

Bibliography and Synopsis of Literature Concerned with Microwave and Millimeter Wave Propagation Effects

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September 1982

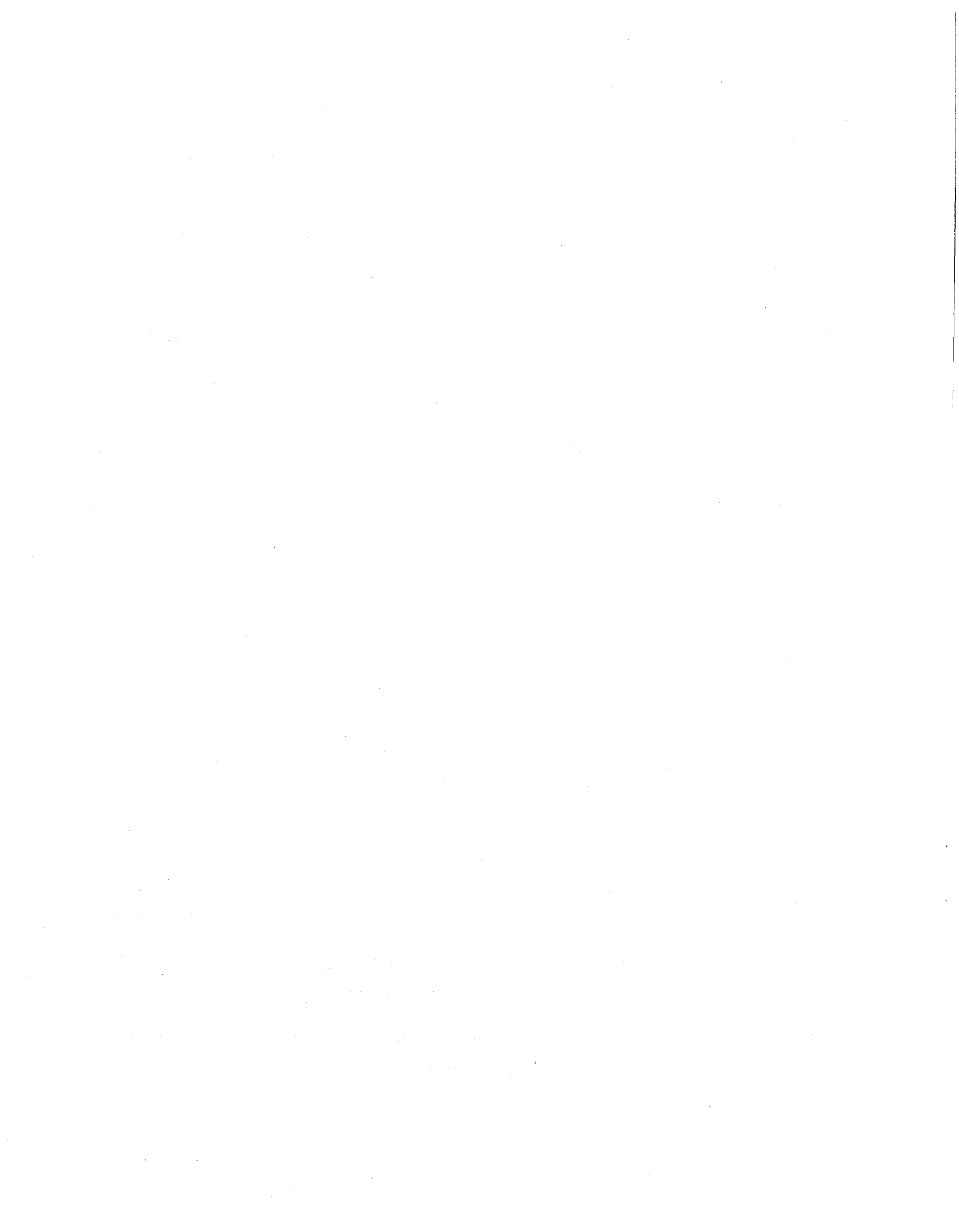


TABLE OF CONTENTS

	PAGE
ABSTRACT	1
1. INTRODUCTION	1
2. SYNOPSIS OF DOCUMENTS CONCERNED WITH SHF-EHF MODELING	2
3. BIBLIOGRAPHY	16
3.1 Ray Tracing Effects	16
3.1.1 Refractive Index	16
3.1.2 Ray Tracing and General Wave Equation Solutions of Interest	19
3.1.3 Angle of Arrival	21
3.2 Transfer Function Effects	22
3.2.1 Line-of-Sight and Terrain Multipath	25
3.2.2 Vegetation	29
3.2.3 Diffraction	30
3.2.4 Gaseous Absorption, Delay, and Dispersion	31
3.2.5 Unstable and Stable Clear Air	34
3.2.5.1 Turbulence	34
3.2.5.2 Stratification and Ducting	37
3.2.6 Inclement Weather	38
3.2.6.1 Rain, Clouds, and Other Hydrometeors	38
3.2.6.2 Sand, Dust, and Smoke	61
3.2.7 Depolarization	61
3.3 Atmospheric Noise Effects	69
3.4 Miscellaneous Articles	71

BIBLIOGRAPHY AND SYNOPSIS OF LITERATURE CONCERNED WITH
MICROWAVE AND MILLIMETER WAVE PROPAGATION EFFECTS

E. J. Dutton and F. K. Steele*

This report presents an extensive bibliography, categorized by effect, of radio propagation through the atmosphere, for the frequency region of 10 to 300 GHz. Preceding the bibliographic presentation is an article-by-article synopsis of that literature which is particularly pertinent to the prospective atmospheric propagation effects modeler. Thus, it should tend to serve as a bridge between earlier modeling efforts (done on a worldwide basis at these frequencies) and needs of future modelers searching for background material for a model foundation.

Key Words: atmospheric effects, bibliography, microwave, millimeter wave, modeling, propagation, radio

1. INTRODUCTION

The direction of use of the frequency spectrum resource has generally been upward in frequency in recent years, primarily because of the relative availability of bandwidth and the requirement of digital systems for wider bandwidths. This has led to considerable interest both here at the National Telecommunications and Information Administration and elsewhere in the usage potential of microwave and millimeter wave systems. The lower atmosphere, sometimes called the troposphere, has a considerable influence in this frequency region if existing and/or intended systems must communicate through the atmosphere. However, the surrounding terrain, and even the ionosphere, can exert an influence as well.

In order to aid the prospective user and, in particular, the prospective modeler, with background material on atmospheric and terrain effects of the propagation medium at these frequencies, we have undertaken this bibliography and article synopsis. Our literature research began with the discovery that approximately 2900 articles and reports could be candidates for the bibliography, based on key word searches conducted both manually and automatically. This number reduced eventually to the present 933 papers, reports, and books that are actually incorporated in the bibliography. All of the papers, reports, and books included in the bibliography were surveyed to determine their potential value to a propagation effects modeler, on the basis of their titles and abstracts. If those appeared promising, we obtained the paper, report, or book, and examined it. Even some of these were not

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adjudged to be as valuable as others, so that finally only 60 papers and reports were selected for the brief commentary and review given in the next section.

It is hoped that this report will be of use to those who are concerned with the microwave and millimeter wave effects of the atmospheric and geographic propagation medium. In order to further accommodate the user, we have subdivided the bibliography in Section 3 into the individual atmospheric effect that we feel was most representative of the particular document (see the Table of Contents of Section 3 for the actual categorization). The authors realize, however, that as with any other effort of this kind, time will relegate it to some degree of obsolescence.

2. SYNOPSIS OF DOCUMENTS CONCERNED WITH SHF-EHF MODELING

Brown, D. M., and M. B. Wells, A Literature Review of Millimeter and Submillimeter Radiation Absorption and Scatter in the Atmosphere, RRA-T-7804-1, Radiation Research Associates, Inc., Ft. Worth, TX, October 1978.

This is an extensive review and bibliography of work done to this point in time (1978) in the millimeter-submillimeter wave frequency region. Not only is there a separate discussion of the work done in the area in general (presented with assorted summary graphs), but there is a sizeable bibliography and a brief discussion of each article in the bibliography presented with the article. Some of the material presented is not especially pertinent to the SHF-EHF propagation modeling problem, but there is other material that could be valuable to the prospective modeler.

Brussaard, G., Variability of Atmospheric Noise Temperature in 11-14 GHz Band Due to Water Vapour and Clouds, Electronics Letters 17, No. 1, 1978, pp. 20-22.

A discussion of the distribution of atmospherically-caused noise temperature across Europe observed by radiometer is presented. Although not a dominating feature of microwave and millimeter wave performance degradation, it is one of the few discussions seen of the "noise" part of "carrier-to-noise" assessment. The results presented are directly applicable to earth-satellite performance and modeling.

Calo, S. B., L. Schiff, and H. Staras, Effects of Rain on Multiple Access Transmission of Data via Satellite, International Conf. on Communications Record, Vol. 2, Toronto, Canada, 4-7 June 1978, pp. 30.1.1-30.1.6.

This paper presents power budget calculations with emphasis on time-division-multiple-access. If this aspect of earth-satellite communications at microwave frequencies is of interest to a modeler, then a detailed look at this paper may be warranted. It does not appear that all the details are included in this particular short contribution; however, it would be necessary to consult with the authors independently.

Chu, T. S., Effects of Sandstorms on Microwave Propagation, BSTJ 58, No. 2, Feb. 1979, pp. 549-555.

This is an interesting paper which covers microwave attenuation and delay due to sandstorms or duststorms as a function of the most commonly observed parameters in such storms--visibility. Similar work has been presented before, and much of the work is comparable to that done at ITS in connection with the work on the Solar Power Satellite rectenna assessment.

Cox, D. C., Depolarization of Radio Waves by Atmospheric Hydrometeors in Earth-Space Paths: A Review, Radio Science 16, No. 5, Sept.-Oct. 1981, pp. 781-812.

This is a thorough review of depolarization on earth-space paths at SHF-EHF. It should be noted that the author uses the terminology "depolarization" to mean the same thing as "cross-polarization discrimination" (XPD), used by other authors. The balance of the article, however, is devoted to experimental results rather than modeled or theoretical results, and, as such, may not therefore be of quite as much use to the prospective modeler, except as a check on proposed models. There is a very extensive section on ice-crystal depolarization, which is a very important aspect of earth-space propagation at SHF-EHF. It is especially important because of the largely unattenuated quadrature component that ice-crystal depolarization produces, which rain apparently does not.

Cox, D. C., H. W. Arnold, and R. P. Leck, Phase and Amplitude Dispersion for Earth-Satellite Propagation in the 20- to 30-GHz Frequency Range, IEEE Trans. Ant. Prop. AP-28, No. 3, May 1980.

This is probably the only article that was found to discuss bandwidth characteristics (i.e., transfer function characteristics) of rain in the 20- to 30-GHz region. At lower elevation angles the problem of multipath and frequency selective fading has been rather extensively covered. The results reported here are from a Bell Labs technique for sampling upper and lower sideband attenuation and phase delay, as well as for the carrier frequency. The dispersion results for amplitude are especially interesting, since the authors found the dispersion to be "less than 3 dB in 30 to 40 dB over a 1-GHz bandwidth at 28 GHz"--implying that microwave amplitude dispersion for wideband communications due to rain is relatively small.

Crane, R. K., A Global Model for Rain Attenuation Prediction, IEEE Electronics and Aerospace Systems Conference, 25-27 Sept. 1978, Arlington, VA, pp. 391-395.

This is a condensed version of one of the more widely used and accepted engineering models for rain attenuation distribution prediction on earth-satellite links, which is presented in considerably more detail in Crane's 1980 IEEE paper. The significance of this paper is that it was the first time the Global Model was presented.

Crane, R. K., Prediction of Attenuation by Rain, IEEE Trans. Comm. COM-28, No. 9, Sept. 1980, pp. 1717-1733.

This is a detailed version of Crane's 1978 introduction of the Global Model for prediction of rain attenuation distributions. Although the model contains U. S. rainfall zone maps, based on limited data, in some parts of the United States, it is a succinct model that is readily usable for engineering purposes. It is presumably applicable on earth-space links up to 100 GHz. The terrestrial-link modeling does not appear to work well, however, for paths much beyond 10 km in length, at frequencies much beyond 20 GHz, and moderate rain rate conditions (0.1% of a year). The prospective modeler is advised to concentrate on the earth-satellite aspects of the modeling.

Daniel, L. D., and R. A. Reinman, Modification of the Bello Model for Performance Prediction of Short Range Troposcatter Links, IEEE International Conference on Communications Record, Vol. III, Philadelphia, PA, June 14-16, 1976, pp. 46.24-46.26.

This paper condenses the Bello troposcatter model to as simplified a form as is probably possible, thus making it a candidate for model incorporation. However, the paper has two drawbacks: First, the microwave and millimeter wave regions are not generally regions in which troposcatter propagation (a long-haul mechanism) is likely to be used. Second, omission of some symbol definitions in the article does not add to its clarity.

Dissanayake, A. W., D. P. Haworth, and P. A. Watson, Analytical Models for Cross-Polarization on Earth-Space Radio Paths for Frequency Range 9-30 GHz, Ann. Telecommunications 35, No. 11-12, 1980, pp. 398-404.

Although this paper presents a detailed modeling effort, the principal features of interest are the rain and ice crystal depolarization models and their combination. This seems to be a well thought-out paper, with just enough detail to satisfy the modeler's curiosity about the origin of modeled results.

Dougherty, H. T., A Consolidated Model for UHF/SHF Telecommunication Links Between Earth and Synchronous Satellites, NTIA Report 80-45, August 1980.

This appears to contain a useful engineering approach, although the extensive material and very large number of graphs make it somewhat confusing and tend to obfuscate the major modeling developments. Numerical examples, however, alleviate this situation, and they are worth examining in detail by the prospective modeler. Much of the material contained in this report could probably be automated, which would tend to make the model less formidable in appearance. The major aspect of the model is a detailed examination of the depolarizing effects of transmission from an earth station to a satellite and then back to another (different) earth station. So far this is the only report reviewed that contains this important consideration.

Dutton, E. J., and H. T. Dougherty, Estimates of the Atmospheric Transfer Function at SHF and EHF, NTIA Report 78-8, August 1978.

The authors consider various lower atmospheric effects that change the attenuation and phase of a signal as it is propagated in the atmosphere. The report considers the 10 to 45 GHz region and the 45 to 350 GHz region of the spectrum separately. Graphs and summary equations that should be useful to the prospective modeler are presented in connection with each of the effects considered. The report is somewhat lacking in rain effects modeling at EHF because it uses a Marshall-Palmer distribution that does not properly account for small droplet populations.

Eaves, R. E., and T. S. Seay, Adaptive TDM Satellite Links to Counter Rain Attenuation, IEEE International Conference on Communications Record, Seattle, Washington, Vol. 1, 1980, pp. 9.6.1-9.6.8.

Various schemes for maximizing use of the resource spectrum by using time-division multiplexing are discussed and results presented. This paper is actually a fairly good tutorial work relating the pragmatics of resource allocation to performance degradation in the presence of rain at SHF and EHF and may as a consequence be a valuable tool in helping the prospective modeler connect propagation effects to resource allocation.

Falcone, V. J., Jr., and L. W. Abreu, Atmospheric Attenuation of Millimeter and Submillimeter Waves, EASCON '79 Conference Record, IEEE, 1979, pp. 36-41.

This model covers the range 1-1000 GHz, and is based on earlier AFGL models. Its usefulness is limited because it does not attempt to model the distribution (time and location variability) of millimeter wave effects along a given path. Since the model appears to be intended primarily for engineering application, this seems to be a major limitation. It is not likely then, that this model could be used exclusive of other models, and would probably have to be incorporated as a subroutine in a larger computer model. There is no consideration of depolarization effects, nor of dispersion effects in the model as well; nevertheless, what the model does cover should be given due consideration by the prospective modeler.

Fang, D. J., and J. Jih, A Model for Microwave Propagation Along an Earth-Satellite Path, COMSAT Technical Review 6, No. 2, Fall, 1976, pp. 379-411.

Here is an older model for earth-satellite performance prediction that seems to have received very little attention. Possibly this is due to some weakness in the model that has been more recently perceived because the analysis is too formidable. The model is presented in matrix algebra format, with concomitant approximations to reduce the difficulty of the model's use as much as possible. The model should be carefully considered by a prospective modeler, with the attitude, perhaps, of more closely examining its strengths and weaknesses, which cannot be determined by cursory inspection. The model does not consider system availability.

Greenstein, L. J., and B. A. Czekaj, A Polynomial Model for Multipath Fading Channel Responses, *BSTJ* 59, No. 7, September 1980, pp. 1197-1225.

This paper introduces considerably more multipath components into the transfer function modeling than does Rummler. Consequently, the complexity of the mathematics is greatly magnified. This, in addition to the length of this article, tends to make it difficult to extract the useful modeling material from the development material. However, since this is a relatively important area (the area of selective fading due to multipath), a close examination of the material by prospective modelers may be worthwhile to assess changes from the simpler Rummler model.

Greenstein, L. J., and V. K. Prabhu, Analysis of Multipath Outage with Applications to 90-Mbit/s PSK Systems at 6 and 11 GHz, *IEEE Trans. Comm.* COM-27, No. 1, January 1979, pp. 68-75.

A microwave application of the Rummler model to 45-Mbit/s QPSK systems and 90-Mbit PSK systems is presented. Although it is presumably a digital application, cursory review did not detect any readily usable modeling results. However, some of the figures are very interesting (Figures 3 and 4 in particular), and it may be worthwhile for prospective modelers to examine this report in more detail.

Hatsuda, T., S. Nakajima, and Y. Morihira, Link Calculation Method for 30/20 GHz Band Satellite Communication System, Review of the Electrical Communication Labs. 28, No. 7-8, July-August 1980, pp. 604-619.

This paper is principally concerned with the power budget (C/N) calculations on earth-satellite up- and down-links. The method of calculation is presented in a simplified, straightforward manner that could make it useful for the engineering modeler.

Hause, L. G., and D. R. Wortendyke, Automated Digital System Engineering Model, NTIA Report 79-18, March 1979.

Although the abstract does not clearly state the purpose of the report, it is intended to produce predictions of bit-error-rate in the 1 to 40 GHz range. In the process, multipath, gaseous absorption, and rain attenuation are considered. Because of this, it would seem logical that a prospective modeler should consider this model in his work, particularly for terrestrial links.

Haworth, D. P., P. A. Watson, and N. J. McEwan, Model for the Effect of Electrical Fields on Satellite-Earth Microwave Radio Propagation, *Electronics Letters* 13, No. 19, September 1977, pp. 562-564.

This paper provides some earlier background for the modeling presented above (Dissanayake et al., 1980), concentrating on the ice-crystal depolarization modeling problem. The description is brief and possibly useful to the prospective modeler.

Hayes, D. T., U. H. W. Lammers, R. A. Marr, and J. J. McNally, Millimeter Wave Propagation over Snow, Proc. EASCON '79 Record, October 1980, pp. 362-368.

This paper reports on an interesting experimental tool used to obtain very short distance multipath and backscatter from snow at 35, 98, and 140 GHz. Multipath results appear to indicate two clearly distinct components. Results, however, were obtained for only a short period of time at one location.

Ihara, T., and Y. Furuhashi, Frequency Scaling of Rain Attenuation at Centimeter and Millimeter Waves using a Path-Averaged Drop Size Distribution, Radio Science 16, No. 6, Nov.-Dec. 1981, pp. 1365-1372.

Since frequency scaling of rain attenuation is an important aspect of any rain attenuation modeling at SHF-EHF, this paper is of interest because it compares various frequency scaling procedures, develops one of its own, and compares the procedures with some experimental results. Differences among the various procedures do not appear to be all that large between 10 and 100 GHz, but they do tend to diverge with increasing frequency.

Ippolito, L. J., R. D. Kaul, and R. G. Wallace, Propagation Handbook for Satellite Systems Design, A Summary of Propagation Impairments on 10 to 100 GHz Satellite Links with Techniques for System Design, Second Edition, NASA Reference Publication 1082, December 1981.

This is one of the most important pieces of literature uncovered in this survey. It is a large handbook covering an extensive amount of material and presents the material in a form readily usable for the application oriented individual. It contains 7 chapters. The first chapter is an introduction. The second chapter, entitled "Characteristics of Rain and Rain Systems," discusses, in essence, the nature of rain and storms, with emphasis on those characteristics important to telecommunications. The third chapter, entitled "An Overview of Several Rain and Attenuation Models," discusses the many models in use today for the purpose of prediction of rain and attenuation for satellite-earth telecommunications purposes. The fourth chapter, entitled "Depolarization on Earth-Space Links," gives a condensed version of the considerably complicated problem of ascertaining depolarization effects, particularly as related to the use of dual orthogonally polarized transmissions. The fifth chapter, entitled "Propagation Data Bases," covers experimental results obtained over the years of attenuation and depolarization data and statistics. The sixth chapter is entitled "Prediction Techniques," but it differs from Chapter 3 in that the emphasis is on system application of models; i. e., availability, diversity, etc. The seventh chapter is entitled "Application of Propagation Predictions to Earth/Space Telecommunications Design," and as such completes the final step in connecting the propagation models to the system parameters such as carrier-to-noise ratio and bit error rate. The prospective modeler can probably shortcut the reading of many papers and reports by using this handbook directly, at least as a starting point.

Kalinin, A. I., The Effect of Rain on the Attenuation of Radio Waves Along Earth Satellite Paths," Telecommunications and Radio Engineering 30, No. 5, 1976, pp. 1-5.

Since work in this area done in the Soviet Union is relatively sparsely reported in this country and often suffers from inaccurate translation, this article takes on added interest. This is because it seems fairly clearly presented. The author

describes an exponential shower model, and then develops an effective distance model from it, resulting in modeled earth-satellite attenuation due to rain. It would seem important that the prospective modeler give this article serious consideration to become aware of what his or her Soviet counterparts are doing in this area.

Kanellopoulos, J. D., Analysis of Short-Term Statistical Variations in Rain Depolarization, *Radio Science* 16, No. 6, Nov.-Dec. 1981, pp. 1355-1359.

This work postulates short-term variation of rain depolarization analogous to procedures sometimes taken in analyzing other tropospheric loss mechanisms (multipath, etc.) by assuming a Rayleigh distribution and finding a 4.34 dB standard deviation about the mean. Since the prospective modeler may be concerned with "worst case" situations in designing fade margins, this type of analysis could prove useful.

Kennedy, D. J., A Model for Calculation of Rain-Induced Cross Polarization Discrimination at 6/4 GHz, *COMSAT Technical Review* 10, No. 1, Spring 1980, pp. 223-232.

The author presents a simple straightforward method of getting desired results. Albeit the frequency region is a bit low for our purposes, the author states: "The restriction of the model to 4 and 6 GHz reflects the assumption that differential attenuation effects are small compared with those of phase. This restriction could be lifted with some penalty in complexity." The most interesting feature of the model is that it presents a new inverse formulation for the Rice-Holmberg model.

Kobayashi, H. K., Effect of Hail, Snow, and Melting Hydrometeors on Millimeter Radio Waves, U. S. Army Electronics Research and Development Command, Atmospheric Sciences Laboratory, White Sands Missile Range, Report ASL-TR-0092, July 1981.

This is a review effort, primarily, which should be useful to the prospective modeler. There is the attendant commentary and discussion of those articles that the author feels are most important, as well as tables and graphs that show many of the results of various authors working in this frequency range. It will serve as a good epitomization of much of the work that has been done at SHF and EHF to date.

Lele, S. G., Equivalent Path Concept in Calculation of Attenuation of Microwaves Due to Rain, *Proc. of SOUTHEASTCON*, 13-16 April 1980, pp. 241-242.

Here is a short article that compares the Crane Global Model and Lin Model effective path length values. The results, however, are generally inconclusive, with correspondingly few conclusions of use to a prospective modeler.

Lin, S. H., A Method for Calculating Rain Attenuation Distributions on Microwave Paths, *BSTJ* 54, No. 6, July-August 1975, pp. 1051-1086.

This is not the version of the terrestrial-link attenuation model that is extensively used today, but a predecessor that seems to have been made almost totally obsolete by the current method. Furthermore, because it is so long and detailed, it is relatively hard to follow.

Lin, S. H., Impact of Microwave Depolarization During Multipath Fading on Digital Radio Performance, BSTJ 56, No. 5, May 1977, pp. 645-674.

Much of the concern on links employing dual orthogonal linear polarizations to increase channel capacity has been with rain depolarization effects. Here is a somewhat unique treatise on depolarization caused by multipath. It postulates a distribution model, using the Nakagami-Rice distribution and claims confirmation of the hypothesized distribution. This appears to be a worthwhile model to consider, especially at microwave frequencies on terrestrial links, since so much dual-polarization is in use today.

Lin, S. H., Empirical Calculation of Microwave Rain Attenuation Distributions on Earth-Satellite Paths, IEEE Electronics and Aerospace Systems Conference, 25-27 Sept. 1978, Arlington, VA, pp. 372-378.

Although this short contribution nominally discusses earth-satellite paths, it also reiterates Lin's most recent effective path length scheme for terrestrial microwave links. Only results are presented in this paper, with detailed derivations omitted. Hence, this paper is in very useful form for the prospective modeler. Since both models (earth-satellite and terrestrial) are well known, and the terrestrial-link model is particularly widely accepted, the prospective modeler should give both due consideration.

Lin, S. H., H. J. Bergmann, and M. V. Pursley, Rain Attenuation on Earth-Satellite Paths--Summary of 10-year Experiments and Studies, BSTJ 59, No. 2, February 1980, pp. 183-228.

An extensive article summarizing the massive amount of data taken by Bell Labs. at SHF on earth-satellite links is presented. It also summarizes the modeling done at Bell Labs. during the ten-year period, in particular by S. H. Lin. As a consequence, the modeling results are relatively briefly presented, mentioning his major contributions (particularly the log-normal conditional distribution of rain rates and attenuations) and his effective distance models. The bulk of the paper is devoted to data results. Unfortunately, for all the data taken, the most usable data (taken directly from satellites) is still rather restricted in time and geographical location. Some aspects of path diversity are also discussed and experimental results shown.

Medeiros-Filho, F. C., D. A. R. Jayasuriya, and R. S. Cole, Probability Distribution of Amplitude Scintillations on a Line-of-Sight Link at 36 GHz and 55 GHz, Electronics Letters 17, No. 12, 1981, pp. 393-394.

This is a brief article that discusses relatively limited data from the U. K., but it is useful because it shows the range of scintillations (Figure 1) that would be expected at these frequencies--and they don't seem to be very large. One has a hard time conceiving what possible damage can be done by 0.15 dB at the most over 4.1 km. Even extrapolated to larger links, it isn't much. There may, however, be other implications of which these reviewers are unaware.

Misme, P., and P. Waldteufel, A Model for Attenuation by Precipitation on a Microwave Earth-Space Link, *Radio Science* 15, No. 3, May-June 1980, pp. 655-665.

This model is very much an engineering-type model, which has been developed on the basis of a convective area or cell, surrounded by a weak stratiform storm. This model has since been confirmed as one of the more applicable techniques in Europe. Hence, it is one that the prospective modeler should consider very carefully.

Morita, K., Study on Rain Rate Distribution, Review of the Electrical Communication Labs. 26, Nos. 1-2, January-February 1978, pp. 268-277.

In this paper, the author introduces his gamma-distribution model for rain rate distribution, which he extends to attenuation distributions elsewhere. The model fits several Japanese locations much better than log-normal distributions, but data from other countries are not examined.

Morita, K., Estimation Methods for Propagation Characteristics on Earth-Satellite Links in Microwave and Millimeter Wavebands, Review of the Elec. Comm. Labs. 28, Nos. 5-6, May-June 1980, pp. 459-471.

This article is an extension of the terrestrial-link model to earth-satellite links. There is little that can be said about the modeling at this point, because no comparisons were made with data in the article. Given the reputation of the author in previous terrestrial-link modeling, however, the prospective modeler should probably give this model due consideration. There is also a brief discussion of diversity modeling for earth-satellite applications included in this article.

Morita, K., and I. Higuti, Prediction Methods for Rain Attenuation Distributions of Micro and Millimeter Waves, Review of the Elec. Comm. Labs. 24, Nos. 7-8, July-August 1976, pp. 651-668.

This is the original paper in which the gamma distribution for use in the prediction of rain rate and attenuation due to rain is introduced. The methodology is compared with data from both Japan and the United States, which gives it a little more universal credibility. It is not especially difficult to obtain the parameters of the gamma distribution, which in this case is entirely for use on terrestrial links. Hence, it is worthwhile for the prospective modeler to give this model due consideration.

Morita, K., and I. Higuti, Prediction of Differential Rain Attenuation on Adjacent Microwave and Millimeter Wave Links, Review Electrical Communication Labs. 25, Nos. 1-2, January-February 1977, pp. 96-103.

In this paper, these two respected authors consider differential attenuation and spatial correlation of separated microwave or millimeter wave links. In the process they derive a spatial correlation function. This modeling is no doubt intended for, and applicable to, the route diversity problem that is important to earth-space communications.

Morita, K., and I. Higuti, Theoretical Studies on Simultaneous Probability of Rain Attenuation in Microwave and Millimeter Wave Multi Radio Relay Links, Review of the Elec. Comm. Labs. 25, Nos. 3-4, March-April 1977, pp. 329-335.

This paper extends the single-link attenuation model during rain to a multi-link (long haul) situation. This circumvents the necessity to perform calculations link by link, and thus would constitute a worthwhile model to consider for engineering purposes.

Movchan, S. P., and N. A. Starchenko, Absorption of Microwaves by Sand and Clay Soils, Radiophysics and Quantum Electronics 21, No. 5, 1978, pp. 546-547.

This is a brief paper on the dielectric properties of various kinds of earth soils at microwave frequencies. Since so little material is published on this subject, even with increased interest in dust and sandstorm effects, Figure 1 of this paper is of especial interest.

Oguchi, T., Scattering from Hydrometeors: A Survey, Radio Science 16, No. 5, Sept.-Oct. 1981, pp. 691-730.

The author is a most famous name in this field, principally because of his introduction of a solution to scattering from an oblate-spheroidal hydrometeor 20 years ago, leading to much work in the field of rain-caused depolarization. This is a very detailed review of the complicated scattering problem at SHF-EHF. Because, however, the survey is restricted to scattering from single drops, its engineering applicability is probably limited. Furthermore, the in-depth theoretical modeling described has been adapted to various engineering models, the examination of which would probably be more fruitful for the prospective modeler with telecommunications applications in mind.

Olsen, R. L., Cross Polarization During Clear-Air Conditions on Terrestrial Links: A Review, Radio Science 16, No. 5, Sept.-Oct. 1981, pp. 631-647.

This review is particularly interesting because it concerns cross-polarization effects on terrestrial links rather than the more commonly treated co-polar effects, such as multipath. As such, it is important that the prospective modeler give these aspects due consideration when using orthogonal polarizations at the same frequency, or even at nearby frequencies in the same bandwidth, either to increase channel capacity or to assure isolation on a long-haul link. The clear air cross-polarization effects are shown to behave similarly to multipath. Although no specific models are given, appropriate references are included, and the results of several experiments are tabulated. Clear air cross polarization effects are not expected to be as severe a problem at EHF as at SHF, because path lengths would likely be shorter.

Olsen, R. L., Cross Polarization During Precipitation on Terrestrial Links: A Review, Radio Science 16, No. 5, Sept.-Oct. 1981, pp. 761-779.

This is a very thorough review, which, along with the NASA Propagation Handbook (described previously), will provide the prospective modeler at microwave and millimeter wave frequencies with considerable background with only minimal mathematical entanglement by highlighting only the important equations. Oguchi's more recent models that incorporate canting angle distribution of raindrops into the equations are discussed as well as methodology for obtaining the attenuation of the quadrature fields and their differential phase shift. A log-normal distribution of cross-polarization discrimination (XPD) is also presented as well as a table and discussion of various experimental observations.

Ott, R. H., Temporal Radio Frequency Spectra of Multifrequency Waves in a Turbulent Atmosphere Characterized by a Complex Refractive Index, IEEE Trans. Ant. Prop. AP-25, No. 2, March 1977, pp. 254-260.

This is a very readable paper when one considers the complexity of the mathematics that the paper contains, resulting in coherence spectra for propagation through the hypothesized turbulent medium. The extensive mathematical formulations may turn out to be uninviting to the prospective modeler, but the paper's effort is concentrated in the SHF-EHF region, and thus may warrant further consideration.

Pappert, R. A., and C. L. Goodhart, Case Studies of Beyond-the-Horizon Propagation in Tropospheric Ducting Environments, Radio Science 12, No. 1, Jan.-Feb. 1977, pp. 75-87.

The paper presents an evaluation of the modal solution for propagation in both ground-based and elevated ducts. The mathematics are kept to a minimum so that salient results, such as equation (5), are presented, rather than extensive derivations. This would be a help to the prospective modeler. Nevertheless, the potential difficulty is that most of these evaluations are for frequencies well below microwave. For microwave frequencies and above, the number of modes required for accurate evaluation of equation (5) increases dramatically. It is unlikely then that such an expression could be used at microwave and millimeter wave frequencies without refinement of unknown extent.

Persinger, R. R., W. L. Stutzman, R. E. Castle, Jr., and C. W. Bostian, Millimeter Wave Attenuation Prediction Using a Piecewise Uniform Rain Rate Model AP-29, No. 2, March 1980, pp. 149-153.

This paper presents a relatively simple model for the computation of attenuation at microwave and millimeter wave frequencies which divides the path trajectory into equal intervals, and then sums the attenuation computed in each interval to achieve total path attenuation. For the limited sample of data the authors present, the model seems reasonably justified; hence, the prospective modeler should not disregard this model as a candidate for attenuation analysis. Further data confirmation of this model would be highly desirable, however.

Rogers, R. R., Statistical Rainstorm Models: Their Theoretical and Physical Foundations, IEEE Trans. Ant. Prop. AP-24, No. 4, July 1976, pp. 547-566.

This is an older tutorial paper but because of the subject matter it is not particularly out of date. One difficulty is, however, that the paper discusses mostly radar applications and radar-derived models in this report. In recent years, there has been a tendency away from trying to model rain attenuation by using the traditional radar modeling approach; nevertheless, much of the background material in this paper is still valid.

Rummler, W. D., A New Selective Fading Model: Application to Propagation Data, BSTJ 58, No. 5, May-June 1979, pp. 1037-1071.

This appears to be an extremely useful model which is reported here and elsewhere throughout the literature. This particular version is long and detailed and is contained, in essence, in an IEEE paper. It describes an estimation scheme for evaluating the coefficients for the amplitude of the medium transfer function based on several multipath models, the most prominent of which is the "three-path" model. Since this, and companion papers, are among the few reviewed that actually treat the medium transfer function, it could be a valuable modeling tool.

Rummler, W. D., More on the Multipath Fading Channel Model, IEEE Trans. Comm. COM-29, No. 3, March 1981, pp. 346-352.

This is a more succinct version of Rummler's BSTJ article. It is especially helpful in demonstrating the depth and spacing of nulls in the frequency spectrum of his modeled transfer function, and shows its significance for wide-band applications, since the secondary path delay (assumed 6.3 ns) inserts a null every 158.4 MHz.

Rummler, W. D., A Comparison of Calculated and Observed Performance of Digital Radio in the Presence of Interference, IEEE International Conference on Communications Record, 4, 1981, pp. 68.1.1-68.1.5.

We debated including this paper because the descriptive material seems rather general, and the prospective modeler would have to augment it with other information in order to apply it. However, it may serve as a useful introduction to those concerned with digital link analysis.

Schlesak, J. J., and J. I. Strickland, Geographic and Elevation Angle Dependence of Rain and Ice-Cloud Depolarization in Canada Along Earth-Space Paths at 12 GHz, IEEE International Conference on Communications Record 3, 8-12 June 1980, pp. 40.2.1-40.2.4.

This paper presents an experimentally derived relationship between cross-polarization discrimination (XPD) and co-polarization attenuation (CPA) in the presence of inclement weather that may in the long run be one of the best ways to approach the problem, considering its theoretical complexity. At any rate, it should be of some interest to the prospective SHF-EHF modeler.

Segal, B., An Analytical Examination of Mathematical Models for the Rainfall Rate Distribution Function, Annales des Telecommunications 35, No. 11-12, 1980, pp. 434-438.

This article compares the log-normal and gamma distributions with a 10-year data distribution from Ottawa for various measurement intervals from "clock" 10-minute to "instantaneous" (which, incidentally, is not clock-1 minute rates as is so often assumed). The comparison loses some impact, because the author could have used annual distributions rather than a 10-year combined distribution. The log-normal distribution appears to be the superior fit to these data for rainfall exceedance percentages above 0.001% of the time.

Stephansen, E. T., Clear-air Propagation on Line-of-Sight Radio Paths: A Review, Radio Science 16, No. 5, Sept-Oct. 1981, pp. 609-629.

This review covers clear-air effects above 1 GHz on LOS paths, in a succinct form, possibly useful for modeling purposes. It covers gaseous absorption, refractive index structure, multipath propagation, and ducting. The most useful material appears to be in the multipath and ducting areas.

Valentin, R., Attenuation Caused by Rain on Terrestrial Radio-Relay Links, Comparison between Theoretical Calculations and Measurements in the Frequency Range between 10 and 40 GHz, Nachrichtentechnische Zeitschrift 30, No. 6, 1976, pp. 509-512.

Ordinarily papers have not been reviewed in this survey that are restricted to results of a very localized experiment. Although this paper represents such a localized experiment, it does contain one pertinent result worthy of mention, and that is the fact that the classical Marshall-Palmer dropsize distribution used in connection with attenuation prediction on terrestrial links between 12 and 39 GHz still yields results that compare very well with observations. This could be an important modeling consideration, although it has not necessarily been confirmed elsewhere.

Vilar, E., and P. A. Matthews, Summary of Scintillation Observations in a 36 GHz Link Across London, IEE Conf. Publication #169, 28-30 Nov. 1978, London, England, pp. 36-40.

Most papers concerned with the subject of turbulence effects usually contain so much mathematical derivation and notation as to render them mostly useless to the engineering modeler. This paper, however, tends to be extremely concise in the presentation of pertinent formulae, thus making it potentially useful to the modeler. The drawback is, at least from these reviewers' aspect, that the amount of amplitude scintillations studied seems relatively negligible.

Vogler, L. E., The Attenuation of Electromagnetic Waves by Multiple Knife-Edge Diffraction, NTIA Report 81-86, October 1981.

This report represents an advance in the diffraction state-of-the-art over the use of classical single and double knife edges to represent diffraction obstacles. It is pertinent at microwave and millimeter wave frequencies because most obstacles can be represented as knife edges. The drawback to the modeling is that it applies to obstructed paths which generally only occur in mobile, interference, and secure applications.

Watson, P. A., Survey of Measurements of Attenuation by Rain and Other Hydrometeors, Proc. IEE 123, No. 9, Sept. 1976, pp. 863-871.

This is primarily a review paper of the many aspects of rain attenuation at microwave and millimeter wave frequencies. This is a good, but old, review paper on the subject, and it discusses many of the aspects of measurement. It is, however, probably of limited use to a prospective modeler for two reasons. First, it is now six years old. Second, it concentrates on measurements rather than models. The first reason is relatively serious, because most of the nonradiometric measurements have been made since 1976. The paper is probably best utilized as tutorial.

Zabolotniy, V. F., I. A. Iskhakov, A. V. Sokolov, and E. V. Sukhonin, Attenuation of Radiation at Wavelengths of 1.25 and 2.0 mm, *Infrared Physics* 18, 1978, pp. 815-817.

There are some interesting results in this paper for propagation through various distinct cloud types, but the frequencies are probably too high to be of particular interest at this time.

Zrazhevskiy, A. Yu., Method of Calculating the Atmospheric Water Vapor Absorption of Millimeter and Submillimeter Waves, *Radio Engineering and Electronics Physics* 21, No. 5, 1976, pp. 31-35.

This paper gives an apparently rather cumbersome "engineering method" for calculating gaseous absorption, similar to the other paper by the same author (below). However, it does appear that there are some differences (to what extent it is hard to say) between this procedure and those of Dr. H. J. Liebe at the Institute for Telecommunication Sciences. Thus, it is suggested that this paper should be given some further consideration.

Zrazhevskiy, A. Yu., and V. G. Malinkin, An Engineering Method for Calculating the Rotational Part of the Dielectric Constant of Water Vapor for $\lambda \geq 0.33$ mm, *Radio Engineering and Electronic Physics* 22, No. 1, 1977, pp. 128-130.

Although this paper claims to present an "engineering method" that would be applicable in the microwave and millimeter wave regions, the method seems unduly cumbersome. Furthermore, it is suspected that it contains much material that is familiar to the gaseous absorption and dispersion modelers, but still may be worth a second look.

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3.2.6.1 Rain, Clouds, and Other Hydrometeors

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BIBLIOGRAPHIC DATA SHEET

1. PUBLICATION NO. NTIA Report 82-107		2. Gov't Accession No.	3. Recipient's Accession No.
4. TITLE AND SUBTITLE BIBLIOGRAPHY AND SYNOPSIS OF LITERATURE CONCERNED WITH MICROWAVE AND MILLIMETER WAVE PROPAGATION EFFECTS		5. Publication Date September 1982	
		6. Performing Organization Code ITS3.4	
7. AUTHOR(S) E. J. DUTTON AND F. K. STEELE		9. Project/Task/Work Unit No. 910 8108	
8. PERFORMING ORGANIZATION NAME AND ADDRESS U. S. DEPT OF COMMERCE NTIA/ITS3.4 325 BROADWAY BOULDER, CO 80303		10. Contract/Grant No.	
		11. Sponsoring Organization Name and Address NTIA WASHINGTON, D. C.	
11. Sponsoring Organization Name and Address NTIA WASHINGTON, D. C.		12. Type of Report and Period Covered	
		13.	
14. SUPPLEMENTARY NOTES			
15. ABSTRACT (A 200-word or less factual summary of most significant information. If document includes a significant bibliography or literature survey, mention it here.) This report presents an extensive bibliography, categorized by effect, of radio propagation through the atmosphere, for the frequency region of 10 to 300 GHz. Preceding the bibliographic presentation is an article-by-article synopsis of that literature which is particularly pertinent to the prospective atmospheric propagation effects modeler. Thus, it should tend to serve as a bridge between earlier modeling efforts (done on a worldwide basis at these frequencies) and needs of future modelers searching for background material for a model foundation.			
16. Key Words (Alphabetical order, separated by semicolons) atmospheric effects, bibliography, microwave, millimeter wave, modeling, propagation, radio.			
17. AVAILABILITY STATEMENT <input checked="" type="checkbox"/> UNLIMITED <input type="checkbox"/> FOR OFFICIAL DISTRIBUTION.		18. Security Class. (This report) UNCLASSIFIED	20. Number of pages 80
		19. Security Class. (This page) UNCLASSIFIED	21. Price:



