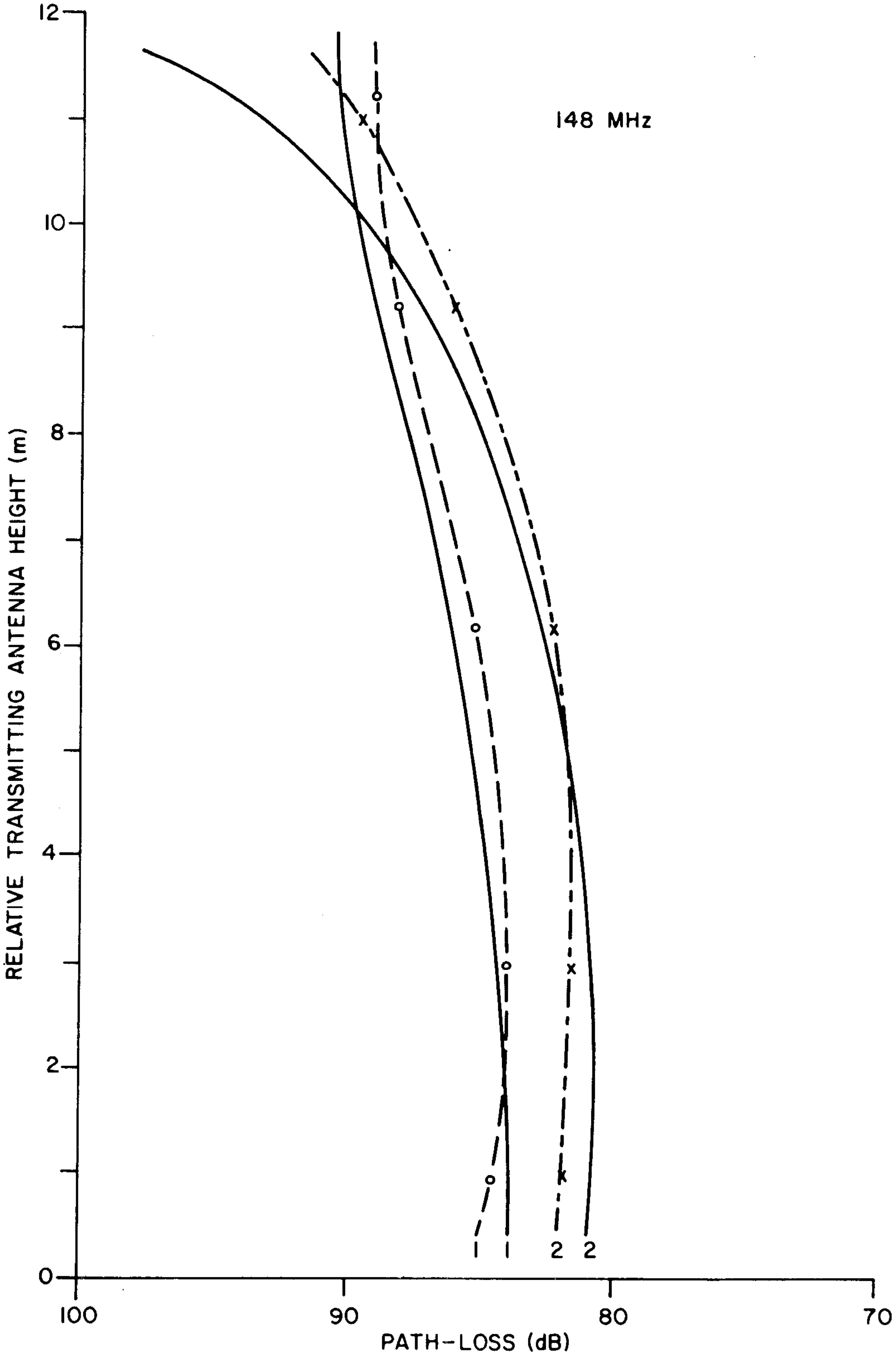

Figure 7b. Measured and predicted 148 MHz path-losses, for the path over Resolute Lake, as a function of transmitting antenna height. Solid lines represent predicted values while the dashed lines are fitted to the measured data points. '1' — vertical polarization; '2' — horizontal polarization.

In carrying out comparisons with the CCIR predictions it is necessary, particularly for horizontal polarization, that the height of the receiving antenna above the water-ice interface be known. For vertical polarization, the CCIR curves show, since the effective antenna height varies only slightly, that path-losses for receiving antennas placed anywhere between 0 and 10 m above the sea surface vary by only about 2.5 dB. Little error is thus introduced by any reasonable estimate of ice thickness. For horizontal polarization on the other hand, as the thickness of the ice increases from 1 to 2 m (actual receiving antenna heights of 2.5 and 3.5 m above the sea-surface for the 1.5 m receiving antenna height) the path-loss decreases by about 5 dB. The same change in thickness results in a decrease in path-loss of about 3 dB for the 3m receiving antenna. Since the ice thickness near Resolute is in the range 1.5 ± 0.5 m during May (the period in which measurements were made), we will assume receiving antenna heights of 3.0 and 4.5 m above the sea surface for comparison with the CCIR curves. There is some uncertainty in determining the effective thickness of sea-ice as opposed to its actual measured thickness, since the conductivity of sea-ice varies throughout its thickness. This uncertainty may lead to prediction errors of perhaps 2 - 3 dB.

Comparisons of predicted and measured path-losses are shown in Figures 8a and 8b for vertically and horizontally polarized signals respectively. Relatively good agreement is found up to distances of about 50 km. For longer paths there is some indication that the measured losses are lower than predicted by 5-10 dB. It must be remembered however that these were short-term measurements which may deviate from the long term medians. Nonetheless, for path lengths up to about 50 km at least, there is less than 5 dB error incurred in predicting VHF path-losses over ice-covered sea-water by using predictions bases upon propagation over open sea water.

9. CROSS-POLARIZATION MEASUREMENTS

A number of measurements were made, at both Inuvik and Resolute, of the cross-polarization losses incurred when using orthogonally polarized transmitting and receiving antennas. At Resolute, these losses were typically 20 to 25 dB at both 148 and 450 MHz. These losses are near the maximum attainable with the types of antennas used. At Inuvik on the other hand, cross-polarization losses ranged from 3.5 to 23 dB. These values showed little correlation with path length, frequency, local antenna environment or any other obvious system parameter.

The consistency of the cross-polarization losses at Resolute when compared to those at Inuvik, seems to indicate that the trees and perhaps other types of ground cover at Inuvik are largely responsible for the low values of cross-polarization loss that are sometimes observed.

10. SUMMARY AND CONCLUSIONS

Empirical descriptions of VHF and UHF path-loss have been derived from path-loss measurements made at Inuvik and Resolute Bay, NWT. These are

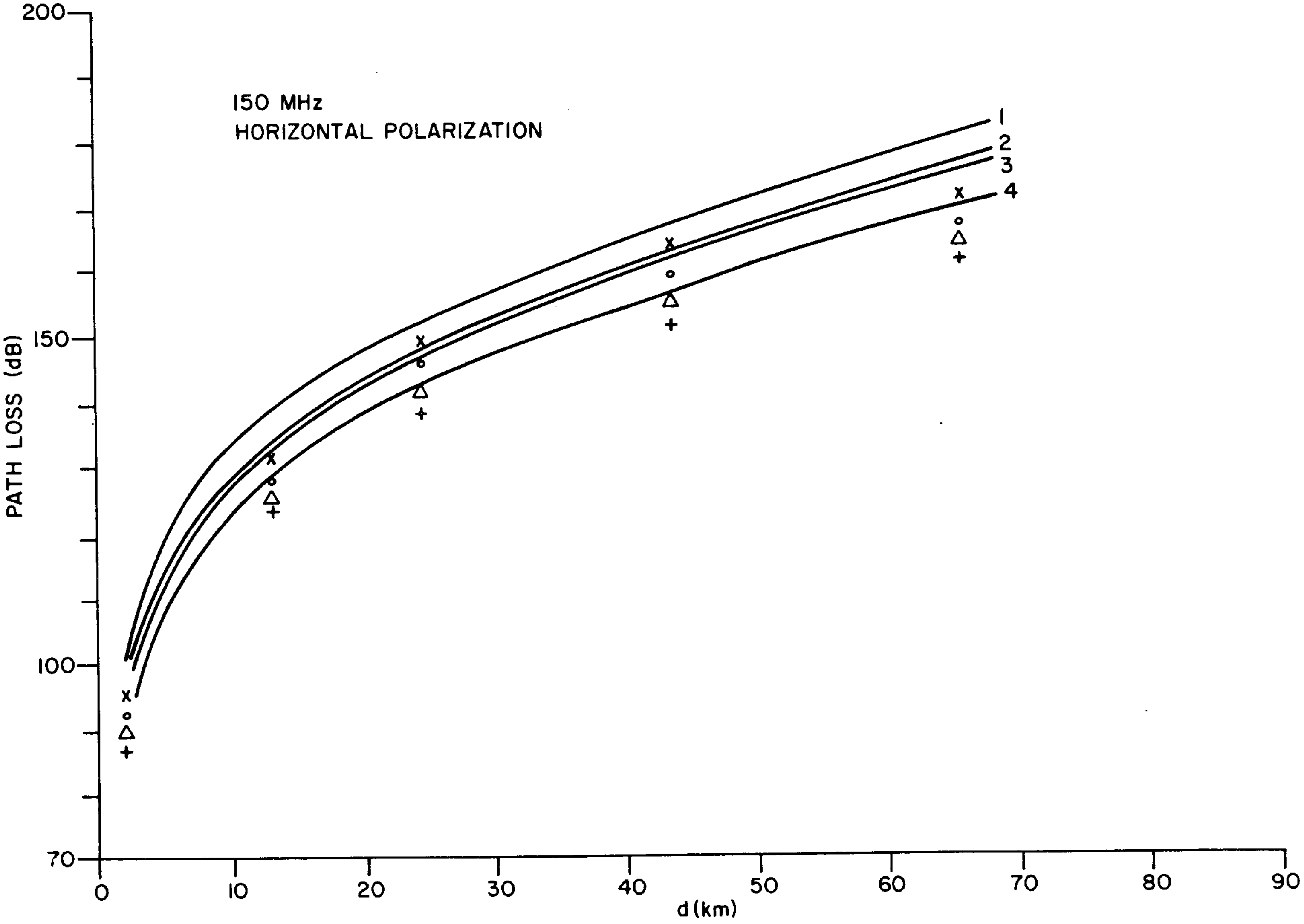

Figure 8a. Measured and predicted 150 MHz path-losses for the oversea path between Resolute Bay and Somerset Island. Horizontal polarization. '1' – predicted path-losses, HTX = 7 m, HRX = 1.5 m; '2' – HTX = 7 m, HRX = 3.0 m; '3' – HTX = 16 m, HRX = 1.5 m; '4' – HTX = 16 m, HRX = 3.0 m. The corresponding measurements are represented by x, o, Δ and + respectively.

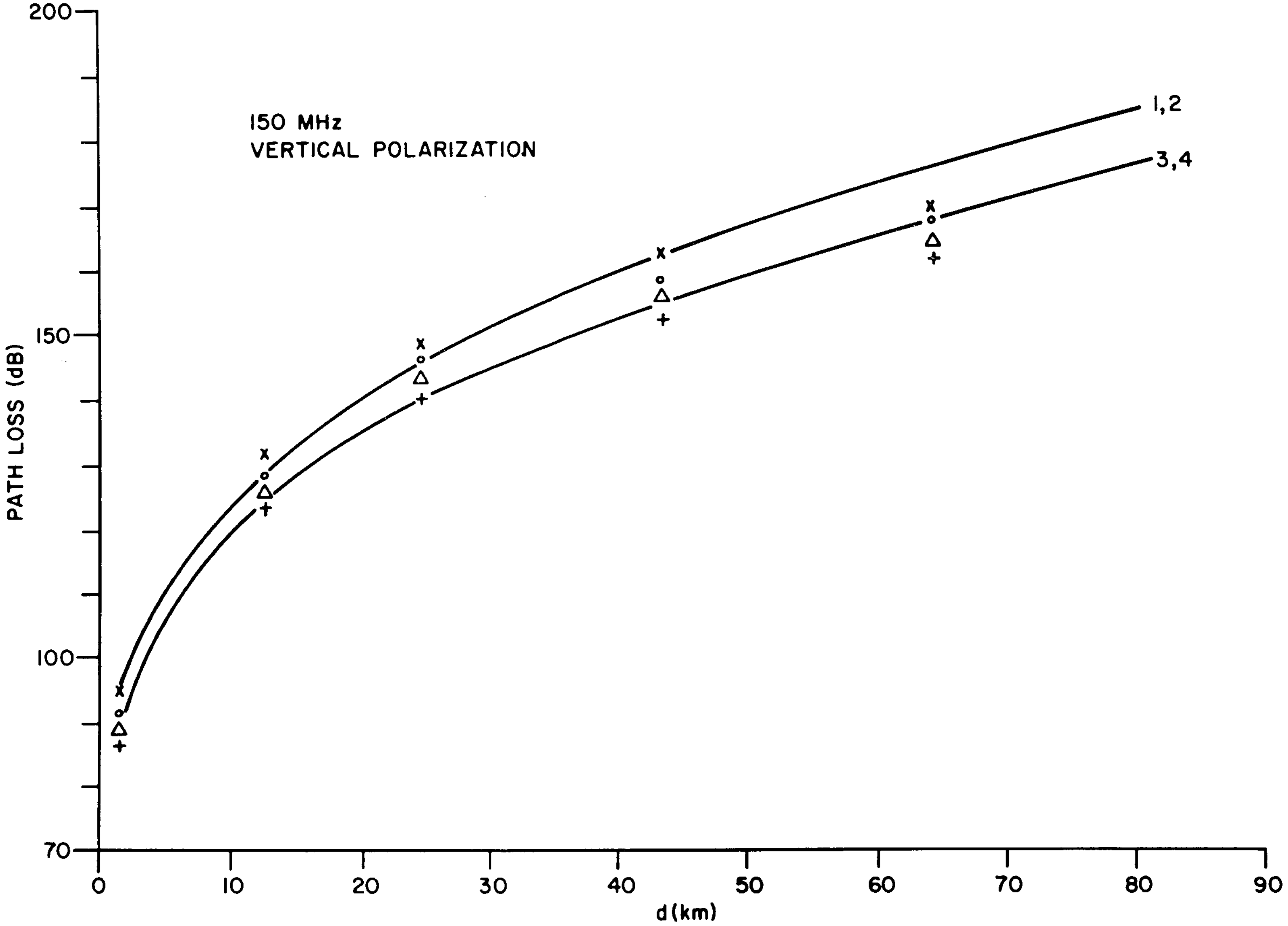

Figure 8b. Measured and predicted 150 MHz path-losses for the oversea path between Resolute Bay and Somerset Island. Vertical polarization. '1' – predicted path-losses, HTX = 7 m, HRX = 1.5 m; '2' – HTX = 7 m, HRX = 3.0 m; '3' – HTX = 16 m, HRX = 1.5 m; '4' – HTX = 16 m, HRX = 3.0 m. The corresponding measurements are represented by x, o, △ and + respectively.

$$L_P = \begin{matrix} 72.9 \text{ (V. Pol.)} \\ 66.8 \text{ (H. Pol.)} \end{matrix} + 7.7\log f + 44.8\log d - 6.5\log h_t - 15.6\log h_r \quad \text{(dB)}$$

for Inuvik, and

$$L_P = \begin{matrix} 88.7 \text{ (Summer)} \\ 96.3 \text{ (Winter)} \end{matrix} + 7.7\log f + 31.3\log d - 6.5\log h_t - 15.6\log h_r \quad \text{(dB)}$$

for Resolute where h_t and h_r are the effective antenna heights. The ranges of experimental parameters used for the derivation of these expressions were

Frequency	150 and 450 MHz
Path length	1 to 100 km
Receiving antenna height	1.5 and 3.0 m
Transmitting antenna height	7.2 and 16.5 m
Polarization	V and H

The losses predicted by the above expressions converge for path lengths approaching 100 km. For short paths, the losses at Resolute were higher than at Inuvik, and it is suggested that this is due to the difference in the siting of the transmitters with respect to the local terrain.

The large-scale (km) location variability of the path-loss was, at both frequencies, 10 dB at Inuvik and 15 dB at Resolute. The small scale location variability (tens of metres) was about 3 dB in wooded areas at Inuvik and about 1 dB in clear areas at both Inuvik and Resolute.

It has been found that receiving sites located within wooded areas experience path-losses about 5 dB higher than predicted by the above expressions, when using vertical polarization, than do similar receiving sites in areas clear of trees. Only a slight increase in path-loss (1 dB) is noted when using horizontal polarization. Even in open areas at Inuvik the losses measured using vertical polarization on non-line-of-sight paths are some 6 dB higher than those measured using horizontal polarization. This is probably due to the tree cover on obstructing hills along the propagation path.

The nature of the ground surface can have a large effect upon the measured height-gain of relatively low vertically polarized antennas. It has been shown that the effective antenna height above the ground, rather than the actual antenna height, must be used in the path-loss expressions, particularly in summer when the ground surface can be quite wet.

Propagation over fresh or salt water paths up to at least 50 km in length are but little influenced by the presence of an ice-cover. Predictions of path-loss based on analytic techniques, such as used in the preparation of the curves presented by the CCIR, should take antenna height to be the height above the water surface below the ice, rather than above the ice surface.

Considerable depolarization of received signals was sometimes observed at Inuvik. It was not possible to correlate the amount of depolarization with any obvious path parameter.

In general, the VHF/UHF propagation characteristics of Arctic paths appear to be much the same as expected for paths having similar types of topography in more southerly areas of the country.

A variety of interesting and useful results have been derived from the present series of measurements. There would be merit in extending the range of measurements both upward and downward in frequency. A similar program using frequencies of 50 MHz and 900 MHz would be useful. The effect of transmitter antenna siting upon the form of the derived path-loss expressions could be examined in more detail by performing measurements in which the transmitting antenna, as well as the receiving antenna, was sequentially located at a number of sites. In order to further investigate the possible height dependence of the loss coefficients a_4 and a_5 it would be useful to make detailed height-gain measurements using transmitter antenna heights ranging from 1 to 16 m rather than from 7 to 16 m as in the present experiment. The present series of measurements determined a single, instantaneous, value of path-loss at each receiver site for a given set of system parameters. This is acceptable over short paths, say up to 50 km, where the time variability of path-loss is usually small. There would be great value in performing long term measurements of path-loss over at least a few long (> 100 km) paths in the Arctic to assess the diurnal and seasonal variability of path-loss in those areas.

11. ACKNOWLEDGEMENTS

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8. **ABSTRACT:**

A series of measurements of VHF and UHF radiowave path loss were carried out near Inuvik and Resolute, N.W.T., during 1976 and 1977. Transmitter sites were chosen to be fairly representative of those that would be selected for actual communications facilities. Measurements of path-loss, for various frequencies, polarizations, and transmitting and receiving antenna heights, were made at a number of receiving sites along several radials from each transmitter. Path lengths ranged from 1 to 100 km and covered land, water, and mixed types of terrain. The measurements have been used to construct empirical models of path loss for these areas, and to form a data base with which to compare the predictions of the CRC VHF/UHF propagation prediction computer program. This report describes the measurement program and the empirical models which have been derived from the results.

9. **CITATION:**