k is a basic loss factor;

K_R is a loss factor dependent on R, the 12-month smoothed Zurich sunspot number;

L_p is the excess polarization-coupling loss (dB); and

G_s is the sea gain correction (dB).

The loss factor, $k_R = k + 10^{-2}bR$, where $k = 3.2 + 0.19f^{0.4}\tan^2(\phi + 3)$, f is frequency in kHz, and b, a solar activity dependence factor, is 4 for North American paths, 1 for Europe and Australia, and 0 elsewhere.

The complete prediction method is presented in Appendix B. Section 6, Appendix B contains a caution on the accuracy of the method when applied to the United States of America.

3.12 The Wang 1979 Method

This is a proposed modification of the recommended CCIR 1978 prediction method given in Section 3.11. Wang suggested that the basic loss factor, k, be changed to

$$k = (0.0667\ |\phi| + 0.2) + 3\tan^2(\phi + 3). \qquad (0 \le \phi \le 60°)$$

This improves the accuracy in high- and low-latitude areas without affecting the prediction in average-latitude areas and assumes f = 1000 kHz, i.e., no frequency dependence is needed. The other change relates to the solar activity dependence factor, b. The CCIR recommends setting b = 4 for North America and b = 0 for South America. Wang proposed the following formula:

$$b = 0.4\ |\phi| - 16 \qquad \text{for } |\phi| \ge 45^{\circ}$$
$$b = 0.0 \qquad \text{for } |\phi| < 45^{\circ} \quad .$$

4. COMPARISON OF PREDICTION METHODS

4.1 General Comparison

A study has been conducted of some of the above sky-wave field strength prediction methods to assess the compatibility and/or variability of the different methods. For this comparison, only the very long paths (>4700 km) for which measured field strengths are available were considered. A total of 46 paths met this criteria, and 36 of these paths were selected for this comparison. In selecting the 36 paths, preference was given to those having at least one terminal in either North, Central, or South America. Twenty-two of the paths are in this category, and the remaining 14 paths are representative of regions other than Region 2. Measurements for 18 of these paths were used to develop the Cairo Curves, and the measurements from most of the 36 paths were probably used to derive the various CCIR methods. The location of the transmitter and receiver, frequency, and great circle distances are given in Table 1.

Only three of the described prediction methods were considered applicable to all of these paths: 1) Cairo Curves, 2) CCIR 1974 method (modified U.S.S.R.), and 3) CCIR 1978. The FCC 1935 Curves are considered valid only within Region 2 and for distances <4300 km; the EBU method is considered valid only for the European Broadcasting Area; Wang's 1979 method is applicable only in Region 2; Barghausen's method was presented only for one-hop reflection; and the Olver et al. and Knight methods were not included because of their complexity and lack of information on certain variables, e.g., electron density profile of the lower ionosphere.

In this analysis, the following conditions were established for both the CCIR methods and for the Wang 1979 method:

F_0 is the annual median of half-hourly median field strengths [dB(μV/m)] for an effective monopole radiated power (e.m.r.p.) of 1 kW, equivalent to a cymomotive force (c.m.f.) of 300 V, relative to local midnight at the path midpoint(s). Average ground conductivity is assumed, typically 3 to 10 mS/m; and the antennas are assumed to be omnidirectional short verticals, therefore, G_V and G_H = 0.

The resulting sky-wave field strength predictions for the three methods for each of the 36 paths are given in Table 2. The Cairo Curve predicted field strengths have been determined using the North-South Curve as well as the East-West Curve, which is applicable only when the propagation path is near the magnetic pole. Both predicted values are shown in Table 2. The predicted field strengths for the Cairo method are shown without and with a correction term for polarization coupling loss (L_p) as suggested by Phillips and Knight (1965) and Barghausen (1966). The inclusion of L_p for MF propagation in the east-west or west-east direction at low latitudes reduces the field strength by about 2 to 6 dB for paths between the Mideast or Asia and Australia (13, 17, 21, and 31). The regional Administrative LF/MF Broadcasting Conference (ITU, 1975) recommended that the Cairo North-South Curve, with a modification for L_p, be used to predict MF field strengths for the Asian part of Region 3, North of 11°S. In this analysis, the modification for L_p has been applied to all the Cairo North-South Curve predicted MF field strengths on the assumption that this correction should be valid everywhere.

Table 1. List of Propagation Paths

PATH NUMBER	TRANSMITTER	RECEIVER	GEOGRAPHIC COORDINATES TRANSMITTER		GEOGRAPHIC COORDINATES RECEIVER		FREQUENCY	GREAT CIRCLE DISTANCE (km)
1	Northern Ireland	Ottawa, Canada	5.0°N	7.0°W	45.4°N	75.7°W	977	4797
2	Sackville, Canada	Chatonnaye, France	45.9°N	64.3°W	46.7°N	6.8°E	1070	5272
3	Moncton, Canada	Chatonnaye, France	46.1°N	64.8°W	46.7°N	6.8°E	1070	5298
4	Northern Ireland	Washington, D. C.	55.0°N	7.0°W	39.0°N	77.0°W	977	5346
5	Rennes, France	Ottawa, Canada	48.0°N	1.7°W	45.4°N	75.7°W	1040	5426
6	Rennes, France	New York City, N.Y.	48.0°N	1.7°W	41.0°N	74.0°W	1040	5573
7	Masirah Island, Oman	Leucate, France	20.5°N	58.8°E	42.9°N	3.0°E	1410	5706
8	New York City, N.Y.	Brussels, Belgium	40.9°N	72.7°W	50.8°N	4.4°E	860	5791
9	New York City, N.Y.	Eindhoven, Netherlands	40.9°N	72.7°W	51.4°N	5.5°E	860	5839
10	Masirah Island, Oman	Limours, France	20.5°N	58.8°E	48.7°N	2.1°E	1410	5884
11	Akita, Japan	Darwin, Australia	39.8°N	139.9PE	12.5°S	130.7°E	770	5885
12	Rennes, France	Washington, D. C.	48.0°N	1.7°W	39.0°N	77.0°W	1040	5910
13	Singapore, Malaysia	Brisbane, Australia	1.4°N	103.9°E	27.5°S	152.0°E	790	6055
14	New York City, N.Y.	Berlin, Germany	40.9°N	72.7°W	52.5°W	13.4°E	860	6287
15	Rome, Italy	Tsumeb, S.W. Africa	41.9°N	12.5°E	19.2°S	17.7°E	845	6795
16	Fort-de-France, West Indies	Jurbise, Belgium	14.6°N	61.1°W	50.5°N	3.9°E	1310	7001
17	Ban Phaci, Thailand	Brisbane, Australia	13.7°N	100.5°E	27.5°S	153.0°E	1580	7198
18	M. Ismaning, Germany	Tsumeb, S.W. Africa	48.2°N	11.8°E	19.2°S	17.7°E	1602	7526
19	Akita, Japan	Brisbane, Australia	39.8°N	139.9°E	27.5°S	152.0°E	770	7584
20	Bangkok, Thailand	Helsinki, Finland	13.7°N	100.5°E	60.2°N	25.1°E	1580	7882
21	Cairo, Egypt	Klang, Malaysia	29.9°N	31.7°E	3.1°N	101.4°E	620	7886
22	Rome, Italy	St. Denis, Reunion	41.7°N	12.6°E	20.9°S	55.5°E	845	8240
23	Buenos Aires, Argentina	Washington, D.C.	34.4°S	58.6°W	39.0°N	77.0°W	1070	8383
24	New York City, N.Y.	Buenos Aires, Argentina	40.9°N	72.7°W	34.6°S	58.5°W	860	8518
25	Buenos Aires, Argentina	New York City, N.Y.	34.4°S	58.6°W	41.0°N	74.0°W	1070	8536
26	Pittsburgh, Pennsylvania	Buenos Aires, Argentina	40.4°N	80.0°W	34.6°S	58.5°W	980	8622
27	Akita, Japan	Melbourne, Australia	39.8°N	139.9°E	37.8°S	145.1°E	770	8644
28	Poro, Phillippines	Helsinki, Finland	15.8°N	120.6°E	60.2°N	25.1°E	1140	8791
29	Buenos Aires, Argentina	Ottawa, Canada	34.4°S	58.6°N	45.4°N	75.7°W	1070	9043
30	Swan Island, Caribbean	Helsinki, Finland	17.4°N	83.9°W	60.2°N	25.1°E	1157	9333
31	Kuwait, Kuwait	Darwin, Australia	29.2°N	48.0°E	12.5°S	130.7°E	1345	9986
32	Rennes, France	Buenos Aires, Argentina	48.0°N	1.7°W	34.6°S	58.5°W	1040	10786
33	Buenos Aires, Argentina	London, England	34.4°S	58.6°W	51.5°N	0.2°W	1070	11127
34	Buenos Aires, Argentina	Brussels, Belgium	34.4°S	58.6°W	50.8°N	4.4°E	1070	11298
35	Buenos Aires, Argentina	Eindhoven, Netherlands	34.4°S	58.6°W	51.4°N	5.5°E	1070	11400
36	Buenos Aires, Argentina	Berlin, Germany	34.4°S	58.6°W	52.5°N	13.4°E	1070	11903

Table 2. Comparison of MF Field Strengths (F_0 in dB relative to 1 μV/m) Predicted by Different Methods for R=0

Path Number	Frequency kHz	GCD km	Cairo E-W	Cairo N-S	Cairo -Lp	CCIR 1974 Without G_s	CCIR 1974 With G_s	CCIR 1978 Without G_s	CCIR 1978 With G_s
1	977	4797	-3.8	12.3		-29.3		-30.0	
2	1070	5272	-7.6	11.2		-22.2	-18.8	-22.2	-17.8
3	1070	5298	-7.7	11.0		-22.7	-20.6	-22.7	-19.4
4	977	5346	-8.0	10.8		-26.8		-26.9	
5	1040	5426	-9.0	10.6		-26.6		-26.6	
6	1040	5573	-9.8	10.0		-22.2	-20.0	-22.0	-18.5
7	1410	5706		9.6	7.9	1.4	17.8	1.5	16.9
8	860	5791	-11.5	9.4		-23.7	-14.8	-23.5	-14.5
9	860	5839	-11.7	9.3		-24.7	-15.8	-24.5	-15.5
10	1410	5884		9.2	7.9	-2.3	6.6	-2.2	4.9
11	770	5885		9.2	9.3	9.9	17.9	11.2	15.4
12	1040	5910	-12.1	9.1		-23.2		-22.9	
13	790	6055		8.9	6.3	3.5	12.4	7.3	16.4
14	860	6287	-14.4	8.3		-28.8	-19.3	-28.5	-18.9
15	845	6795		7.0		3.7	9.3	4.6	11.0
16	1310	7001		6.6		-15.6	-11.3	-15.3	-9.9
17	1580	7198		6.2	3.8	-1.1	7.5	2.1	11.0
18	1602	7526		5.2		-2.6		-2.2	
19	770	7584		5.0		1.1		3.1	
20	1580	7882		4.6	3.6	-16.3	-7.7	-16.2	-7.3
21	620	7886		4.6	-.9	-4.8	5.0	-4.0	5.8
22	845	8240		3.7		-3.0	6.3	-1.8	7.6
23	1070	8383		3.4	3.2	-6.6		-5.7	
24	860	8518		3.1	3.0	-7.4	0.3	-6.5	1.7
25	1070	8536		2.9	2.8	-8.1	-0.9	-7.2	0.6
26	980	8622		2.7	2.5	-8.1		-7.2	
27	770	8644		2.6		-5.7		-2.7	
28	1140	8791		2.3	1.5	-20.8	-11.8	-20.5	-9.1
29	1070	9043		1.8	1.7	-12.8		-11.9	
30	1157	9333		1.4		-40.6	-31.6	-40.2	-31.1
31	1345	9986		0.4	-3.3	-11.9	5.7	-10.7	7.4
32	1040	10774		-1.3	-2.1	-19.1	-10.9	-18.2	-12.2
33	1070	11127		-1.8	-2.5	-25.0	-15.9	-24.0	-17.7
34	1070	11298		-2.3	-3.1	-22.5	-13.4	-21.6	-15.3
35	1070	11400		-2.5	-3.3	-23.2	-14.1	-22.3	-16.0
36	1070	11903		-3.2	-4.1	-25.4	-16.3	-24.5	-18.2

Both of the CCIR methods include an explicit expression for determining the additional gain (G_s) when one or both of the terminals are located near sea water. The predicted field strengths for these methods are calculated without the sea gain and with the sea gain when applicable. When sea gain is not included, the minimum difference between the three predictions is about 2 dB, the maximum is about 42 dB, and the median difference is 12 dB. When sea gain is included, the minimum difference between predictions is 3 dB, but the maximum difference is 33 dB, and the median difference is about 10 dB. Even though the addition of sea gain reduces the differences in the field strength predictions somewhat, the median difference of 10 dB would still suggest that the Cairo predictions are not compatible with the CCIR predictions.

4.2 Sea Gain Effect

The increase in field strength which occurs when the antenna is radiating over open sea is treated as an additional gain in the various CCIR methods. In the physical models (e.g., Norton's) the ground conductivity determines the ground losses for the antenna gain and, therefore, this so-called sea gain is included implicitly as a reduction in ground loss. The CCIR method for computing sea gain can produce significantly different answers depending on individual interpretation. For example, according to Knight (1977), the estuary of the River Plate, which is about 50 km wide, could have produced a sea gain of 6 dB at 1 MHz for long paths. However, the instructions for sea gain (see Appendix B, Section 2.3) define the distance, d, as the distance of the terminal from the sea measured along the great circle path. Clearly, for paths between Europe and Buenos Aires, the great circle path is over the estuary of the River Plate; but for the paths 23, 25, and 29 between Buenos Aires and North America this is not the case, as the location of the transmitter is northwest of Buenos Aires. Although the receiver for paths 24 and 26 was southeast of Buenos Aires, it is still questionable as to whether the great circle path is over the estuary of the River Plate. The sea gain included in the predicted field strengths for paths 24 and 25 was determined from the proximity of the northern terminals to the Atlantic Ocean.

4.3 Solar Activity Effect

In both CCIR methods, the relationship between sky-wave field strengths and solar activity is different for different geographical areas. The solar activity dependence factor, b, is 1 for Europe, Australia, and New Zealand, and 4 for North America. For the rest of the world, b = 0; e.g., solar activity