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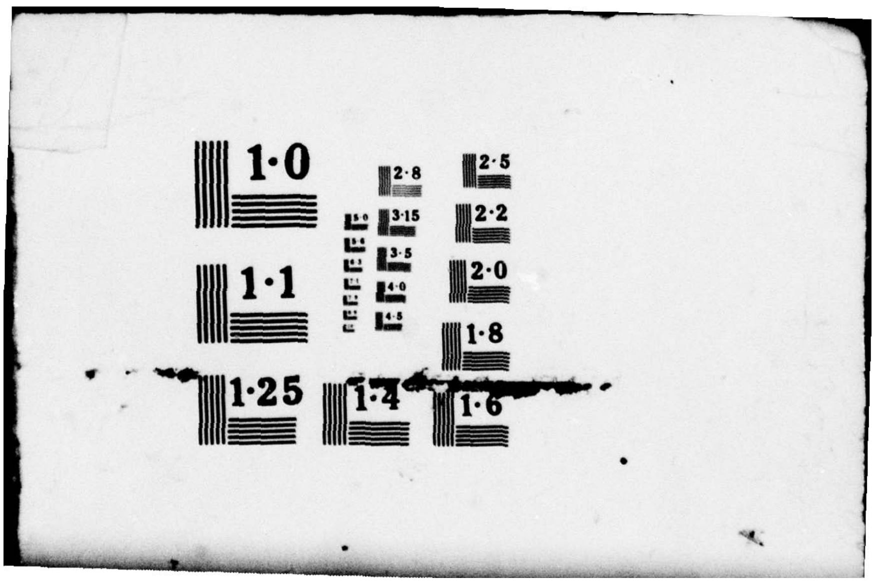
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ETL-0155

RADAR IMAGE SIMULATION: VALIDATION OF THE POINT SCATTERING METHOD ADDENDUM

J. C. Holtzman
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RSL Technical Report 319-31

June, 1978

Approved for public release; distribution unlimited

Prepared for:
U. S. Army Engineer Topographic Laboratories
Fort Belvoir, Virginia 22060

Contract DAAG53-76-C-0154

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The purpose of this report is to present the additional results of applying the Point Scattering Model for radar image simulation to three (3) new cases. This work is supplemental to that previously reported[1,2]. The work was sponsored by the U.S. Army Engineer Topographic Laboratories (ETL).

The results reported were obtained for four (4) simulations corresponding to four specific altitudes in the terminal trajectory of a guided missile (three of the simulations are new), each successively lower. The sequence of four

simulations was tested against actual radar data of the same site via the Correlatron*. The correlation tests showed performance of simulations produced by the PSM to be acceptable in three cases, and to be unacceptable in one case. The unacceptable performance was explained by geometric errors inadvertently introduced into the data base and was not produced by the simulation method.

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September 1977, AD-A053 240.

* Correlatron is a two-dimensional cross-correlation measuring device manufactured by Goodyear Aerospace and installed at ETL.

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[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September 1977, AD-A053 240.

*Correlatron is a two-dimensional cross-correlation measuring device manufactured by Goodyear Aerospace and installed at ETL.

PREFACE

This document was prepared by the Kansas Simulation Group, Remote Sensing Laboratory (RSL), The University of Kansas, Lawrence, Kansas, to report the work performed and results obtained for a radar simulation study performed under Contract DAAG53-76-C-0154, modification P00003, dated 22 June 1977, with the Engineer Topographic Laboratories (ETL), Fort Belvoir, Virginia.

The original effort performed was a radar simulation study to validate the Point Scattering Method, a radar image simulation model which had been developed previously, to investigate terrain feature extraction techniques for constructing category data bases (digital ground model) for radar simulation, and to use this point scattering radar simulation model to generate radar reference scenes for terminal guidance applications. The work performed and results obtained in the original study have been reported previously [1,2].

The study conducted under modification P00003 included preparation of three (3) radar reference scenes at three (3) different scales. The work performed to construct these three additional radar reference scenes and results obtained from using them in a test configuration are reported in this document.

This document is designed to be an addendum to the reports prepared for the original effort[1,2] and reports only the additional work and results obtained under modification P00003. It reports only the additional results and relies heavily upon the knowledge of the earlier documents for philosophical discussions, derivations, and technical details.

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. 1, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

PURPOSE

The purpose of this document is to report the results of applying the Point Scattering Method (PSM), a radar image simulation model, to construction of radar reference scenes for a missile terminal guidance application utilizing area correlation as the guidance technique. The work was performed at the Remote Sensing Laboratory (RSL), The University of Kansas, Lawrence, Kansas under contract with the Engineer Topographic Laboratories (ETL), United States Army, Fort Belvoir, Virginia.

The purpose of the work performed was to test the feasibility of using the PSM, previously developed and reported[3,4], to produce high quality radar reference scenes for terminal guidance applications. This purpose was accomplished by constructing the three (3) additional radar reference scenes needed to go with the one (1) developed in previous work[1,2] to make a complete set for one (1) target site.

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[3]Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," ETL-0047, RSL Technical Report 234-13, The University of Kansas Center for Research, Inc., February, 1976, AD-A027 151.

[4]Holtzman, J. C., V. H. Kaupp, and J. L. Abbott, "Radar Image Simulation Project," ETL-0098, RSL Tech. Report 234-15, University of Kansas Center for Research, Inc., September, 1976, AD-A051 501.

[1]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

SCOPE

The scope of the work performed in this feasibility study regarding the use of the PSM to make high quality radar reference scenes for terminal guidance applications was limited to constructing three (3) radar reference scenes for one (1) target site. The radar reference scene previously constructed and reported[1,2] was the largest scale (and, thus, greatest detail) scene required in a set of four (4). The three (3) radar reference scenes produced in the work reported here were the successively smaller scale (and, thus, larger area coverage) scenes in the set.

The lone target site selected for the feasibility study of the PSM was the topographic region in the states of Alabama, Tennessee, and Mississippi centered on the northwest corner of the power house at the Pickwick Landing Dam, Tennessee (coordinates; 34° 04' 15" N by 88° 15' 05" W).

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0018, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

EXECUTIVE SUMMARY

The Point Scattering Model (PSM) for radar simulation, developed at the RSL (Remote Sensing Laboratory, University of Kansas, Lawrence, Kansas) has been applied to the problem of synthesizing radar reference images for use in the terminal guidance system of a missile. The guidance system for which the PSM was tested utilizes a Correlatron* for deriving guidance information from the two-dimensional cross correlation between reference images and actual, "live" radar data.

Four (4) reference images were produced via the PSM, each successively representing lower altitudes and later stages of terminal descent over a target. The two higher altitude reference images were produced via the PSM from one radar data base, and the two lower altitude reference images from a second data base. The first of these data bases was constructed in work performed and reported in this document. The second data base was constructed in earlier work[1,2] for band 1 simulations, and was upgraded here for both bands 1 and 2 simulations. The same philosophy and construction techniques were utilized for both data bases. The bands 3 and 4 data base covers a much larger geographic area and was built having a smaller inherent scale than the bands 1 and 2 data base, consistent with the higher altitude simulations it is designed to support. Aside from these obvious differences in area or coverage and scale, a major difference exists between the two data bases. The bands 3 and 4 data base was built using

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*Correlatron is a two-dimensional cross-correlation measuring device manufactured by Goodyear Aerospace Corp.

[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A052 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

a 1:100,000 scale ortho photo and elevation data developed via UNAMACE* as the input source intelligence information. The bands 1 and 2 data base was constructed using standard 7-1/2 quadrangle USGS (United States Geological Survey) 1:24,000 scale maps and elevation data derived from the maps by DMA (Defense Mapping Agency) as the input source intelligence data. The ortho photo was constructed as a tangent plane projection centered on the target site. The USGS maps are modified polyconic projections. Thus, differences in geometric fidelity underlie the two data bases.

The sequence of four (4) reference scenes was tested on a Correlatron at ETL (U.S. Army Engineer Topographic Laboratories) versus actual radar data previously collected and recorded in a flight test program conducted over the Pickwick test site. Results of this test were very favorable for the PSM, but results were not as decisive as expected because of geometric fidelity problems inadvertently created by mechanical means when constructing the bands 3 and 4 data base. A qualitative assessment of the results produced is:

1) Band 1 (Lowest Altitude) - Very good performance within accuracy requirements;
2) Band 2 (Higher Altitude) - Excellent performance well within desired accuracies;
3) Band 3 (Next Higher Altitude) - Failure to perform within accuracy requirements;
4) Band 4 (Highest Altitude) - Acceptable performance within accuracy requirements.

These results represent a single preparation of the radar reference images and are not the best possible results produced after much changing and custom-tailoring of various parameters as this has not been done. The bands 1 and 2 simulations were developed from the data base having the highest degree of detail. Performance of these simulations was

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*Bertram, Sidney, "The Universal Automatice Map Compilation Equipment," Photogrammetric Engineering and Remote Sensing, Vol. 31, No. 2, March 1965.

spectacular in view of the fact that they worked so well on the first trial. Band 3 and 4 simulations were developed from the data base having geometrical problems as discussed in Section 6. Performance of the simulations produced from this data base was better than expected in view of the nature of the problems built into the data base.

The problems in the bands 3 and 4 data base are unfortunate because they cloud what otherwise should have been a clear decision in favor of the PSM. Surely if this data base had not contained geometrical errors, the PSM simulations for bands 3 and 4 would have performed as well as the bands 1 and 2 simulations did. Of course, this cannot be proved by the data that exist, but it is a reasonable conjecture, especially in view of the fact that even with the errors, the simulation for band 4 was acceptable.

Simulations produced via the PSM should work well in this guidance application. The PSM rigorously models the radar guidance system, and accuracy of performance in this application should be limited by the accuracy of the data base.

In conclusion, the results produced in work performed in this study verify the validity of using the PSM for producing radar reference scenes to be used in conjunction with the Correlatron. The verification is not as strong as it might have been if errors of construction technique (i.e., implementation or mechanical errors, not errors in construction philosophy) had not been introduced into the bands 3 and 4 data base. The work performed show the PSM to be a viable tool for solving "real-world" problems, not just an academic exercise, which can and should be applied to many present and future problems.

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1.0 INTRODUCTION

The work reported in this document was performed to test the feasibility of using the Point Scattering Method (PSM), a previously developed, validated, and reported radar image simulation model,[1,2,3,4] to produce high quality radar reference scenes for terminal guidance applications. The study performed here was supplemental to the work previously performed and reported in references 3 and 4. In the previous work preliminary indications of using PSM, for terminal guidance applications were investigated by producing one (1) radar reference scene for one (1) target site. That test was very successful but was deemed not conclusive because the terminal guidance application for which PSM was being tested required a set of four radar reference scenes for each target site and only one (1) of the set (the lowest altitude and largest scale) had been produced by the PSM. The work reported here was performed to produce the additional three (3) radar reference scenes required to complete the set for the one target site. The target site for which this sequence of reference scenes was formed was the Pickwick Landing Dam test site. This site is located in the states of Alabama, Tennessee, and Mississippi with the site centered on the northwest corner of the power house at the dam (coordinates 34° 04' 15"N by 88° 15' 05" W).

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[1]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davision, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0018, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

[3]Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," ETL-0047, RSL Technical Report 234-13, The University of Kansas Center for Research, Inc., February, 1976, AD-A027 151.

[4]Holtzman, J. C., V. H. Kaupp, and J. L. Abbott, "Radar Image Simulation Project," ETL-0098, RSL Tech. Report 234-15, University of Kansas Center for Research, Inc., September, 1976, AD-A051 501.

Philosophical discussions of the terminal guidance problem, the PSM radar image model, and work plan are presented in this section (1.1, 1.2, and 1.3, respectively) and the technical details of the work performed and the results obtained are incorporated in succeeding sections.

1.1 Terminal Guidance

The task of delivering an explosive projectile accurately enough to destroy an intended target has three (3) basic components: (1) Distinguish the target from its surroundings; (2) Determine the exact position of the target relative to the launching point of the missile; (3) Guide the projectile onto the target. "Terminal guidance" is the descriptive phrase used to signify the final segment of an explosive projectile's flight in which it is guided onto the target (item 3, above). In this work we are concerned only with the question of "terminal guidance". How the first two (2) phases of delivering a projectile onto a target (items 1 and 2, above) are satisfied doesn't enter this concern. A variety of ways exist to deliver a projectile into the neighborhood of a target. These span the gamut from ballistic to cruise to bomber delivery techniques.

Different terminal guidance philosophies exist. The philosophy for which the feasibility of using the PSM was investigated was area correlation. In this particular scheme reference radar images of the target site (computer-generated simulations formed via the PSM in this work) are stored on-board the projectile in its guidance package. In the terminal phase of its trajectory a radar interrogates the terrain below the projectile and the guidance device compares the radar data to the previously stored reference scene, deriving guidance data from the comparison. The comparator employed in the work performed here was the Correlatron, an area-cross-correlation measuring device manufactured by Goodyear Aerospace. The Correlatron has been discussed in Aviation Week[5] and in the earlier report of applying the PSM to the question of terminal guidance,[6] thus a discussion of the Correlatron will not be repeated here.

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[5] Klass, Philip, J., "Guidance Device Set for Pershing Tests," Aviation Week and Space Technology, May 12, 1975.

[6] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253, pp. 105-110.

The guidance package incorporating a Correlatron requires that four (4) reference radar images be stored on-board the projectile for comparison with "live" video radar data (acquired via a resident radar) of the terrain in the vicinity of the intended target (this presupposes that the first two phases of the projectile problem have been satisfied accurately and the projectile is in the neighborhood of the target). These four reference scenes form a sequence starting with the smallest scale (largest area coverage) and progressing to the largest scale (smallest area coverage) corresponding to the highest altitude to the lowest altitude, respectively.

It is this sequence of four (4) reference scenes for which the feasibility of using the PSM was tested in the work reported here and in the earlier work[1,2]. Radar reference images have been formed via the PSM in this work for the three (3) smallest scale (each progressively larger) scenes corresponding to the three (3) highest altitudes, and a radar reference image was produced in the earlier work via the PSM for the largest scale (lowest altitude) scene. These four (4) radar reference images together comprise a complete sequence of scenes for one target site.

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

1.2 The Point Scattering Method: A Model for Radar Image Simulation

The Point Scattering Method (PSM) for radar image simulation has been developed[3] and validated[1,2] in previous work. A detailed description is not repeated here but the essence of the PSM is summarized to lay the framework for understanding what is involved in constructing radar reference scenes for the Correlatron guidance package. The appropriate references should be consulted for additional technical information.

1.2.1 Introduction to the PSM

The PSM is a model developed for the end-to-end simulation of radar images. By radar image simulation is meant synthesis of the image which would have been produced by a radar had it been flown according to a prescribed flight path over the actual ground site. The radar senses the terrain in the microwave portion of the electromagnetic spectrum and produces an image on ordinary photographic film. The radar image represents the reflectivity characteristics of objects on the ground at radar wavelengths and displays the terrain in fine detail and with spectacular relief. So does the simulated radar image.

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[3]Holtzman, J. C., V. H. Kaupp, R. L. Martin, E. E. Komp, V. S. Frost, "Radar Image Simulation Project: Development of a General Simulation Model and an Interactive Simulation Model, and Sample Results," ETL-0047, RSL Technical Report 234-13, The University of Kansas Center for Research, Inc., February, 1976, AD-A027 151.

[1]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977 , AD-A053-253.

[2]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

The Point Scattering Method represents the radar, the terrain and its microwave response, and the image and its record on photographic film by a closed-system model in this guidance specialization of the model. The model rests on firm theoretical foundations and is mathematically rigorous. It incorporates all aspects of the imaging radar problem. The model is, however, more than equations. It is a philosophy of radar image synthesis.

Just as all mathematical models are abstractions of reality, so is the PSM. It attempts to describe in closed form the processes of the imaging radar system consisting of the radar, ground, and image. The PSM is completely general and is capable of producing images having whatever accuracy is required (at least for distributed targets) and producing them in a desired output format for any particular application if the cost is paid in time, complexity, and resources expended. The true value of the PSM comes from the flexibility to specialize it for each application by making valid approximations and simplifications. The model can be made efficient and cost-effective to use.

The development of the general PSM and the philosophy of radar image simulation embodied by this model are summarized according to the following four natural divisions of the problem: (1) Imaging model; (2) Radar geometrical/propagation phenomena; (3) Ground model; and (4) Reflectivity model. In all that follows, it should be kept in mind that regardless of how the model is implemented (e.g., on a digital computer), there are three basic input data requirements of the model. These are illustrated in the block diagram of Figure 1. First, the operating parameters of the radar being simulated must be incorporated. Second, a symbolic representation of the relief and dielectric properties of each selected ground site must be specified. This symbolic representation of the terrain (the ground truth) is called the data base. Last, the reflectivity properties of all the different dielectric categories (radar categories) included in the ground truth data base must be specified. The reflectivity properties of the different categories are modelled by the differential scattering cross-section (σ°); either theoretical or empirical backscatter data are used.

Upon satisfaction of all three input data requirements, the computational algorithms of the Point Scattering Model are employed to synthesize the radar image that would have been collected if the modeled radar had been flown over the selected ground site, a fact attested to by the images presented later.

Previous efforts in the area of radar image simulation have incorporated over-simplifications in either the model of the imaging process or in the representation of the microwave reflectivity of the various categories. The Point Scattering Method does not rely on arbitrary over-simplifications; it is completely rigorous and general. Thus, for the first time a complete radar image simulation model, representative of all facets of the process, is available.

1.2.2 Imaging Model

The imaging model is the final computational algorithm of the Point Scattering Method. After the ground truth data base (terrain feature model) of the desired site has been specified, the reflectivity (σ°) data for the various categories included in the data base have been obtained, and the complex geometry relating the radar platform to the scene has been determined, the imaging model is used to calculate the power reradiated from the ground back to the radar for each pixel (picture element) in the image. It calculates the intensity of the ground-return signal exiting the receiver, and in the present guidance specialization of the PSM, it calculates the conversion of this intensity into density of silver grains in the exposed and developed image. This algorithm determines the shade of grey of each pixel in the image, and hence, is called the greytone equation. The greytone equation produces the final results, drawing upon all preceding data and calculations. It relates the ground to the radar and to the image.

An appropriate starting point for this development of the imaging model would be a description of the principles of imaging radars. However, as these principles have been well documented in the literature, they will not be repeated here[7,8]. The starting point for the radar simulation imaging model (greytone equation) is the prediction (estimation) of the power reradiated from each resolvable ground element (resolution cell) The size of a resolution cell is determined in the range direction by the pulse length and in the azimuth direction by the directional properties of the antenna, either real or synthetic. For the purposes of radar image simulation, it's assumed that the ground can be modeled as a collection of homogeneous regions, each at least the size of a resolution cell (these are called distributed targets). Point, or cultural, targets can be handled

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[7] Skolnik, M. K., (Editor), Radar Handbook. New York: McGraw-Hill, 1970.

[8] Moore, R. K., "Microwave Remote Sensors," in R. G. Reeves, Remote Sensing Manual, Falls Church, Virginia: American Society of Photogrammetry, 1975, Chapter 9.

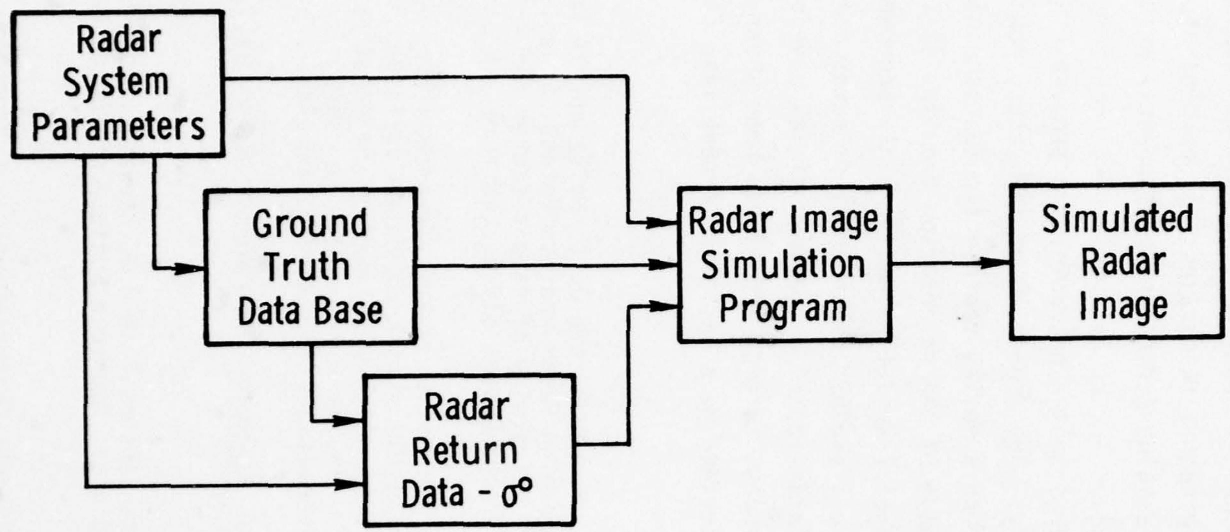

Figure 1. Fundamental Block Diagram - Simulation.

statistically, symbolically, by scattering calculations, or alternately by the area spatial filtering method[9]. The power reradiated from all the scattering centers located within a resolution cell combine at the receiving antenna to produce one value for the resolution cell which is designated the return power (P_R).

In reality the return power is not a deterministic process as the foregoing discussion might imply. The amplitude of the return power received by the antenna mounted on a moving vehicle fluctuates widely because of variations in the phase of the reradiation from the different scatterers in the illuminated area (resolution cell). This phenomenon accounts for the speckled nature ("grainy" appearance) of radar images and is called "fading". The statistics of a "fading" signal have been well-documented for most homogeneous targets and it has been shown that the signal amplitude can be described by a Rayleigh* probability distribution[7,8,10].

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[9]Frost, V. S., J. L. Abbott, V. H. Kaupp, and J. C. Holtzman, "A Mathematical Model for Terrain-Imaging Radar and Its Potential Applications to Radar Image Simulation," University of Kansas Center for Research, Inc., Remote Sensing Lab., Tech. Report 319-6, Lawrence, Ks., Nov. 1976.

*The Rayleigh probability distribution is one of the probability models[12,13] which can be used to describe the signal amplitude variation. Use of a different probability model would modify the resulting "fading" per cell somewhat. However, for medium to coarse resolution radars, final averaging yields similar results.

[7]Skolnik, M. I., (Editor), Radar Handbook. New York: McGraw-Hill, 1970.

[8]Moore, R. K., "Microwave Remote Sensors," in R.G. Reeves, Remote Sensing Manual, Falls Church, Virginia: American Society of Photogrammetry, 1975, Chapter 9.

[10]Bush, T. F. and F. T. Ulaby, "Fading Characteristics of Panchromatic Radar Backscatter from Selected Agricultural Targets," IEEE Trans. Geosci. Electron., Vol. GE-13, October 1976, pp. 149-157.

[12]Zelenka, J. S., "Comparison of Continuous and Discrete Mixed-Integrator Processors," J. Opt. Soc. Amer., Vol. 66, No. 11, November 1976.

[13]Porcello, J. L., Norman G. Massey, Richard B. Innes, and James M. Marks, "Speckle Reduction in Synthetic-Aperture Radars," J. Opt. Soc. Am., Vol. 66, No. 11, November 1976.

If square-law detection is assumed for the radar being modeled, then the postdetection signal is a random variable having a chi-square probability density function with 2NS degrees of freedom[10] where NS specifies the number of "independent samples" being averaged. The minimum width of a backscatter lobe in the azimuth direction (best azimuth resolution) is specified as L/2 where L is the real antenna length[11]. A real-aperture SLAR (Side-Looking Airborne-Radar) has an azimuth resolution given by βR where β is the diffraction-limited beamwidth given by λ/L (the illuminating energy wavelength divided by the real antenna length L) and R is the range distance from the antenna to the resolution cell on the ground. From these two concepts of resolution the number of "independent samples" which are effectively combined to produce the instantaneous average return power (P_R) from a resolution cell can be determined:

$$NS = \frac{\beta R}{L/2} = \frac{2R\lambda}{L^2} \qquad (1)$$

In a fully-focused synthetic-aperture radar, the azimuth resolution (βR) is L/2, so there is but one sample of the random process (NS = 1) used and, hence a speckled appearance in the radar image[11].

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[10] Bush, T. F. and F. T. Ulaby, "Fading Characteristics of Panchromatic Radar Backscatter from Selected Agricultural Targets," IEEE Trans. Geosci. Electron., Vol. GE-13, October 1976, pp. 149-157.

[11] Moore, R. K. and G. C. Thomann, "Imaging Radars for Geoscience Use," IEEE Trans. Geosci. Electon., Vol. GE-9, July 1971, pp. 155-164.

Averaging a larger number of "independent samples" as occurs typically in real-aperture systems reduces signal fading, (i.e., reduces the variance and thus, smooths the image appearance[12,13]). But, increasing the number of samples averaged also degrades the final image resolution.

After detection, it can be shown that the return power from each resolution cell is estimated by[14]:

$$P_R = \left(\frac{\overline{P}_R}{2NS}\right)\left(Y\right) \qquad (2)$$

where $\overline{P}_R$ is the expected value of the return power from a resolution cell Y is a random variable with a standard chi-square distribution having 2NS degrees of freedom, and NS is the number of "independent samples" averaged (Equation 1). When the number of independent samples being averaged is large, (2) becomes:

$$P_R = \overline{P}_R \left(1 + \frac{RN}{\sqrt{NS}}\right) \qquad (3)$$

where RN is a normalized Gaussian random variable with zero mean and unit variance[1].

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[12]Zelenka, J. S., "Comparison of Continuous and Discrete Mixed-Integrator Processors," J. Opt. Soc. Amer., Vol. 66, No. 11, November 1976.

[13]Porcello, J. L., Norman G. Massey, Richard B. Innes, and James M. Marks, "Speckle Reduction in Synthetic-Aperture Radars," J. Opt. Soc. Am., Vol. 66, No. 11, November 1976.

[14]Frost, V. S., J. L. Abbott, V. H. Kaupp, and J. C. Holtzman, "Derivation of the Radar Image Fading Characteristics," University of Kansas Center for Research, Inc., Remote Sensing Laboratory, Technical Report 319-29, Lawrence, Kansas, September 1977.

[1]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

For terrain that can be modeled as a collection of homogeneous, distributed targets the value of P_R calculated from either (2) or (3) is the best estimate of return power after detection that can be made when each resolution cell is treated as a single point. Even for collections of scatterers not homogeneously distributed this may still be a good approach, but statistics other than Rayleigh may be in order, for example, when several dominant scatterers are located within a resolution cell. If the terrain cannot be modeled in this way the location and reradiation properties of each of the numerous scattering points within a resolution cell are modeled, the amplitude and phase of the return from each point is calculated, and the resulting phasor sum (magnitude) at the antenna is chosen to become the estimate of return power. For high-resolution and synthetic aperture radar applications of radar image simulation, either approach is possible but the latter is computationally inefficient and requires investment of a vast amount of time to model the ground properly. For medium resolution applications such as those reported here, Equations (2) and (3) represent very good estimates of the post-detection return power.

Usually after detection the intensity of the video signal exiting the receiver is recorded on film. This can be expressed by [1]:

$$D = \gamma \log_{10} P_R + \gamma \log_{10} M + \log_{10} K \tag{4}$$

where P_R is given by either Equation (2) or (3); D is the density of metallic silver grains in the exposed transparency corresponding to the intensity of the illumination; K is a constant depending upon the exposure time and the film processing and development time; γ is a positive constant representing the slope of the linear portion of the film curve of density

[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

versus logarithm of exposure (the Hurter-Driffield curve [15]) where $\log_{10}K$ is the extrapolated intercept of this line; M is the transfer function of the radar receiver (including all appropriate linear and non-linear effects such as AGC, Automatic Gain Control, or saturation) such that the video intensity incident on the film during exposure is specified by MP_R.

The next step in the development of the imaging model is to define how the simulation process is to be quantized for implementing the model on a digital computer. The return power calculated for each resolution cell is coded into one pixel in the simulated image. Each pixel in the image will represent one precise shade of grey between black (no return power) and white (saturated signal, high return power). Thus, Equation (4) for the film density must be altered to reflect digital data processing requirements. The shade of grey (greytone) for each pixel in an image can be shown to be specified by $G_R = \left(\frac{2^n-1}{g}\right) D$ where D is given by Equation (4), 2^n is the number of discrete levels of grey available in a computer word having n bits, and g is the base 10 logarithm of the dynamic range of the radar signal being mapped into the linear portion of the film dyamic range[1]. Using this result, the final "greytone" equation, or imaging model, is given by:*

$$G_R = G_{R_c} + \frac{2^n-1}{g} \left\{ \gamma \log_{10} \frac{P_R}{P_{R_c}} + \gamma \log_{10} \frac{M}{M_c} + \log_{10} \frac{K}{K_c} + \gamma \log_{10} \left(1 + \frac{RN}{\sqrt{NS}}\right) \right\} \quad (5)$$

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[15] Goodman, J. W., Introduction to Fourier Optics. New York: McGraw-Hill, 1968, pp. 150-153.

[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1976, AD-A053 253.

*This final form for the greytone equation is predicated upon using film as the final image medium. If film is not the final image medium, the greytone equation would take an appropriate, alternate form.

where substitution for D has occurred and the result has been calibrated. Calibration is shown in two phases. The first phase of calibration is calculating the photographic density of a point in the image by the expression $\frac{2^n-1}{g} \{\log_{10} [(I_c)^{\gamma} K_c]\}$ where I_c is the intensity of the signal exposing the film for the calibration point ($I_c = P_{R_c} M_c$), and M_c, K_c, and γ are the receiver transfer function and film constants for the calibration point as previously defined. The last phase is setting G_{R_c}, the greytone to that point, to a desired level (between 0 and 2^n-1). Together these calibration parameters have the effect of determining how much of the dynamic range of the radar signal will be mapped into the 17-20 dB dynamic range available in ordinary film, and exactly what portion of the dynamic range of the radar signal will be displayed.

In the development leading to Equation (5), the power reradiated as a result of the illuminating-energy/terrain interaction was not specified. An excellent model for the return power reradiated from distributed targets is given by the radar equation [7,8]:

$$\bar{P}_R = \frac{P_T G^2 \lambda^2 \sigma^0 A}{(4\pi)^3 R^4} \tag{6}$$

where the average transmitted power is represented by P_T; the two-way gain of the transmitting/receiving antenna (a function of the elevation, and azimuth angles) is given by G^2; the transmitted wavelength is given by λ; the reflectivity model, (a function of wavelength and local angle of incidence, among others) is σ^0; the element of area on the ground being sensed (a function of the ground slope, pulse length, azimuth resolution, and altitude) is A; and the range from the antenna to the element of area being sensed is R.

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[7] Skolnik, M. I., (Editor), Radar Handbook. New York: McGraw-Hill, 1970.

[8] Moore, R. K., "Microwave Remote Sensors," in R. G. Reeves, Remote Sensing Manual, Falls Church, Virginia: American Society of Photogrammetry, 1975, Chapter 9.

Certain conditions must exist for this form of the radar equation to be valid. First, the area being sensed must be a distributed target. A distributed target is a homogeneous region of a specific radar reflectivity category in which there must be a large number of individual scattering centers located within a resolution cell and they must be positioned randomly [7]. Second, it must be assumed that all the parameters of the radar equation are constant across a resolution cell. When these conditions are satisfied by both the terrain being simulated and radar being modeled, then Equation (6) a particularly tractable form of the radar equation, can be used in the greytone Equation (5) in conjunction with either Equation (2) or (3) to estimate the return power from each resolution cell, as was done for the results reported here.

1.2.3. Radar Geometrical/Propagation Phenomena

The greytone Equation (5) is the final computational algorithm of the Point Scattering Method but it does not represent the complete model. It represents conversion of the signal returned from each resolution element into the appropriate grey shade for each image pixel after the elevation profile, dielectric categories, and spatial relationships of the various cells have been properly considered. The degree of accuracy of treatment of these and all the normal radar effects (such as illuminating-energy/terrain interaction, layover, shadow, range compression, etc.) depends upon the application for which the simulated radar images are being prepared. Greater accuracy is required for some applications than for others. It would be inefficient and expensive to treat all applications as requiring the same detail. Thus, while the model is theoretically capable of any degree of accuracy of treatment, each specific implementation of the model is adjusted to meet the requirements of each application.

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[7] Skolnik, M. I., (Editor), Radar Handbook. New York: McGraw-Hill, 1970.

The condition called shadow, manifested as a black area on an image, is caused by obstructions in the terrain which prevent illumination of certain areas and, thus, power will not be reradiated continuously thereby causing gaps in the returned signal. Layover is also a result of geometrical/propagation phenomena whereby the return power from an object nearer to the radar, by virtue of being taller than its surroundings, is recorded sooner, and therefore, closer to the near-range edge of the image than the return from surrounding portions of the terrain. Local angle of incidence is the effective angle made between a line drawn from the antenna to the element of area being sensed and the normal to the element of area (resolution cell) thereby accounting for the local slope (or tilt) of the resolution cell. This angle is necessary for calculating the value of σ^o for each resolution cell (Equation (6)). If the radar system being modeled records in a slant-range mode, then the effect of range compression must be included. Range compression is the condition where there is a monotonic decrease (in the range direction) of the scale toward the near-range edge of the image. If the radar system being modeled records in a ground-range mode the terrain is assumed to be flat and the scale of the image is altered by the inverse of the slant-range scale compression to preserve geometric fidelity. The ground-range mode adequately preserves geometric fidelity for areas in which relief is small compared to the scale of the image, however, it accentuates layover and positional errors with these becoming intolerable in areas of high relief.

Treatment of all of these effects, and more, is included in the software implementation of the PSM. Development of the specific algorithm implemented for each of the geometrical/propagation effects is beyond the scope of this report. Full development of the simulation model is reported by Holtzman, et al.[1,2] The total software package computes the greytone on a resolution cell basis for each pixel in the image and accounts for all geometric/propagation effects. There is no one-to-one correspondance between

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., Sept. 1977, AD-A053 240.

elements in the data base and the pixels in the simulated image since the algorithms developed to model geometric/propagation effects perform the same function as the radar system being simulated.

1.2.4 Ground Model

A model of the ground must be constructed (ground truth data base) for each site for which simulated radar images are to be produced. The data base is a symbolic representation of the different radar reflectivity categories and the elevation variations of the terrain present in a target scene. Since the PSM has been implemented on the digital computer, the data base must be in a digital format.

Typically , the data base consists of a digital matrix containing four dimensions. These four dimensions are the range and azimuth coordinates, elevation, and radar reflectivity (backscatter) category of each point in the scene. It is this matrix together with the backscatter data (reflectivity model) upon which the simulation program operates to calculate such parameters as return power level, look-direction, range, angle of incidence, shadow, layover, range compression, etc.

The data base can be considered to be a symbolic digital model of the physical (geometric) and radar reflectivity (dielectric) properties of the ground. Accurate construction of this digital terrain model is crucial to the overall simulation effort. Ground truth data bases are built, typically, using manual cartographic feature extraction techniques. Once the source imagery (photos, maps, etc.) have been obtained for a particular site, a radar/photo-interpreter uses these input sources of intelligence data, and his knowledge and intuition to construct a backscatter category map of the area.

When this symbolic data base map has been finished, it is a symbolic line drawing of the boundaries separating distributed targets. For use on the computer, this line drawing must be digitized and formed into a matrix. Digital elevation data must then be added to the category matrix to produce the final ground truth data base. After the category and elevation data are merged into a digital matrix, the ground truth data base is ready for input to the radar simulation program. Construction details for the data bases used to produce the results presented later in this paper are reported by Holtzman, et al. (1977) [2].

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[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

The choice of spacing of the elements of the ground truth data base is governed by three factors. First, a terrain Nyquist sampling interval for elevation data can be determined by the maximum rate of change of elevation in the scene of interest. Second, each backscatter category data point must represent a homogeneous region containing a large number of randomly located scatterers for validity of the radar equation (6). However, since the ultimate resolution of a fully-focused radar is L/2 (L is the real antenna length) we need not have the sample interval $<< L/2$. Thus, there are several criteria which set lower bounds on spacing (i.e., minimum spacing) between sample points of the terrain in the ground truth data matrix. On the other hand, the maximum desirable spacing of sample points is set by the application.

1.2.5 Reflectivity Model

For each reflectivity category included in the ground model (data base) the dielectric properties must be modeled. The PSM uses both empirical backscatter data (differential scattering cross section, σ^o) and theoretical results to do this. The backscatter data (σ^o) model the illuminating energy and terrain interaction and specify the fraction of energy reradiated from the ground back to the antenna. Categories are represented in the data base as, for example, Category 1, or 2, or 3, or . . . The simulation program, upon reading Category 1,2,3, etc., for a point, solves the complex geometry relating the radar platform to the orientation of the ground at that point, selects the appropriate backscatter data-set for that category and then solves the σ^o versus angle-of-incidence relationship to calculate the return power via equation (5). Naturally, the return power calculations must reflect the real situation in which atmospheric scattering and attenuation may become significant. In this way the greytone is computed for each pixel in an image.

Empirical σ^o versus angle-of-incidence data are used in the PSM wherever possible for the categories of scatterers typically encountered in the terrestrial envelope of interest for radar simulation. These empirical σ^o data are taken both from an extensive agricultural/soil moisture data bank under development at the Remote Sensing Laboratory as well as from the literature[10,16].

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[10] Bush, T. F. and F. T. Ulaby, "Fading Characteristics of Panchromatic Radar Backscatter from Selected Agricultural Targets," IEEE Trans. Geosci. Electron., Vol. GE-13, October 1976, pp. 149-157.

[16] Cosgriff, R. L., W. H. Peake, and R. C. Taylor, "Terrain Scattering Properties for Sensor System Design," Eng. Experiment Station Bulletin, 181, Vol. 29, Ohio State University, Columbus, Ohio, May, 1960.

1.3 Work Plan

The feasibility of using the PSM for making reference radar images for a terminal guidance concept using the Correlatron was investigated in a joint effort between the RSL (Remote Sensing Laboratory, The University of Kansas) and the ETL (U.S. Army Engineer Topographic Laboratories, Fort Belvoir, Virginia). Figure 2 is reproduced from reference (1) to illustrate the apportionment of work between RSL and ETL because the same plan was followed in this study. The three major classifications of work at RSL are: (1) produce data bases, (2) obtain terrain reflectivity data, and (3) produce reference scenes. The activities at ETL included supplying digital elevation data, producing reference scene film, and running Correlatron tests.

The first and most time consuming task accomplished was the construction of the ground truth data base. The Pickwick Landing Dam site had been previously selected for the lower altitude scene produced earlier on the basis of: (1) existence of real radar video data, (2) diversity of radar scattering types in the scene, (3) availability of source data to construct the ground truth data base, (4) accessibility of empirical backscatter coefficient data to describe the scatterers within the site. Likewise, the Pickwick site met these criteria for the higher altitude scene reported in this work. Two data bases were constructed for the reference radar images formed. The first data base was constructed to support reference scenes for the two larger scale (lower altitude) images (called bands 1 and 2) and one for the two smaller scale (higher altitude)

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[1]Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977 , AD-A053 253.

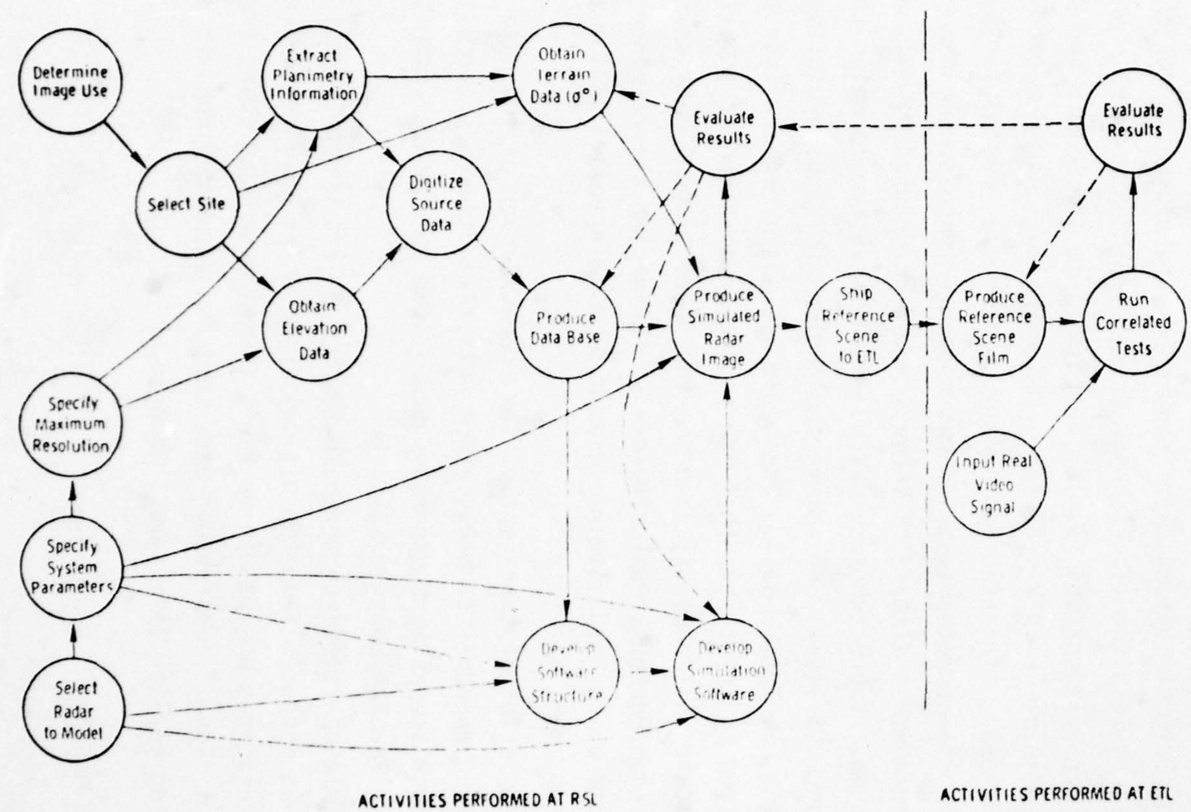

Figure 2. Work Plan - Terminal Guidance Plan.

images (called bands 3 and 4). Part of the work of making the data base for the two larger scale images was done and reported earlier (a data base sufficient for the band 1 image was produced and reported in reference (1)). Construction of these data bases is discussed in a subsequent section.

Terrain reflectivity data were sought for the microwave reflectivity categories built into the two Pickwick ground truth data bases. As a consequence of the poorer spatial resolution built into the band 3 and 4 data base, quite often many distinctly different scattering regions were grouped together. However, since the planimetry source data (aerial photographs) displayed much finer resolution, it was possible to determine the constituency of areas where a mixture of targets would be grouped as one composite scattering type. There are no clear cut methods on how to weigh the importance of the response of individual scattering regions (of sub-resolution cell size) within a resolution cell. Therefore, it was a venture into the unknown, guided by intuition, that led to the combination of empirical backscatter data that were utilized for the bands 3 and 4 data base categories for inhomogeneous resolution cells. Weighting the response of scattering regions by the relative percentage of area coverage within a resolution cell was often used.

Upon completion of these activities (construction of the data bases and cataloguing appropriate backscatter data from diverse sources), the three reference scenes were generated and stored on computer-compatible magnetic tape for shipment to ETL.

The completed reference scenes were sent to ETL where the reference scene film was produced from the digital tapes. The film containing the reference scenes was stored on ETL's Correlatron test stand and was tested versus "live " radar video data that had been recorded via a video recorder in an earlier flight-test program.

2.0 REFERENCE SCENE GROUND TRUTH DATA BASES

Two ground truth data bases have been constructed to support making reference radar scenes for the Pickwick Landing Dam target site. One data base was prepared for the bands 1 and 2 scenes (largest scale and lowest altitude scenes) and one for the bands 3 and 4 scenes (smallest scale and highest altitude scenes). These data bases were developed to model the terrain in the topographic region of the target site in the states of Alabama, Tennessee, and Mississippi centered on the northwest corner of the power house at the dam (coordinates 34° 04' 15" N by 88° 15' 05" W).

Each of the data bases is a digital model of the terrain (digital matrix) in the target site containing the range and azimuthal coordinates of each point, the microwave backscatter category of each point, and the elevation above sea-level of each point. The bands 1 and 2 data base is discussed in section (2.1) and the bands 3 and 4 data base in section (2.2).

2.1 Bands 1 and 2 Data Base

Construction techniques, source data, and details for the bands 1 and 2 data base are adequately related in reference (17). The discussion will not be repeated here, however, specification of pertinent parameters regarding this data base is presented in Table 1.

Table 2 lists the microwave backscatter categories determined to be in the Pickwick target site within the area comprising the bands 1 and 2 data base. The actual backscattering (σ^{o}) data for each category used in conjunction with this data base are listed in Appendix A.

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[17] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253, pp. 139-143.

Table 1: Parameter Specifications: Bands 1 and 2 Data Base (Pickwick Site).

Data Base Size: Square of approximately 19.8 km (12.3 miles) on a side;

Site Location: Center located at coordinates 34° 04' 15"N by 88° 15' 05"W (Pickwick Landing Dam, Tenn.);

Spatial Sample Size: 6.25m (20.5 feet) in both range and azimuth;

Elevation Data Accuracy: Estimated to be approximately $\pm$ 3m ($\pm$ 10 feet);

Backscatter Category Resolution: Estimated to be approximately 30.5 m (100 feet) in both range and azimuth;

Number of Elements in Digital Matrix: 10,042,561 (3169 samples at 6.25 m per sample in both range and azimuth) where N=3169 records and M=3169 points;

Scale: 1:24,000;

Source Intelligence Data Used:

Elevation Data: Provided by ETL and produced by DMA (Defense Mapping Agency) from 20 foot contour data of USGS (United States Geological Survey) standard 7 1/2' quadrangle maps;

Category Data: Spatial geometry and detail was obtained from USGS standard 7 1/2' quadrangle maps (1:24,000 scale) and distributed category boundaries interpreted from 1:100,000 high-resolution aerial photographs (Note: the geometry of the terrain in a standard 7 1/2' USGS quadrangle is displayed as a modified polyconic).

Table 2

Pickwick Test Site Microwave Backscatter Categories: Bands 1 and 2

Data Base

Category Identification Number	Category Description
100	Group Targets - Roads
110	Heavy duty improved roads (none present)
120	Medium duty improved roads
130	Light duty improved roads
140	Unimproved roads
200	Group targets - Railroads
230	Fish Pond Dikes
240	Water Plant Plumbing
300	Group Targets - Water Bodies
310	Small Impoundments
320	Small streams and rivers
350	Large streams and rivers
360	Large Impoundments (Pickwick Lake)
400	Group targets - Forested areas
450	Wooded Marshes
500	Group Targets - Forested Areas
600	Group Targets - Agricultural Lands
610	Bare ground
620	Soybeans
630	Corn
640	Milo
650	Wheat
660	Orchards
670	Garden plots
700	Group Targets - Grass-covered areas (parks, etc.)
800	Pickwick Dam
810	Blockhouse
820	Spillway
900	Small buildings
910	Large buildings

Note: The microwave reflectivity categories listed in this table represent a level of spatial detail of approximately 18 meters.

2.2 Bands 3 and 4 Data Base

Specification of pertinent parameters regarding the data base is presented in Table 3. A listing of the microwave backscatter categories determined to be in the Pickwick target site within the bands 3 and 4 data base area is arrayed in Table 4 and the actual backscatter (σ^o) for each category used in conjunction with the data base are included in Appendix B.

The bands 3 and 4 data base was constructed by following the basic philosophy developed for the bands 1 and 2 data base. The only significant differences in the construction of the bands 3 and 4 data base from that reported earlier for bands 1 and 2[17] are the source data used.

The bands 1 and 2 data base was developed from standard 7 1/2' USGS (United States Geological Survey) Quadrangle maps at a scale of 1:24,000 (the scene geometry and elevation data were obtained from such maps and the backscatter region boundaries were interpreted from 1:100,000 scale aerial photographs). The data base for bands 3 and 4 was developed from an orthophoto which itself had been constructed via the UNAMACE[18] computer system. The orthophoto is a controlled mosaic of high-resolution aerial photographs in which the geometry is rectified to become a tangent plane approximation to the Earth at a specified point. This signifies a basic difference between the bands 1 and 2 and bands 3 and 4 data bases: The geometry of the former is a modified polyconic projection according to standard USGS mapping practices while the geometry of the latter is a tangent plane projection centered on the specified Pickwick target. In the bands 1 and 2 data base both the geometry of the scenes and elevation data for the scene were obtained from a modified polyconic projection

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[17] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253, pp. 139-143.

[18] Bertram, Sidney, "The Universal Automatic Map Compilation Equipment," Photogrammetric Engineering and Remote Sensing, Vol. 31, No. 2, March 1965.

Table 3 Parameter Specifications: Bands 3 and 4 Data Base (Pickwick Site)

Data Base Size: Square of approximately 74.5 km (46.3 miles) on a side;

Site Location: Center located at coordinates 34° 04' 15" N by 88° 15' 05" W (Pickwick Landing Dam, Tenn.);

Spatial Sample Size: 25 m (82.0 feet) in both range and azimuth;

Elevation Data Accuracy: Estimated to be approximately ± 10m (±32.8 feet);

Backscatter Category Resolution: Estimated to be approximately 244 m (800 feet) in both range and azimuth;

Number of Elements in Digital Matrix: 8,880,400 (2,980 samples at 25 m per sample in both range and azimuth) where N=2980 records and m=3169 points.

Source Intelligence Data Used:

Elevation Data: Provided by ETL from the output of the UNAMACE elevation data computer program;

Category Data: Spatial geometry and detail was obtained from 1:100,000 scale orthophoto (rectified geometry) and distributed category boundaries were interpreted from the high-resolution, 1:100,000 scale aerial photographs which also served as the source for the orthophoto. (Note: The geometry of the terrain in the orthophoto was rectified for a tangent plane approximation to the Earth centered on the target center).

whereas in the bands 3 and 4 data bases both the geometry and elevation data were obtained from a tangent plane projection.

A simple reason explains this difference in projections between the large scale (bands 1 and 2) and small scale (bands 3 and 4) data bases: Expediency. When the original work was performed resulting in the band 1 data base, it was decided to utilize the USGS maps in the modified polyconic projection instead of the tangent plane projection of the UNAMACE orthophoto because the geometry contained in the maps was believed to be a better approximation to reality at the target site than the tangent plane offered by UNAMACE. In addition, a group of researchers at ETL were using the UNAMACE data as source information and the use of USGS maps provided an evaluation of an alternate source. However, when the bands 3 and 4 work was started the UNAMACE data (elevation and category) was selected as source material because elevation data were available from ETL at a desirable sampling rate (one sample every 25m) and a 1:100,000 scale orthophoto was available, whereas the elevation data corresponding to the USGS maps were arrayed at too fine a sampling rate (6.25 m/cell) across more than fifty (50) separate computer-compatible magnetic tapes, each tape having a unique coordinate system. In view of the fact that in an operational environment source data such as high-resolution aerial photographs would be used for construction of reference scenes, it was decided to use the UNAMACE data (which uses aerial photographs as source material) for the smaller scale data base because of its availability and to save rectifying the coordinate systems of fifty tapes in order to select desired elevation data from them.

The sequence followed when constructing a data base (either bands 1 and 2 or bands 3 and 4) consists of several basic steps:

1) Obtain elevation data at a suitable scale;
2) Obtain source data for the category map;
3) Develop the category map;
   a) Interpret the source data and draw the various features and boundaries onto a stable-base drawing medium;
   b) Digitize the category maps;
   c) Develop matrix from the digitized form of the maps which has a category specified for each of the elements;

4) Merge the elevation data and category matrix into the digital matrix representing the final data base;
5) Rotate the data base into the required orientation.

2.2.1 Elevation Data for Bands 3 and 4 Data Base: Pickwick Site

Elevation data prepared via the UNAMACE[18] software system were obtained from ETL. These data were stored on a single computer-compatible magnetic tape. A sample of the elevation was stored for each 25 m cell in the tangent plane projection used by the UNAMACE system. The accuracy of these data were estimated to be approximately ± 10 m.

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[18] Bertram, Sidney, "The Universal Automatic Map Compilation Equipment," Photogrammetric Engineering and Remote Sensing, Vol. 31, No. 2, March 1965.

2.2.2 Source Data for Bands 3 and 4 Data Base: Pickwick Site

Source data for the Pickwick site consisting of high-resolution aerial photographs (1:100,000 scale, nominally) and an orthophoto (1:100,000 scale tangent plane projection of target site prepared by the UNAMACE system) were obtained from ETL. Only these source data were used for the bands 3 and 4 data base; no radar or other ancillary data were used.

2.2.3 Develop the Bands 3 and 4 Category Map: Pickwick Site

The bands 3 and 4 data base was constructed at a scale of approximately 1:150,000. This was accomplished via a scale-reduction-table and was done to accomodate requirements of the digitizer system that was to be used. The 1:100,000 scale orthophoto was placed on the table and a projection of the scene was focused upon a glass plate, forming a backlit image on the stable-base material which had been placed over the glassplate. The planimetry of the data base was traced at a scale of 1:150,000 directly onto the drawing material from this backlit image.

The planimetry of the data base was developed via standard feature extraction technique. A photo interpreter defined the boundaries outlining homogeneous regions (homogeneous at radar wavelengths) and drew these on the stable-base drafting material. Care was exercised throughout construction of this feature map to hold spatial resolution to approximately 0.05 inches on the orthophoto which, at 1:150,000 scale, corresponds to approximately 800 feet on the ground. This means that any radar image constructed from this data base will not contain scene variations of less than 800 feet; a scattering region cannot be differentiated from its surroundings unless it has a spatial extent of 800 feet, or more. This is the inherent resolution designed into the data base and is not necessarily the resolution of any resultant radar reference scene.

The planimetry of the Pickwick site was drawn on two sheets of the stable-base drawing material: One of the sheets contained the homogeneous regions of two-dimensional extent (areas having a finite width and length) and the other sheet contained the "category map", or "distributed target map". The first of these was called the "distributed category map" and the second was called the "cultural target map", or "hard target map". On the "category map" was drawn the boundaries of each different backscattering region such as water bodies, forests, agricultural fields, etc., identified to be within the target site. On the "cultural target map" was drawn all the linear features such as roads, railroads, etc. The locations of buildings were marked on the "cultural target map" as was one type of area target: Cities.

Table 4 Pickwick Test Site Microwave Backscatter Categories: Bands 3 & 4 Data Base

Category Identification* Number	Category Description
2	Forested Area
3	Agricultural Lands - Undifferentiated
4	Reservoir
5	River
6	Low Grass Area
7	Agricultural Lands - Flooded
8	Roads - Heavy Duty
9	Roads - Medium Duty
10	Roads - Light Duty
11	City Category - Mostly Structures
12	" - Mostly Trees
13	" - Mixed Structures & Trees
14	" - Open Land
15	Utility Cut - Low Grass

* Category 1 was not used.

Cities were modeled as consisting of different regions, each region having the average backscattering properties of one of four (4) city backscatter categories. The four (4) city backscatter categories and the σ^0 values used for the production of radar reference images are listed in Table 5. As can be seen from the table this listing of four (4) city backscatter categories is very subjective. Nothing quantitative is being claimed about the radar echo from cities or their backscatter properties. The goal of this work was to develop a data base for producing reference radar scenes for terminal guidance. Reference scenes must be as omnidirectional as possible because no a priori knowledge exists concerning the direction of approach of the projectile. This being the case, it was desired to model the cities in the target region in a manner which would acknowledge their presence without separately accounting for each building, road, intersection, corner, etc. (this information would be desirable for a simulation having highly directional properties). It was decided to do more than just "paint the city regions white," thus the four (4) separate, subjective city backscatter categories were created for the data base in an attempt to refine the city into a "reasonable" number of distinct levels.

After both the "category map" and the "cultural target map" were finished (all of the appropriate regions and linear features of the Pickwick site were drawn on one of the two sheets of drafting material), the line content of the drawings was digitized. A large table digitizer interfaced to a minicomputer was used for this task. Each sheet was separately placed on the digitizer table and an operator first specified a coordinate system (the coordinate system specified was that of the UNAMACE elevation data) and then traced the data using the tables cursor. As the operator traced a line, the system periodically sampled the location of the cursor with respect to a wire grid built into the table. As the operator encountered a new region, or line, he identified it to the minicomputer by typing its label via a teletypewriter. The minicomputer then converted each sample position into an x,y pair of numbers in the specified

Table 5 City Backscatter Categories

Category No.	Description of Category	Backscatter Values
1	Mostly hard targets such as a business district in a city;	+ 20 dB isotropic*
2	Primarily hard targets but also including a significant proportion of grassy or forested regions;	- 5 dB isotropic*
3	Primarily grassy, or forested region but also including a significant proportion of hard targets;	- 9 dB isotropic*
4	Mostly grassy, or forested regions in a city such as a park.	Low Grass (Category 16 in Appendix B)

* The backscatter values cited are nominal values attained in the final simulations. To attain these values, a cosine rule was utilized to modify the data for input to the reference scene simulation program. Copies of plots of these data are included in Appendix B.

coordinate system and stored these data with the label for ultimate output on computer-compatible magnetic tape. This portion of the data base construction task was inordinately long because of numerous problems encountered such as hardware failures (the cursor became defective causing a lengthy delay while the problem was investigated andrepaired), schedule problems (both the system was overscheduled as well as understaffed), operator training problems (a new operator was hired and trained by digitizing this data base - a deplorable state of affairs but one over which we had no control as the system on which this work was being done was the only one in the local area), etc. The final product of this digitizing effort was computer-compatible magnetic tapes on which were stored the data from both maps, separately.

After both maps were digitized, these digital boundary data were converted into a matrix which has a category specified for each of its elements. In principle this task is not difficult because it is only desired to sort the boundary data by their x and y values and "fill-in" the correct category for each element in the matrix bounded by a unique line. In practice this is not as trivial as it might sound because the data base matrix contained ten million (10^7) elements, there being several hundred thousand boundary values, alone, and it was highly desirable to program the computer to do this task without external manipulations of the data. The programs developed to accomplish this task have been discussed previously,[19] so they will not be discussed here.

This task was complicated by errors created during the digitizing of the maps by, in particular, the lack of experience on the part of the table operator. These errors caused an extensive delay in producing the final category matrix because they required human investigations to determine the nature of the problems and to identify and to implement corrections. It would be highly desirable to create the finished category matrix while the digitizing is being done, and to provide a visual reconstruction of

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[19] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253, pp. 131-163.

each step of the process via a graphics terminal (or equivalent) so that errors could be dispensed with while the map is still on the table and while the digitizer operator can assess what he views as the finished product.

After both the "category map" and the "cultural target map" were developed into completely specified matrices, they were merged into one array. The data from the "cultural target map" was given priority over the data from the "category map" thus creating a single matrix containing both area targets and linear, or cultural (buildings, etc.) targets.

2.2.4 Merge Elevation and Category Data: Bands 3 and 4

As the category data had been digitized in the same coordinate system, with the same cell size, as the UNAMACE's elevation data, it was easy to merge the two (elevation and category data). One complication arose in this task, the UNAMACE elevation data were anomalous over very flat regions such as water surfaces. This was solved by specifying the elevation for water bodies; the elevation of the river was set at 362 feet and of the reservoir at 414 feet above mean sea level. This correction obviously is inadequate wherever the river or reservoir blends smoothly into a flat flood plain, for there the anomalous elevation data still exists. The percentage of the target site for which this condition exists was so small the problem was not corrected.

After completion of the task, the bands 3 and 4 data base was finished; it was ready for the production of radar reference scenes.

2.2.5 Rotate Bands 3 and 4 Data Base into Desired Orientation

The radar reference scenes which were to be formed from this data base must have a specified orientation with respect to true north. The first pixel stored on the computer-compatible magnetic tape of the reference scenes arrayed in a rectangular grid format must be the northwest corner of the scene. The UNAMACE coordinate system was skewed 30° from true north. Rather than rotate the data base at this time, it was decided to rotate after the simulations (reference radar images) were produced and while the data were still in a polar coordinates system. This technique was considerably easier to implement and was much less expensive of computer time.

3.0 RADAR REFERENCE SCENE SIMULATION MODEL

No changes in the Point Scattering Method (PSM) implementation for producing radar reference scenes were required for bands 2, 3, and 4 reference scenes. The software implementation developed for the band 1 reference scene and previously reported[20] was adequate for the bands 2,3, and 4 scenes. The implementation previously developed is summarized here for convenience.

The PSM was to be adapted to model the terminal guidance problem consisting of a PPI (Plan-Position Indicator) radar and Correlatron. The first step in this specialization of the PSM to a specific system was to attempt to describe the operating parameters of the PPI radar, itself. However, limited information about the operating characteristics of both the radar and Correlatron was available. Therefore, in the absence of system design data, the reference scene simulation software was developed assuming an ideal system. For instance, the PPI radar (for simulation purposes) was given constant azimuthal gain between its 3 dB points and no sidelobes (an aspiration for any antenna designer!). The elevation pattern was chosen to be $(\csc^2\beta)$ $(\cos\beta)$, where β is the depression angle. Past the rf portion, the receiver of the ideal system was made to map the received power into video intensity. A realistic film transfer characteristic was employed (logarithmic) with a linear dynamic range of 20 dB. Outside this range, either in the "toe" or "shoulder" of the exposure curve, lack of sufficient exposure or saturation, respectively, would result.

It was secondly considered whether there should be modifications to the reference scene simulation model to account for the Correlatron.

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[20] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253, pp. 115-124.

It was assumed to have identical paths for both the reference scene and real video. The process of converting a reference scene stored on photographic film to a video signal was assumed to be linear. And, of course, identical tests run at different times were assumed to result in the same degree of cross correlation. All of these criteria were assumed to be the case for the Correlatron.

Complicating the situation of specializing the PSM for constructing reference scenes was the fact that the direction of approach of the vehicle was not specified. To optimize the chances of high correlation, and to allow the reference scenes to be useful despite the radar position and angle of approach, it was necessary to make the reference scenes as nearly omnidirectional as possible. This was shown to dictate a nadir-looking antenna because of the angular dependence of both radar shadow and the backscattered fields. The only information about the system available before either constructing the data bases or the reference scenes was: (1) the reference scene altitude and (2) the corresponding diameter of each simulated PPI image. Thus, each image was formed with the radar centered over the power house of the Pickwick Landing Dam, looking radially outward, as though its trajectory was, at least momentarily, vertical to the earth.

Figure 3 illustrates the peculiar image format of the guidance PPI radar being employed, in comparison with the ordinary PPI radar scan format. Data are recorded by the test radar for a full circular sweep of the scene instead of the usual sector associated with PPI radars. The terrain imaged by the radar beam is within an annular ring bounded at the near range by 35° (incidence angle) and at the far range by 65°. The reference scene simulation model does not produce imagery in exactly this format because of (1) the likelihood of centering and angle of approach errors, and (2) the use of the Correlatron as the diagnostic device.

The direction of approach of the projectile and real PPI radar and the center of the real imagery, being unknown before forming reference scenes, might occur any place within a circular region of the target

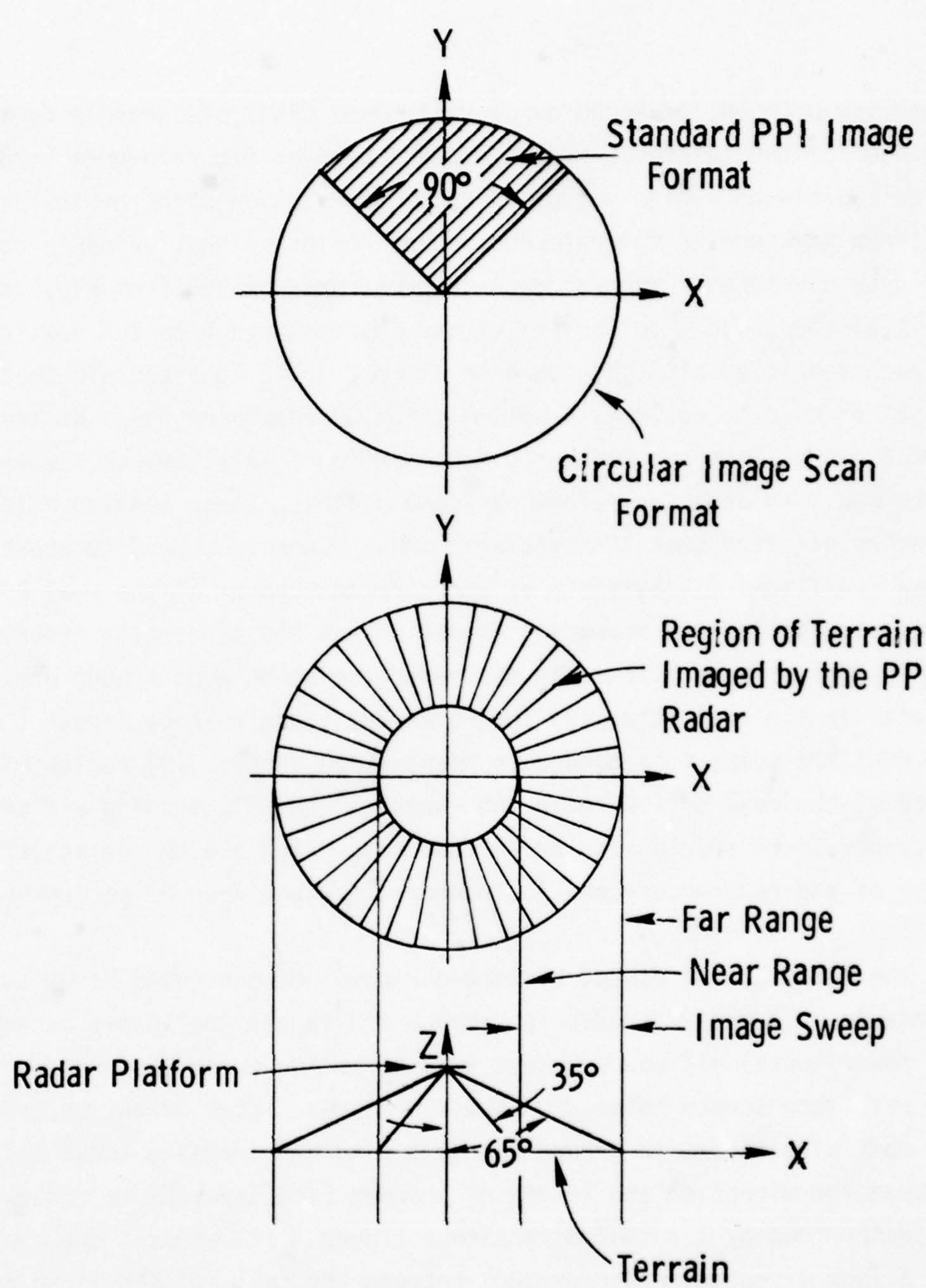

Figure 3. Special PPI Image Format.

depending upon ballistic guidance variables. This presented a formidable problem for the reference scene software because the reference scene had to be capable of a high degree of cross correlation with the real image centered anywhere in the reference scene region so that guidance corrections could be developed. According to information received from ETL, the angle of the tangent to the trajectory (as measured from the vertical) at each specified altitude would be at most 45°. To ascertain that the "live" video data would fall well within the reference scene at the maximum angle of approach (measured from vertical) an allowance was made which would enlarge the reference scene radius. These considerations together dictated that the simulated image boundary extend to about 75°. These conditions (uncertainty of approach and center of the real PPI video signal) imposed necessary conditions on the simulation effort: (1) No "holes" were allowed in the reference scene even though one existed in the real data; (2) The reference scene must be larger than the real PPI scene to accommodate "centering" errors; (3) Angles of incidence of the real data were in the range 35° to 65°, meaning all of the reference scene should also be in that range even though the actual geometry of the reference scene would decree a range from 0° to approximately 75°.

The difficulties caused by look-direction errors could be of severe magnitude. If the PPI radar approaches the target (northwest corner of the power house) off course, then look-direction errors between real and and reference scenes between 0° and 180° occur. Look direction effects are most significant in ground scenes having considerable local relief because the direction and length of shadows (and layover) in radar images are determined by the look direction. Figure 4 illustrates the problem for a look direction error of 180° between the real and simulated radar image. Test sites having significant local relief variation would appear <u>very</u> different depending upon the direction of approach of the real PPI radar. Fortunately, the Pickwick test site had only a modest amount of local relief, so this is one problem which was not tackled. But it certainly warrants attention if a test site having a considerable amount of local

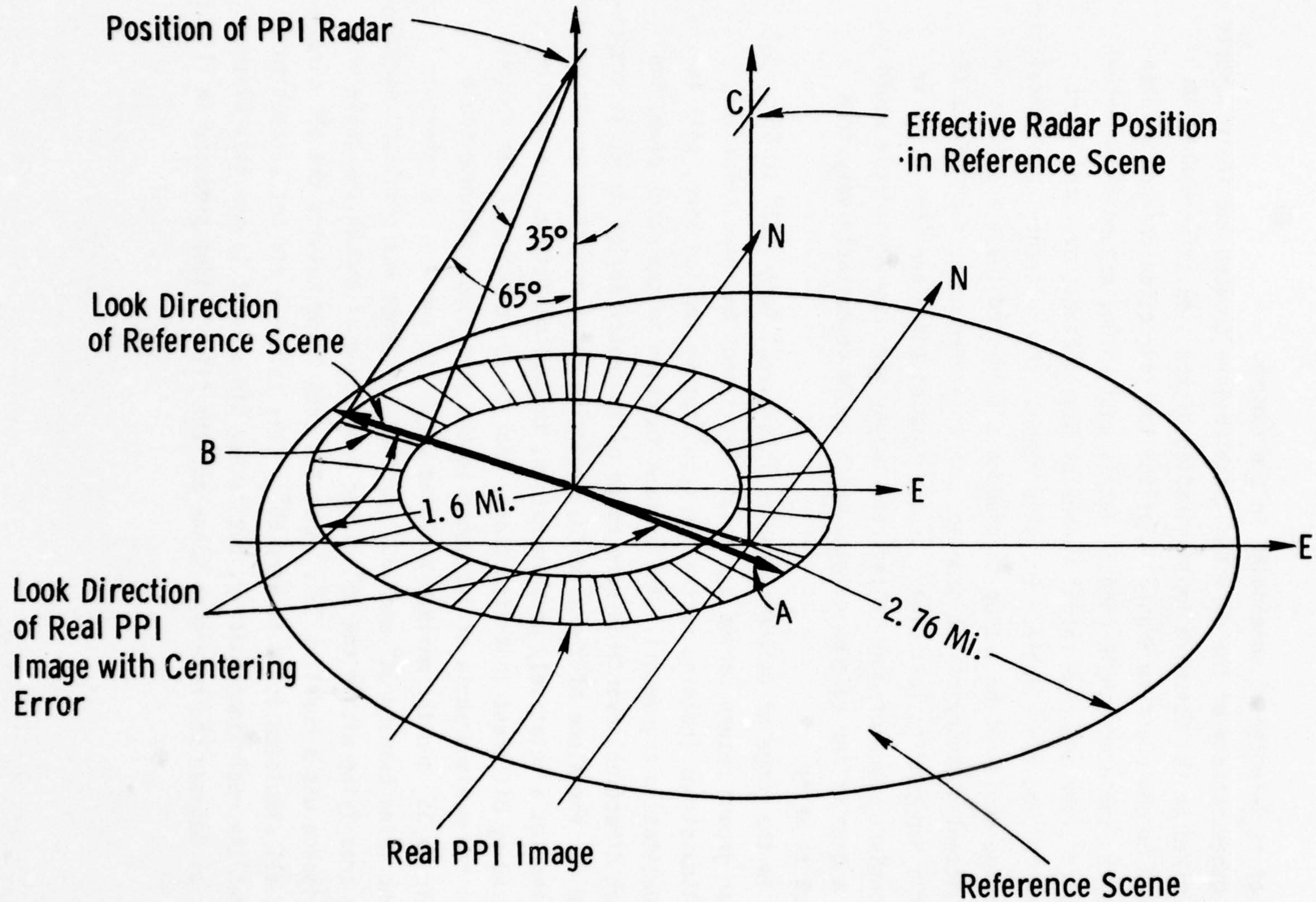

Figure 4. Comparison of Reference Scene to PPI Radar Image Format.

relief is selected at some point in the future.

Other aspects of the direction problem were treated and their impacts minimized in the software implementation of the simulation model. As should be obvious from Figure 4, as the look direction changes so also does the incidence angle change. As is well known, ground radar return data (σ^o) for the same target varies by many decibels over the range 0° to 70° incidence angle. For this reason, the reference scene simulation software could not be set up to produce a simulated image according to the actual geometry of the problem. If this were done, even if the 65° circle happened to fall always on the same category and thus would be a constant shade of grey in the real image, the same 65° circle would trace out a path on the reference image which could conceivably vary from black to white.

In the range of incidence angles in the real image, 35° to 65°, most radar ground return curves are relatively linear and have relatively shallow slopes (nothing factual or quantitative implied here, this is a qualitative arguement). The antenna function in the range direction (look direction) over this same range of incidence angles tends to compensate for the slope of the σ^o data, producing for a number of ground return categories a relatively uniform return, thereby minimizing the problem caused by different look directions. For these reasons, it was decided that the minimum angle of incidence in the simulated reference scene would be 35° and the maximum would be 65°. The area in the reference scene lying between 35° and 65° angle of incidence was simulated normally. The area lying within the 35° circle was imaged as though the angle of incidence was a constant 35°. And, the area lying outside the 65° circle was all simulated as if it were 65°. This solution did not attempt to model the real video exactly, but rather did attempt to minimize discrepancies between the reference scene and the "live" video produced in flight.

This is not to say that local slope variations were not accounted for; they were indeed, incorporated. What is meant is that the incidence angle (θ) between the antenna "boresight" and the local vertical was always in the range 35° to 65°. Local slope variations then altered the incidence angle to the local incidence angle (θ_{ℓ}), just like in the simulation models described in References [1] and [2]. In fact, the limitations imposed on minimum and maximum values of θ_{ℓ} come strictly from the local relief in the scene.

This solution to the angle of incidence problem created data handling problems for the computer program, and data base problems. For instance, 35° angle of incidence specifies a resolution cell size for short pulse and narrow beamwidth radars. Yet, the geometry of the data base indicates that as data base cells get closer to the center (in polar coordinates), they get larger in the range direction and smaller in the azimuth direction. This problem was minimized by accurately modeling another feature of the real PPI; it recorded data in ground range mode. Ground range mode means that (for a flat earth) equal size objects located in the near and far range will have equal sizes in the image format. This is normally accomplished by applying a nonlinear sweep to the electron beam of the viewing CRT. But for simulation purposes, it simply meant building the simulation data base with equal size cells in the range direction. It should be noted at this time that in the presence of terrain having significant relief, ground range mode introduces large distortions, a fact to keep in mind for such future sites.

In summary, the general point scattering radar image simulation model was specifically tailored to the special requirements imposed to simulate reference scenes for use on the Correlatron. The software implementation of the reference scene simulation model included the following special features.

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[1] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. I, ETL-0117, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 253.

[2] Holtzman, J. C., V. H. Kaupp, J. L. Abbott, V. S. Frost, E. E. Komp, and E. C. Davison, "Radar Image Simulation: Validation of the Point Scattering Method," Vol. II, ETL-0118, The University of Kansas Center for Research, Inc., September, 1977, AD-A053 240.

Table 6 Reference Scene PSM Special Features

(1) 360° PPI image scan format

(2) Simulated area was larger than the real image to allow "centering" errors.

(3) No holes allowed, the reference scene was completely filled-in with radar image simulations.

(4) Minimum angle of incidence = 35°

(5) Maximum angle of incidence = 65°

(6) Local angle of incidence was properly treated.

(7) In the reference scene, the area between 0° and 35° was simulated at a constant 35° angle of incidence.

(8) The area between 35° and 65° was simulated normally.

(9) The area outside 65° was simulated at a constant 65°.

(10) Variations due to angle of incidence difference between real and simulated image were minimized.

(11) Reference scenes were formed in the ground range model.

(12) Layover and shadow were properly included.

(13) Local slope variations in the terrain were properly included.

4.0 TERRAIN BACKSCATTER DATA: PICKWICK SITE

The Point Scattering Method (PSM) for radar image simulation utilizes empirical backscatter (σ^o) data (whenever possible), in combination with relief data, to model the radar echo from terrain. The backscatter data (σ^o) supplies the needed information about the type of terrain and provides the mechanism to predict what tone will be recorded for that type of terrain in an image. The elevation data determines the radar-to-target distance and the direction of the local normal to the surface and, thus, determines the angle between the radar antenna and the normal to the surface. Together, the σ^o and elevation data are used to predict the tone for each pixel (picture element) in a simulated radar image; the σ^o data predict what percentage of transmitted energy illuminating each piece of ground will be reradiated back to the radar receiving antenna for the particular range and local angle of incidence considerations that exist.

After specification of the PPI radar configuration (polarization and frequency) and after the different types of scatterers had been recognized for the Pickwick site, efforts were begun to find appropriate terrain return data. Targets were first grossly classified as distributed or cultural and symbolic representation was necessary for the latter.

Distributed targets are homogeneous regions with the same microwave scattering properties throughout the extent of a resolution cell. Each homogeneous region must be at least as large as the resolution element of the radar being modeled, the individual scattering centers must be randomly located, and there must be a large number of scattering centers in each resolution cell within a homogeneous region. When these conditions are satisfied, an average value of the scattering cross-section (σ^o) can be used to model the radar return from these homogeneous areas of terrain (distributed targets). Most of the terrain located in the reference scene data base of the Pickwick site satisfied these criteria. Thus, differential scattering cross-section data (σ^o) were used to model the radar return properties of the terrain in the reference scenes formed from the Pickwick data base. Actually, empirical σ^odata were used (as opposed to theoretical). These data were obtained from the literature and from the RSL data bank. The best match that could be found between available empirical σ^odata and the identified distributed targets in the Pickwick site was sought (the data used are presented in Appendices A and B).

Cultural targets are here defined to be manmade objects and features. Their radar returns are characterized by specular reflection. They cannot be modeled as distributed targets. That is, the return from hard targets are not readily predicted by the greytone equation. To model cultural targets by digital computer is an exceptionally complex task requiring tremendous detail about each such target to be included in the data base. An evaluation was made of the kinds of cultural targets present in the Pickwick site, their orientations, and the number of them. It was concluded that symbolic modeling of these targets would provide the best probability of correlation. By symbolic modeling we mean that the location of each cultural target was pin-pointed in the data base but the orientation, size, geometry, etc., was not. Cultural targets were assumed, for the purposes of reference scene formation, to be isotropic radiators having a constant effective differential scattering cross-section. This most certainly is not accurate. But, consider the task: Cross correlation with "live" video data with an unknown heading and center with respect to the center of the reference scene. The orientation (not the location) of cultural targets was unknown. Given no a priori knowledge of the heading of the "live" data, it would not be possible to properly simulate all the corner reflectors, etc., of cultural targets to match the look-direction of the "live" data. The best that could be done would be to accurately mark the location of them and assume them to be isotropic radiators. Then, given a direction of approach for the real data, those cultural features properly aligned would be in the real data which, of course, would match very nicely with the simulation. Those not properly aligned would be some lower shade of gray which should still improve correlation. Thus, it was concluded that symbolic simulation of cultural features would enhance cross correlation between the real and simulated images, and this is the way they were treated when forming reference scenes.

Since two (2) different data bases were constructed, one for bands 1 and 2, and one for bands 3 and 4, the definition of backscatter targets identified to be in the sites was specialized to take advantage of the different resolutions. The backscatter data used for each data base are discussed in the following.

4.1 Backscatter Data for Bands 1 and 2: Pickwick Site

The backscatter data used to make bands 1 and 2 reference radar scenes are presented in Appendix A. The data are identified as to category, frequency, polarization, and source from which the data were acquired.

4.2 Backscatter Data for Bands 3 and 4: Pickwick Site

The backscatter data used to make bands 3 and 4 reference scenes, except the city backscatter data which are listed in Table 5, are presented in Appendix B. The data are identified as to category, frequency, polarization, and source from which the data were acquired.

5.0 RADAR REFERENCE SCENE FORMATION

It is to this point where all the previous work has been aimed: Production of radar reference scenes. The various kinds of input data have been assembled in the above work and they are ready to be combined appropriately into reference scenes. Figure 5 illustrates, in block diagram form, how the separate pieces fit together and the interactions that occur between them to make reference scenes.

Figure 5 shows the flow of data, from start to finish, when forming a radar reference scene. The left side of Figure 5 illustrates where the data comes from, and the right side where it goes. The central portion of Figure 5 shows the formation of reference scenes.

As can be seen from Figure 5, the radar reference scene implementation of the PSM is for a digital computer. Three separate computer programs (separate according to function) must be run sequentially in order to form radar reference scenes. The first of these computer programs (POLAR CONVERSION) converts a rectangular ground truth data base matrix into a polar radar data base array as dictated by the desire to simulate a polar-scanning radar (PPI) for making reference scenes. The second computer program (REFERENCE SCENE) accepts the polar-form radar data base from the first, solves all the complicated geometrical relationships between the radar (located at a specific point) and each resolution element on the ground, computes the power returned from each resolution element to the radar, incorporates the appropriate antenna correlation function between resolution elements, and produces an output array of image density values (called greytones). The third program (RECTANGULAR CONVERSION) converts the array of greytones which were output from the second program in a polar array into a rectangular grid matrix having either a format compatible with viewing the finished simulation for evaluation purposes or a format compatible with the Correlatron test equipment utilized at ETL. Communication between programs is accomplished via computer-compatible magnetic tapes. These tapes contain intermediate products and only serve as temporary storage either for error analysis or for input to the next program, thus their formats will not be discussed here.

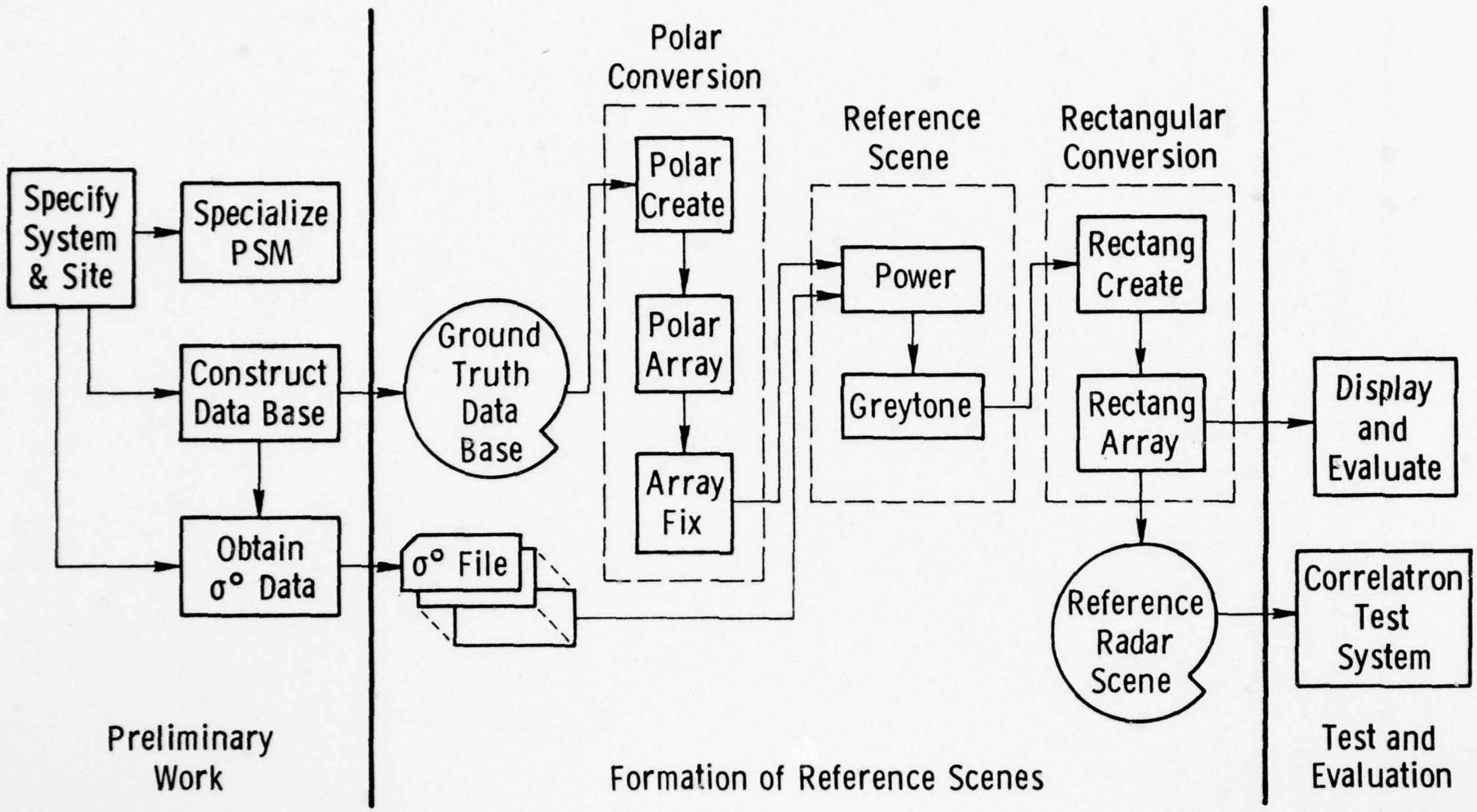

Figure 5. Flow of Data for Reference Scene Formation.

In the following five (5) sections, radar reference scene formation is summarized. First, the work preliminary to making radar reference scenes is briefly recapitulated (section 5.1). Second, third, and fourth, computer programs used for forming radar reference scenes are discussed (sections 5.2, 5.3, and 5.4, respectively). Fifth, mechanisms for evaluation of radar reference scenes are briefly mentioned (section 5.5).

5.1 Preliminary Work

As can be seen from Figure 5, the first tasks to be accomplished, in the chain of events which leads ultimately to radar simulation for reference scenes, are specification of the guidance system to be modeled, and the terrestrial location of the target site. After system and site have been specified three important tasks can be performed: 1) An implementation can be designed of the PSM which is specialized for the system and its unique features; 2) A ground truth data base can be developed which is a digital representation of the terrain in the target site; and, 3) A catalogue of σ^0 data can be obtained which is a model for the dielectric properties of the terrain backscatter categories identified in the target site. Upon completion of these tasks, the data necessary to satisfy input requirements of the computer programs which form the reference radar scenes are available.

An implementation of the PSM was designed around the navigation system consisting of PPI radar and Correlatron. This implementation was a specialization of the PSM for making reference radar scenes for terminal guidance. The details of this specialization, the work performed, and the resultant reference scene model are summarized in section (3.0). The resultant model is a set of programs, called REFERENCE SCENE SIMULATION, which has been tailored specifically to make reference scenes for the Correlatron guidance system.

Two different scale ground truth data bases were developed for a target site centered on the Pickwick Landing Dam, Tennessee. One data base was developed to support formation of reference scenes for the two (2) large scale (low altitude) scenes, and the other for the two (2) small scale (high altitude) scenes. The development of these data bases is summarized in section (2.0). The completed data bases were rectangular grid matrices of N records, each record containing M points, each point being eighteen (18) bits long. N and M are specified in Tables 1 and 3 for the two different data bases. The first twelve (12) bits, of each eighteen (18) bit point in a data base, contain the elevation in feet above mean sea level for that point, and the trailing (6) bits are used to identify up to sixty-three (63) different backscatter categories. Each data base is stored on a 9-track, 1600 bpi computer-compatible magnetic tape in a binary unformulated format. These two ground truth data bases stored on magnetic tape serve as fundamental inputs to the reference-radar-scene-formation computer programs.

Terrain backscatter ($\sigma°$) data were obtained and catalogued for all the different reflectivity targets in the Pickwick site. Thirty (30) different categories were identified for the bands 1 and 2 data base (Table 2) and fourteen (14) for the bands 3 and 4 data base (Table 4). This work and the data obtained are discussed in section (4.0). These data were obtained in the form of backscatter versus angle of incidence [$\sigma°(\theta)$]. Third-order polynomials were fit to these data according to standard Least-Squares techniques and the coefficients were catalogued for input to the simulation program. These data are lead-card input to the program for ease of changing categories and backscatter data. They are stored in a P x 4 matrix where P represents the number of categories and, thus, data sets, for a data base, each category having four (4) entries, there being one entry for each coefficient of the third-order polynomial. Validity of using a third-order polynomial to represent the average properties of the $\sigma°$ data can be observed in Appendices A and B.

Upon completion of these tasks, the input data for the reference scene computer programs have been obtained (ground truth data base and terrain backscatter) and the PSM model has been specialized to represent the guidance system. The next task is to construct radar reference scenes from the input data.

5.2 Polar Conversion

The first step performed by the sequence of computer programs illustrated in Figure 4 is POLAR CONVERSION, the computer program which converts the rectangular grid matrix of the ground truth data base into a polar array which is compatible with the scanning format of the PPI radar being modelled. POLAR CONVERSION actually consists of three (3) distinct computer programs, POLAR CREATE, POLAR ARRAY, and ARRAY FIX; copies of these programs are provided in Appendices C, D, and E, respectively.

Three programs have been developed to perform this straight-forward function of rectangular-to-polar coordinates conversion in order to minimize the costs of performing it. The first program, POLAR CREATE, is a highly computational program requiring minimal core storage. This program accepts as input the ground truth data base stored on digital magnetic tape, computes the polar address (r,θ) of each point as it is read from tape, performs one-dimensional compression on the data and stores the data sequentially on an intermediate magnetic tape. Compression arises from the fact that the rectangular version (original version) of the data base contains finer resolution and, consequently, more sample points than are desired in the polar data base. The number of elements desired in the final polar data base (calculated from the radar resolution parameters) is a control parameter input to the program and is used to quantize the polar conversion calculations and, thus, produce a mechanism for compression. Table 7 lists the number of elements and the resolution element size (estimated to represent one independent sample; NS= 1, equation (1)) utilized for each of the four (4) bands of reference scenes produced here.

Table 7 Resolution Element Size: Bands 1-4

Reference Scene Band No.	Resolution Cell Size*		No. of Elements in Polar Data Base
	r	θ	
1	30.5m (100 feet)	1/2°	105,120
2	30.5m (100 feet)	1/2°	210,240
3	100 m (328 feet)	1/2°	128,160
4	100 m (328 feet)	1/2°	255,600

*Resolution in the range direction was maintained constant at the value specified, as was resolution in the azimuth direction.

The second program, POLAR ARRAY, is a core-intensive but computationally-minimal program. This program accepts as input the intermediate magnetic tape output from POLAR CREATE, orders the data from the sequential rectangular file to the correct polar array, and stores the POLAR ARRAY on an intermediate magnetic tape. Two-dimensional compression is performed by this program. This follows the same philosophy as does the earlier compression. The category data are compressed on a priority basis; the highest priority category brought from the rectangular data base for each polar cell is retained, the others deleted. Elevation data are averaged. The elevation value stored in any polar cell is the average of the elevation of all the rectangular points which were mapped into it.

The third program, ARRAY FIX, was created to rectify the problem created by the fact that the rectangular-to-polar-conversion mapping is less than one-to-one in the center portion of the polar data base. This program interrogates the nearest filled neighbor to determine the category and elevation of a polar cell found empty. Upon satisfactory operation of this program, the completed polar data base is stored on an intermediate magnetic tape.

In this way POLAR CONVERSION functions to convert a large rectangular grid matrix data base into a smaller polar array data base for minimal cost. Cost is minimized because the amount of core (a high-cost component) which must be used during the computationally-intensive portions of the operation is reduced to the bare-essential amount. The output of POLAR CONVERSION is a computer-compatible magnetic tape containing the ground truth data base arrayed in a polar format with the correct resolution to support directly the REFERENCE SCENE programs, the next programs which must be run.

5.3 Reference Scene

Reference to Figure 4 will show the second step performed is REFERENCE SCENE, the computer program which actually performs the simulation of the guidance radar system and forms the desired simulations of radar images. REFERENCE SCENE actually consists of two (2) computer programs, POWER, and GREYTONE: copies of these programs are provided in Appendices F and G, respectively.

Two programs have been developed, instead of one, to minimize the costs and improve the operational efficiency of running the programs many times. The first program, POWER, is a computationally-intensive program requiring minimal core storage. This program accepts as input both the polar ground truth data base on digital magnetic tape from program POLAR CONVERSION and the terrain backscatter data lead-card input, calculates the average power exiting the receiver on a pixel-by-pixel basis for each pixel (picture element, previously called "point") in the final scene, and stores these data on an interim magnetic tape. POWER recognizes each radial record in the polar data base as the scan line corresponding to the energy returned from one pulse of the radar, each point in the record corresponds to a resolution element. The polar data only contains a record for successive, independent scan lines (pulses).

The PRF (Pulse Repetition Frequency) of a radar system is normally quite high with successive pulses producing a return having a large overlap with several preceding pulses. POWER calculates a new scan line (new pulse) of data only for scan lines which are independent of one another (they do not overlap each other), and calculates the dependency of overlapping pulses statistically as noted by equations (2) and (3) together with their incorporation in the greytone equation (5). This is done in order to minimize both the size of the polar data base and the computational load (and, thus, cost) required to produce radar reference scenes.

Similarly, POWER recognizes each point in a scan line from the polar data base as an independent resolution element in the radial direction, and calculates the data relating each point on the ground to a pixel in the image. Dependency of overlapping samples in the radial direction is statistically incorporated in the model (equations 2 and 3).

For each point in the data base (each resolution element on the ground), POWER solves the geometry relating the position of the radar platform (three-dimensional position) to the point and calculates the slope of the terrain, and the angle of incidence and the range between platform and point. These calculations are made sequentially for each point of each record as the tape containing the polar ground-truth data base is read into the computer. Upon determining these parameters for a point, POWER enters the main computational algorithm of the program which calculates the average power exiting the receiver from that point. This calculation of power uses the slope of the ground (two-dimensional slope), the angle of incidence between radar and ground (both normal and local angles), the range from platform to the point on the ground being interrogated, the power pattern of the antenna, the category identification from the polar data base, backscatter data from the σ^{0} file, and the transmitter/receiver/image model incorporated for the radar system whose response is being simulated. All of these variables and parameters are combined appropriately for calculating the estimate of power exiting the radar receiver for each point on the ground. In this way POWER calculates the average power exiting the receiver on a pixel-by-pixel basis. The resultant data are stored on an interim magnetic tape for further processing in later stages. The data are ordered sequentially on this tape in the same form as the polar array in which the polar radar data base was input.

The second program of REFERENCE SCENE was developed to incorporate the spatial relationships between adjacent, independent cells decreed by the antenna pattern, and to convert the resultant estimates of power into greytones. This program, GREYTONE, calculates the spatial relationships between cells via an autocorrelation. The shape and length of the autocorrelation are input parameters. Upon completing the autocorrelation, GREYTONE converts the data, power, into density values, greytones, quantizes them into the desired number of bits, and biases the range to that desired for ultimate storage in a photograph.

The bias required to display a desired power range in an image is an input parameter to GREYTONE. The desired mapping ratio of power exiting the receiver into density in the photograph is also an input parameter; the portion of the radar dynamic range (XdB) desired to be mapped into the dynamic range of the photograph (17-20dB) is specified. Thus, upon specification of an autocorrelation function shape and length, and quantizing parameters (bias and mapping ratio, or gain) GREYTONE operates on the power map input via digital magnetic tape from the previous program, POWER, producing the greytone map of the final image on a pixel-by-pixel basis. The greytone data are stored on an intermediate digital magnetic tape. The stored data order is still the same as the input polar ground truth data base.

At this point, the radar image simulation work is complete but the data are still stored in a polar array. The following program converts these data from polar back to rectangular coordinates for compatibility with either standard raster-scan format display devices for evaluation or the Correlatron for testing purposes.

5.4 Rectangular Conversion

Reference to Figure 4 will show the third step performed is RECTANGULAR CONVERSION, the computer program which converts the simulated radar image from a polar array to a rectangular grid matrix. RECTANGULAR CONVERSION actually consists of two (2) computer programs, RECTANGULAR CREATE, and RECTANGULAR ARRAY; copies of these programs are provided in Appendices H and I, respectively.

These two programs exist for the same purpose as POLAR CREATE and POLAR ARRAY (section 5.2) and perform the inverse operations of them. RECTANGULAR CREATE requires input specification of the size of the rectangular grid desired for the output data. The size of this grid is dependent upon the purposes for which the data have been created. If the data have been created for display and evaluation purposes, the size of the grid is entirely determined by the size of the area to be viewed and the size limitations of the display device. If the data have been created for testing on the Correlatron, the size of the output grid is specified to be 921 x 921 pixels. Upon specification of the size of the output rectangular grid matrix, RECTANGULAR CREATE calculates again the polar address (r,θ) of each point in the specified rectangular array and stores these data on an intermediate magnetic tape.

RECTANGULAR ARRAY requires input specification of the data format of the magnetic tape to be output. For display and evaluation purposes, the format is defined to be raster format with the word length for the grey-tones of each pixel , and whether a positive or a negative is desired, to be specified. For testing on the Correlatron, the output format is defined to be:

9 track digital magnetic tape;
1600 bpi;
921 records;
921 pixels per record;
0 Corresponds to white;
255 Corresponds to black.

Upon specification of these input parameters, RECTANGULAR ARRAY converts the data output from RECTANGULAR CREATE into a completely specified rectangular grid having the desired output format, and stores these data on a digital magnetic tape.

When these data have been created for testing on the Correlatron (the appropriate specifications have been made), the tape output from RECTANGULAR ARRAY contains the desired reference radar scene for one of the bands.

5.5 Testing and Evaluation

Upon completion of the previous activities and having a data tape output from RECTANGULAR ARRAY, the data are available for testing and evaluation. Standard display devices such as a monochrome television set which is interfaced to the digital computer via IDECS* are employed at RSL for image evaluation. This capability is exploited frequently for trouble-shooting problems and for validating reference scenes before they are sent to ETL for testing on the Correlatron.

Once a simulated radar image has been produced and has passed the evaluation phase at RSL, the output of RECTANGULAR CREATE is run again through the reference scene format version of RECTANGULAR ARRAY for producing a digital tape having the right format for the Correlatron test system. This tape contains a reference radar image for testing at ETL on the Correlatron. The tape is mailed to ETL and the reference scene is run through the Correlatron system by personnel at ETL. The results of running our reference radar scene against "live" video data on the Correlatron are communicated to RSL from ETL.

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*IDECS is the acronym standing for Image Discrimination, Enhancement, Combination, and Sampling. The IDECS is an analog image enhancement station located at the RSL.

6.0 PROBLEMS AND SOLUTIONS

6.1 Geometric Fidelity

When planning the various aspects involved in the construction of the data base for bands 3 and 4, it was decided to produce the hand-drawn planimetry at a smaller scale than the source intelligence (1:150,000 instead of 1:100,000 scale). This was decided so that the resultant hand-drawn map could be digitized on a digitizer table which was more readily available than the one used for the bands 1 and 2 data base. To accomplish this reduction in scale, a reducing table was used. Use of this reducing table caused geometric fidelity problems.

The ortho photo which was used as the source intelligence for the bands 3 and 4 data base was too large to fit completely on the reducing table. This meant that only a small segment of the data base could be developed for a given orientation of the ortho photo on the table. Then both the ortho photo and the hand drawing had to be moved and re-registered. Not apparent at the time of construction but discovered later, this moving and re-registering of ortho photo and data base created small errors in the location, orientation, and scale of any given registration with all others. The errors were not apparent to the eye, but when radar images were simulated from this data base and the cross correlation calculated between these simulated and real images, the decrease in geometric fidelity reduced the height and broadened the peak of the cross correlation. This problem also had the potential for causing a shift in the location of the match point, the peak of the cross correlation, creating an apparent centering error.

This problem could have been averted easily if the scale of the ortho photo had been reduced photographically to that desired and the reduced ortho photo used as source intelligence for the data base. This was not done because the table was available and past experience using the table for other kinds of projects did not flag a potential problem. In all subsequent work, when scale reduction has been desirable, it has been realized photographically.

It was impossible to fix the data base having these errors. The only correction possible would have been scrapping the data base containing the problems and making a new one, and this was prohibitive in terms of time and resources.

6.2 Mis-Registration of Planimetry and Elevation Data

When setting-up the coordinate system in which the hand-drawn planimetry for the bands 3 and 4 data base was to be digitized, one point was incorrectly specified. The intent was to digitize the planimetry data in the coordinate system of the elevation data. This was desired to minimize problems associated with merging the two sets of data, planimetry and elevation. Incorrect specification of one point created both scale and rotation errors of the digitized planimetry with respect to the elevation data.

This problem was not detected until all source data which might have contained details of the error were destroyed. In the abscence of facts relating to the exact nature of the error, it was attempted to affect a scale and rotation that would map points from the planimetry coordinate system into the desired point in the elevation data coordinate system. A unique mapping was impossible to obtain because of the problems with the geometric fidelity previously discussed (Section 6.1). A best registration between planimetry and elevation data was obtained for selected points which were readily identifiable in both data sets.

Radar simulations were created from the data base containing the merge of the scaled and rotated planimetry with the elevation data. The cross correlation was calculated between these simulations and real images. Misregistration between planimetry and elevation data caused several problems with the cross correlation. First, the location of the match point (the peak of the cross correlation) was shifted creating an apparent centering error. Second, the weight was reduced and the width broadened of the peak. These problems mean, of course, that the data base for bands 3 and 4 was not suitable for testing the PSM as a viable radar simulation technique for guidance systems using the Correlatron.

7.0 RESULTS AND RECOMMENDATIONS

7.1 Correlatron Test Results

Radar simulations were produced for four (4) different scales from the two (2) data bases constructed in the studies reported here. Radar simulations of two different scales were made from each of the data bases. These four simulations represented the altitudes of specific points on the terminal trajectory of a missile, each successively lower. The highest altitude simulation is called band 4, the next lower is called band 3, next is band 2, and lowest is called band 1. Band 3 and 4 simulations were produced from one data base, and band 1 and 2 simulations from the other.

The sequence of four radar simulations were tested at ETL (U.S. Army Engineer Topographic Laboratories) by a Correlatron. The simulations were input to the Correlatron as reference guidance scenes for correlation with actual radar data previously collected and recorded in a flight test program conducted over the Pickwick test site. The results of this test are mixed, primarily as a result of the problems in the bands 3 and 4 data base as previously discussed (Section 6.0). Complete analyses of the results are not reported here as that is beyond the scope of this report. Qualitatively, the results obtained were:

1) Band 1 (lowest altitude)
   Very good performance within accuracy requirements;
2) Band 2 (higher altitude)
   Excellent performance well within desired accuracies;
3) Band 3 (next higher altitude)
   Failure to perform within accuracy requirements;
4) Band 4 (highest altitude)
   Acceptable performance within accuracy requirements.

Band 1 and 2 simulations were developed from the data base having the highest degree of detail. Performance of these simulations was spectacular in view of the fact that they worked this well on the first trial.

Simulations produced by any other technique have required numerous trials, each successive trial testing a change, to obtain acceptable performance at this scale. Simulations produced via the PSM should work this well as the PSM rigorously models the radar guidance system.

Band 3 and 4 simulations were developed from the data base having the problems discussed in Section 6. Performance of these simulations was better than expected in view of the nature of the problems in the data base. The problems in the data base are unfortunate because they cloud what otherwise should have been a clear decision in favor of the PSM. Acceptable performance has been readily attained by most other simulation techniques, in part because of the large reduction in detail and scale. Surely if the band 3 and 4 data base had not contained geometrical errors, the PSM simulation for these bands would have performed as well as the band 1 and 2 simulations did. Of course, this cannot be proved with the data that exist, but it is a reasonable conjecture, especially in view of the fact that even with the errors, the simulation for band 4 was acceptable.

7.2 Recommendations

As the test conducted here was not decisive, it is recommended that the band 3 and 4 data base be rebuilt, and new simulations produced and tested on the Correlatron. This is recommended because only those intimately familiar with the technical aspects of the radar simulation problem will recognize that the band 3 failure to meet expectations was for the reasons enumerated, and an objective test needs to be conducted to satisfy others. This is important because the PSM offers a technique for radar simulation which does not require target specific special processing and fooling around, as other techniques do. All the PSM requires is an accurate data base, a requirement, incidentally, which is fundamental to any simulation technique.

It is further recommended that the PSM be used to produce radar simulations of other sites for testing on the Correlatron. Results of such tests will establish the validity of the PSM for application to all manner of target scenes, thereby eliminating the site specific customizing presently required for other techniques.

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APPENDIX A

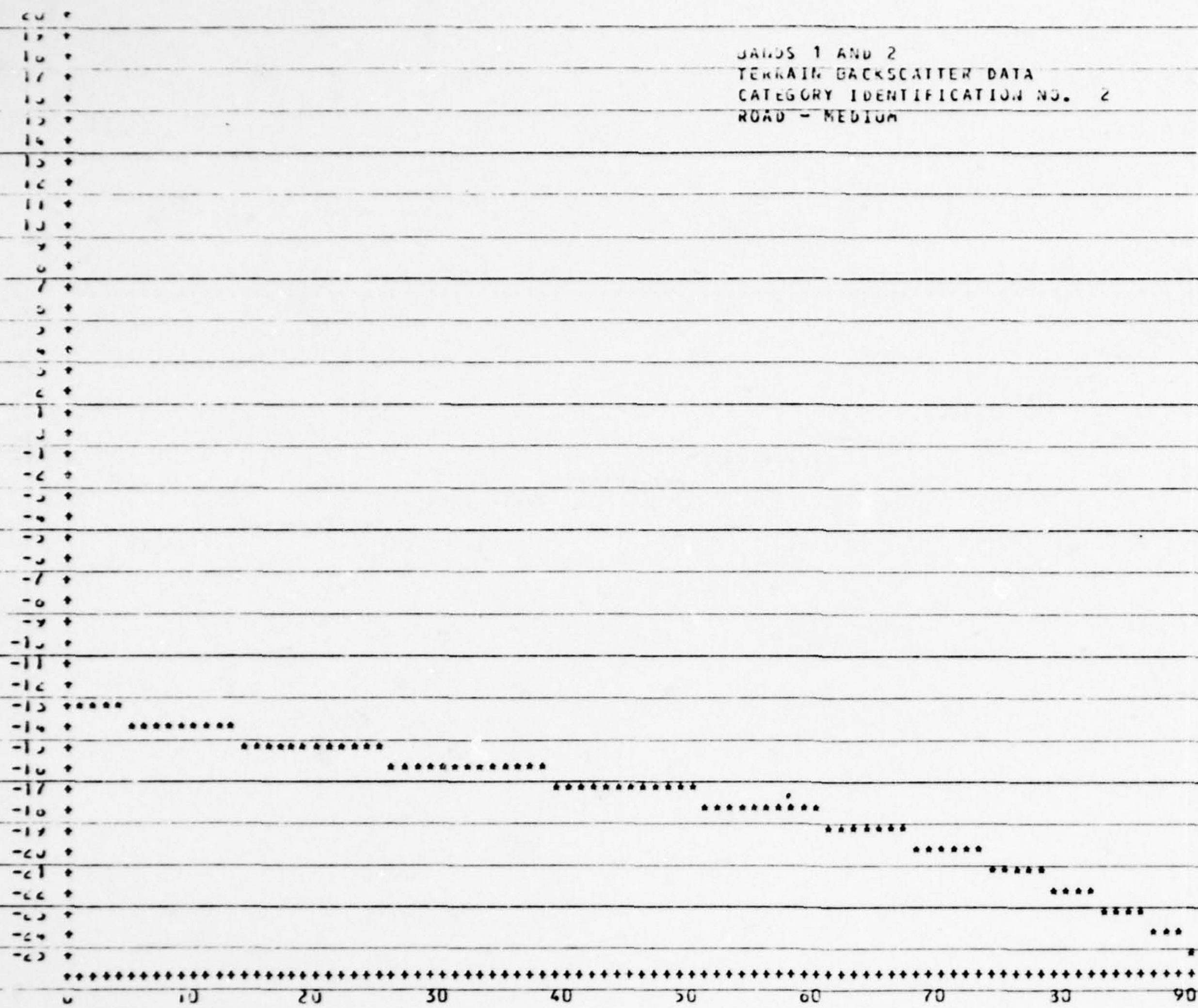
Backscatter Data
for
Bands 1 and 2
Reference Radar Scenes:
Pickwick Site

All of these data represent the following radar parameters:

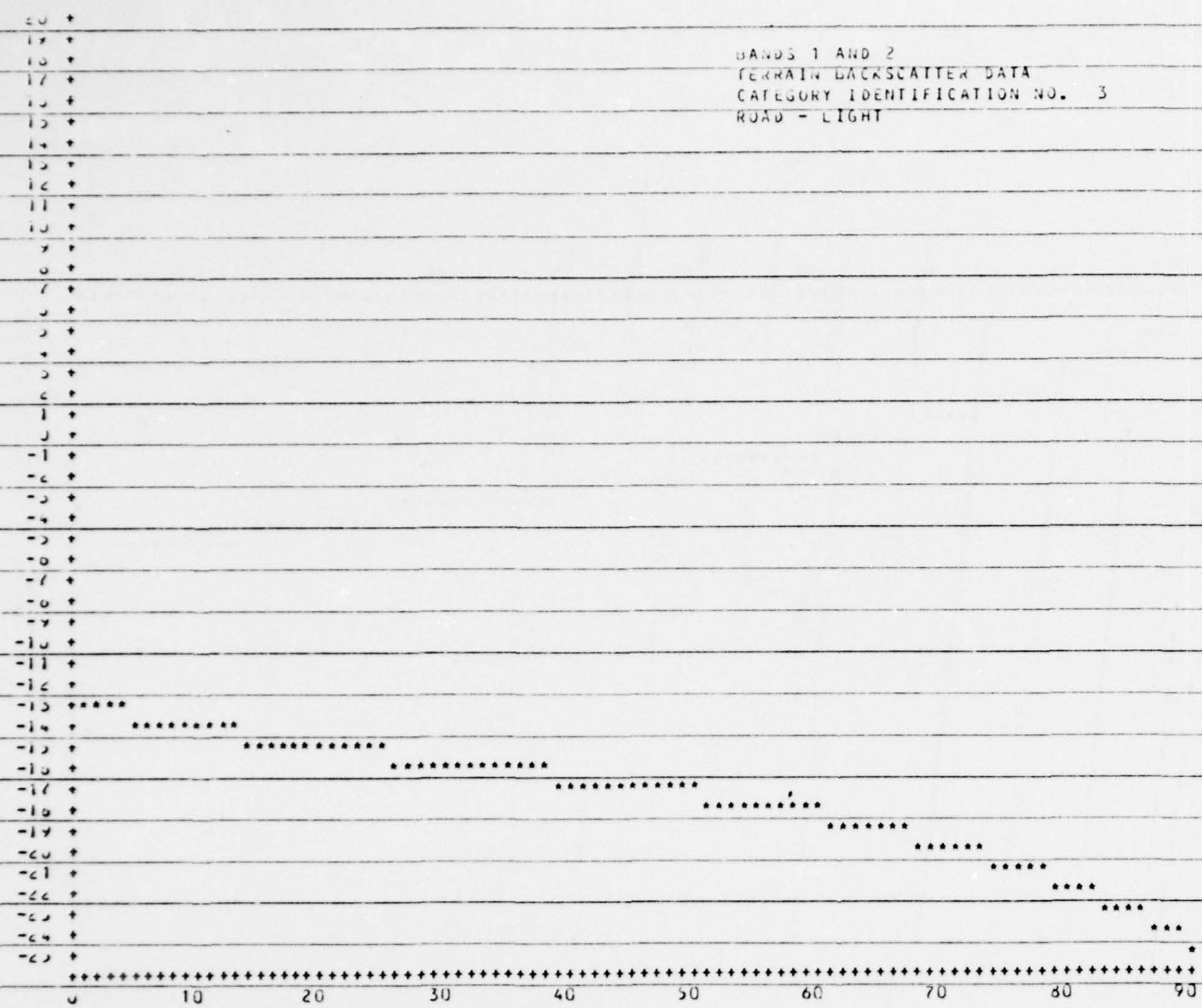
1) Frequency - X-band

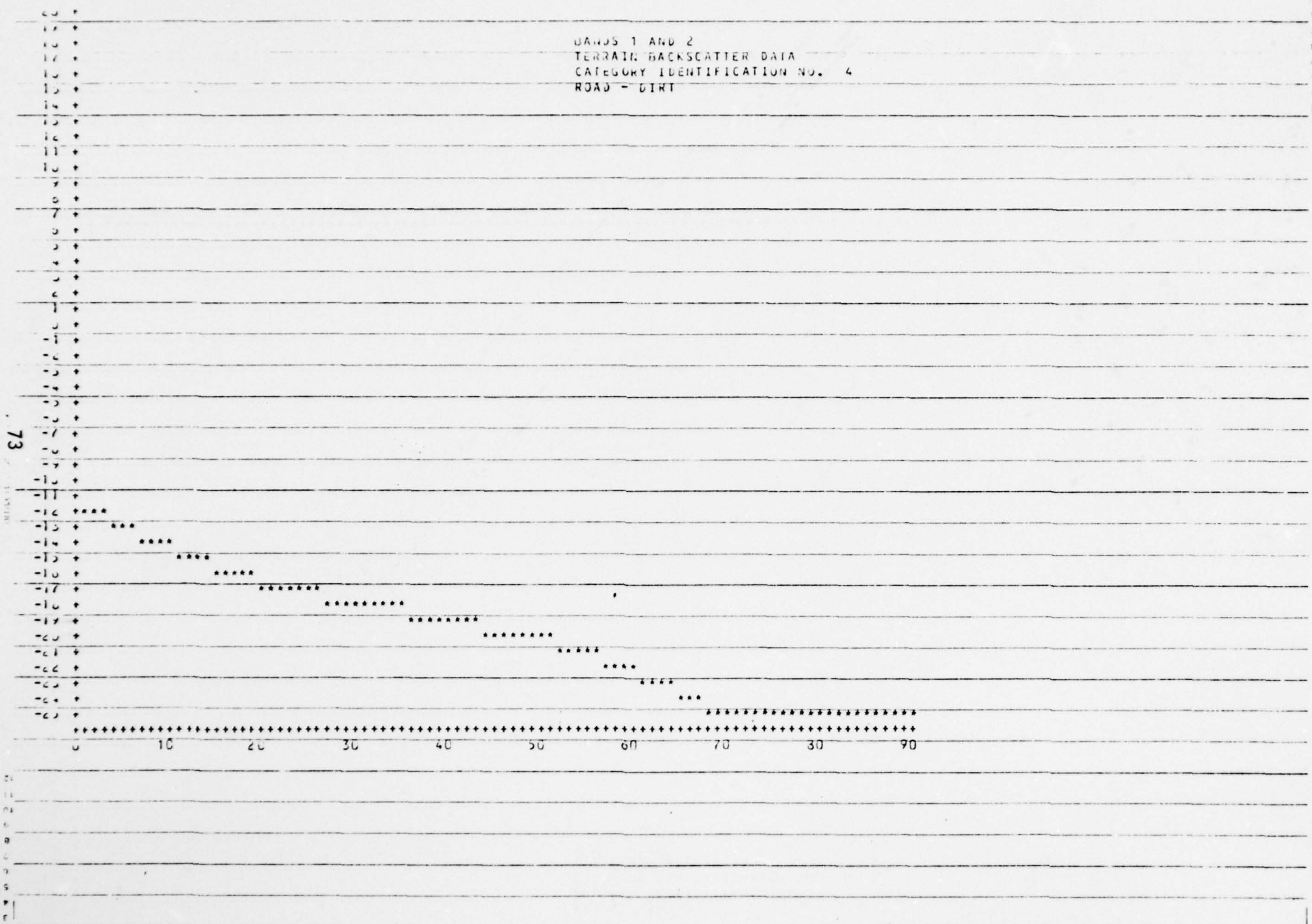
2) Polarization - Horizontal transmit, Horizontal receive (HH)

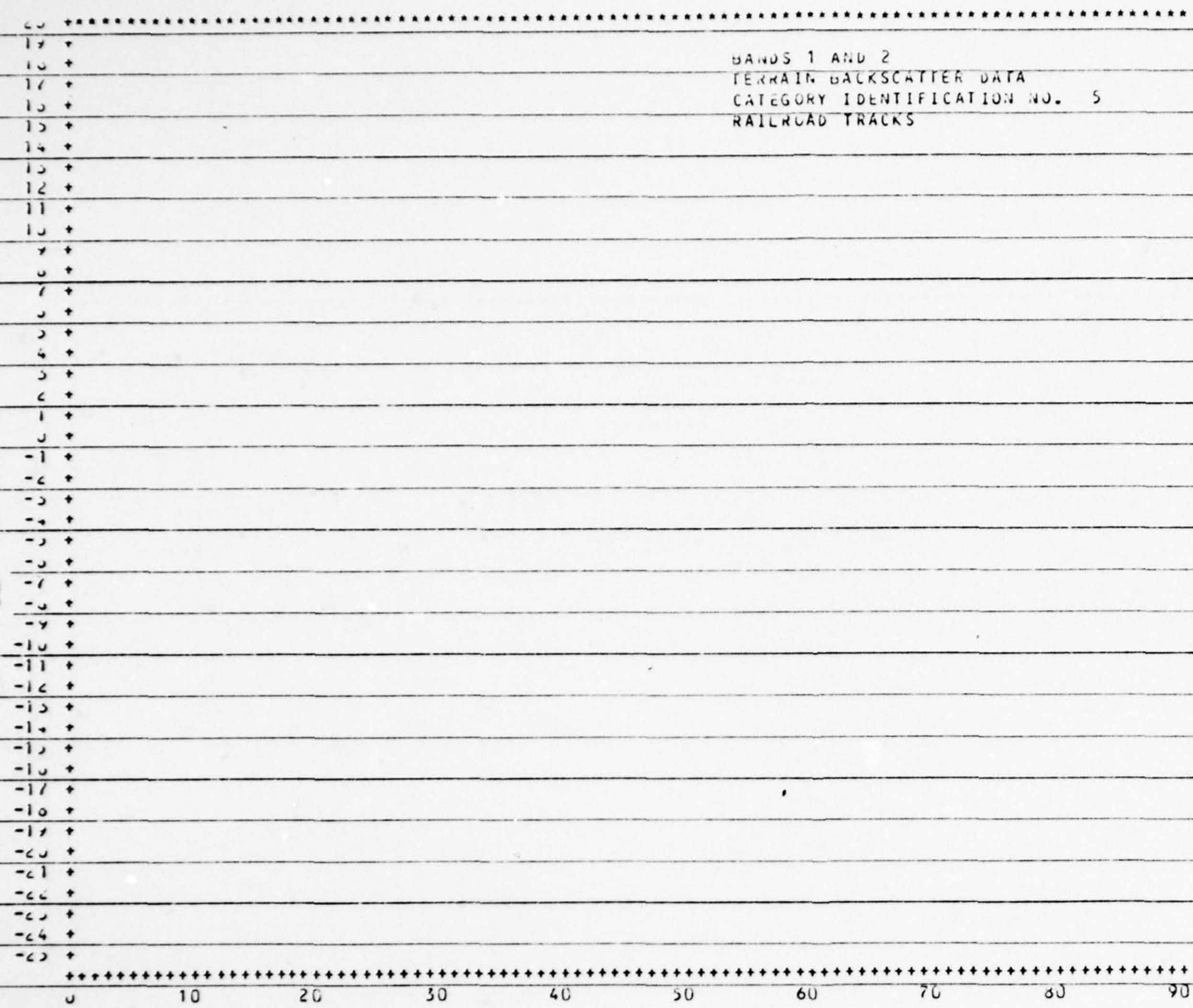

BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 1
NO CATEGORY (OUTSIDE DATABASE)
0
10
20
30
40
50
60
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 2
ROAD - MEDIUM
-10
-11
-17
-21
0
10
20
30
40
50
60
70
80
90

BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 3
ROAD - LIGHT




BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 4
ROAD - DIRT
0
10
20
30
40
50
60
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 5
RAILROAD TRACKS
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
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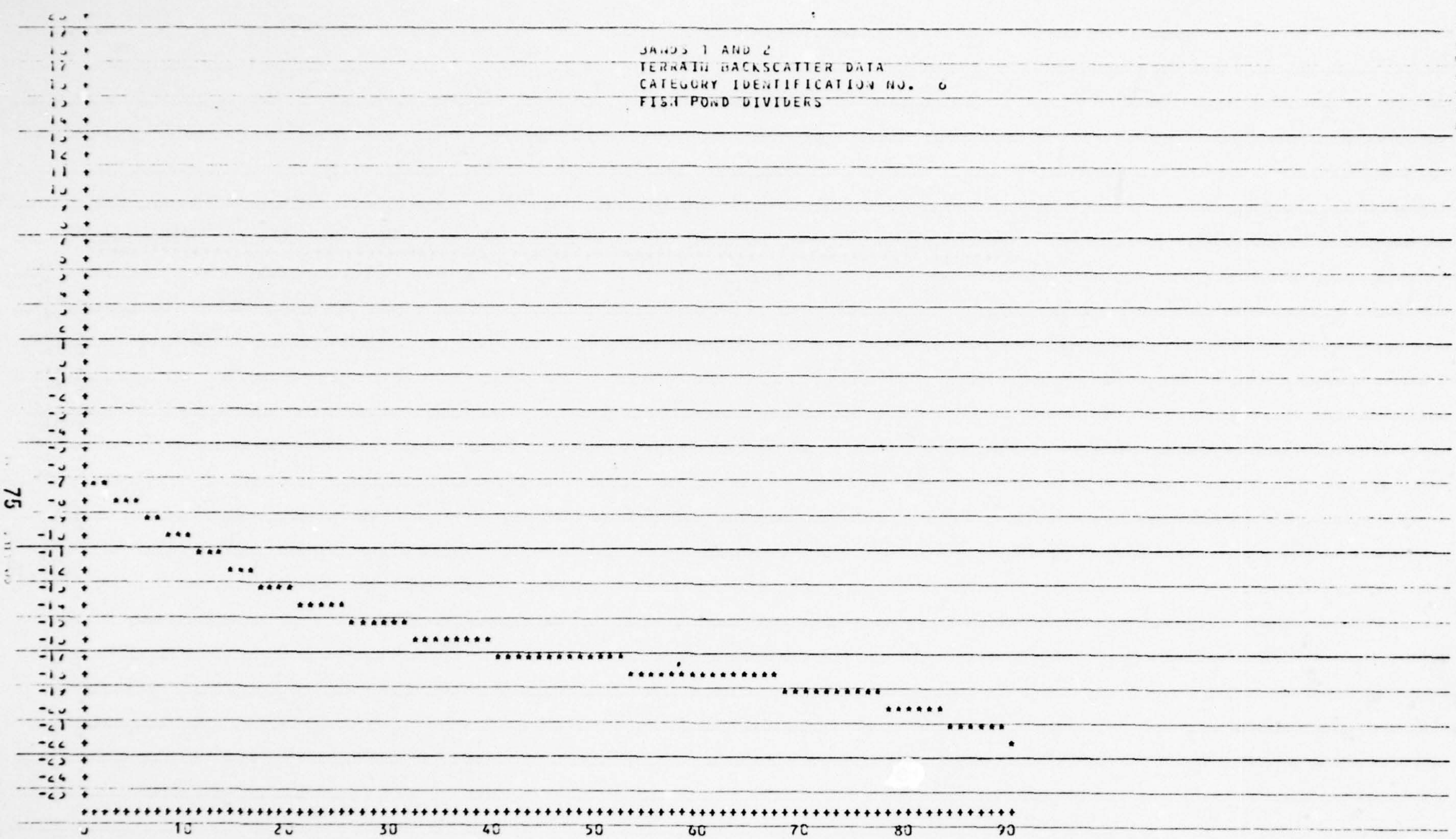
50
60
70
80
90



BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 6
FISH POND DIVIDERS
-7
-11
-15
-21
10
30
40
50
60
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 7
IRON GRATING
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
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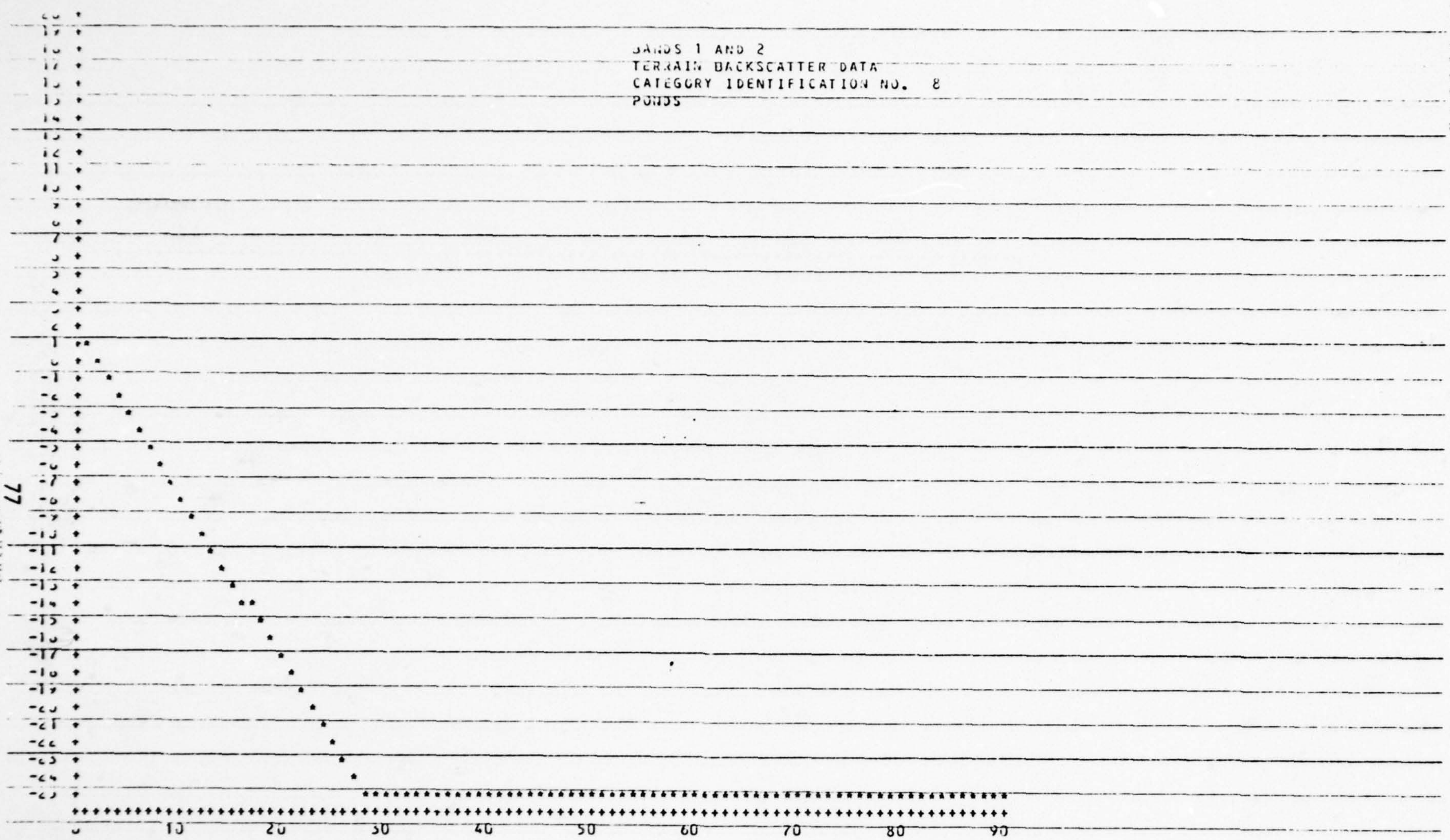
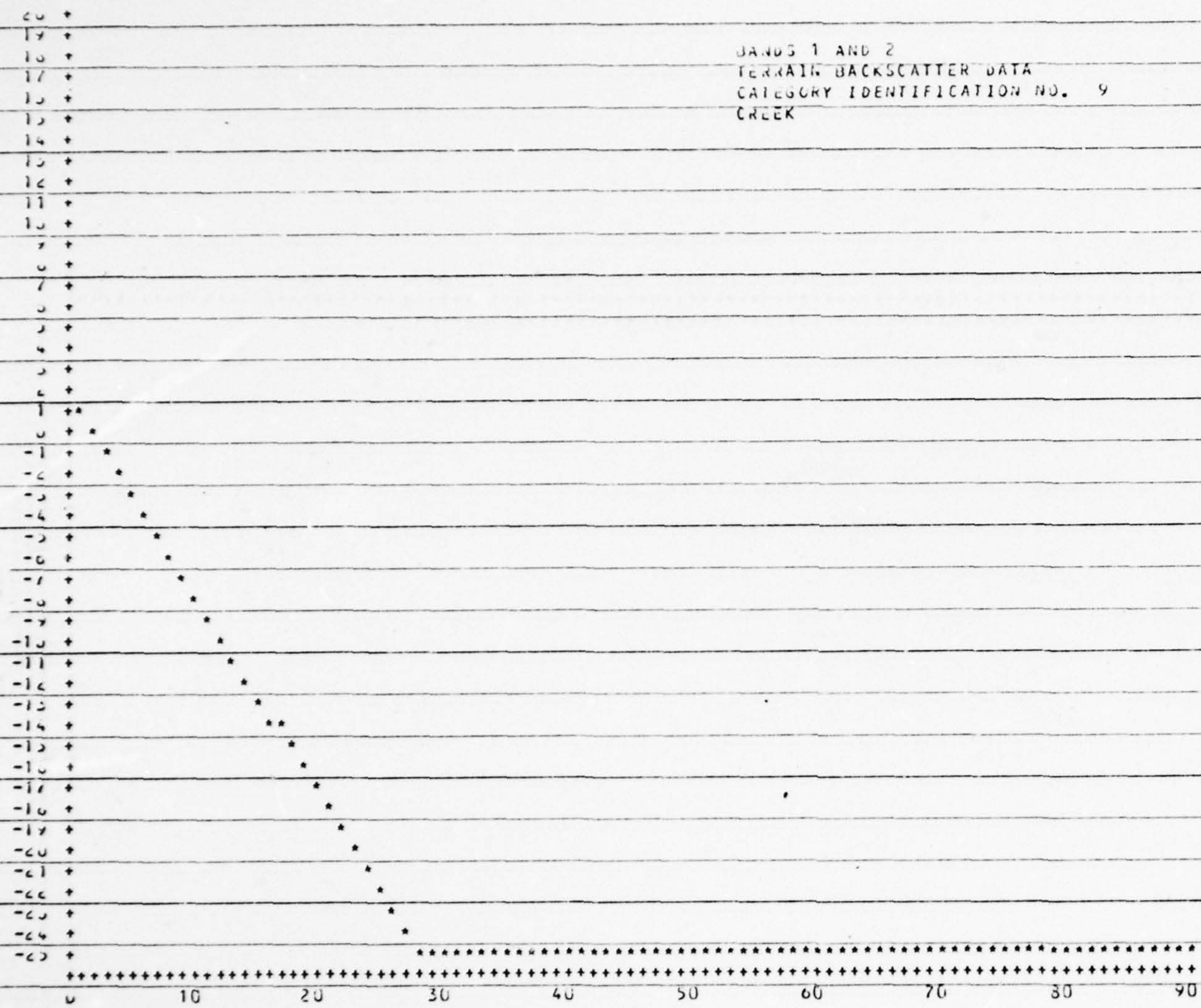
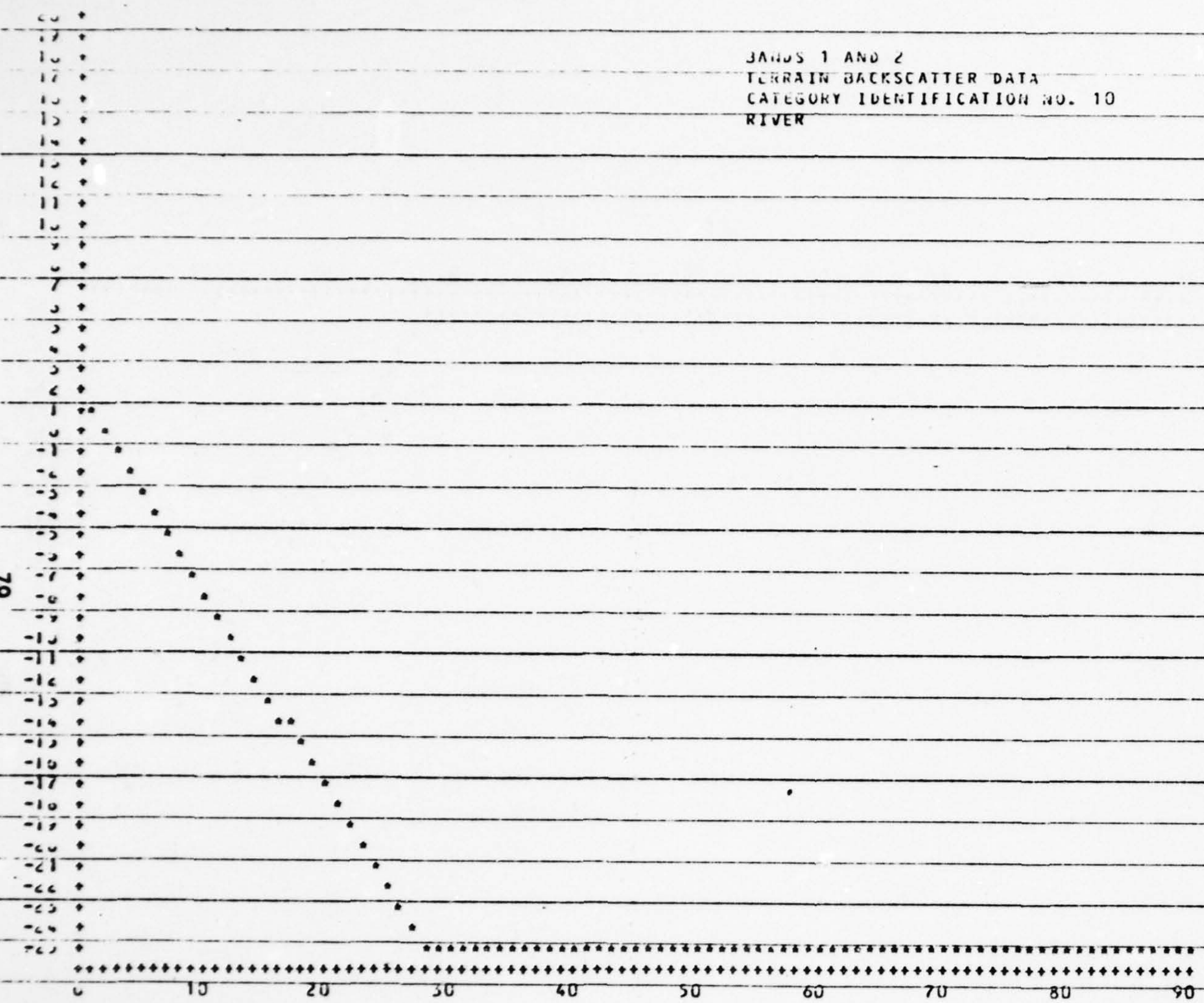
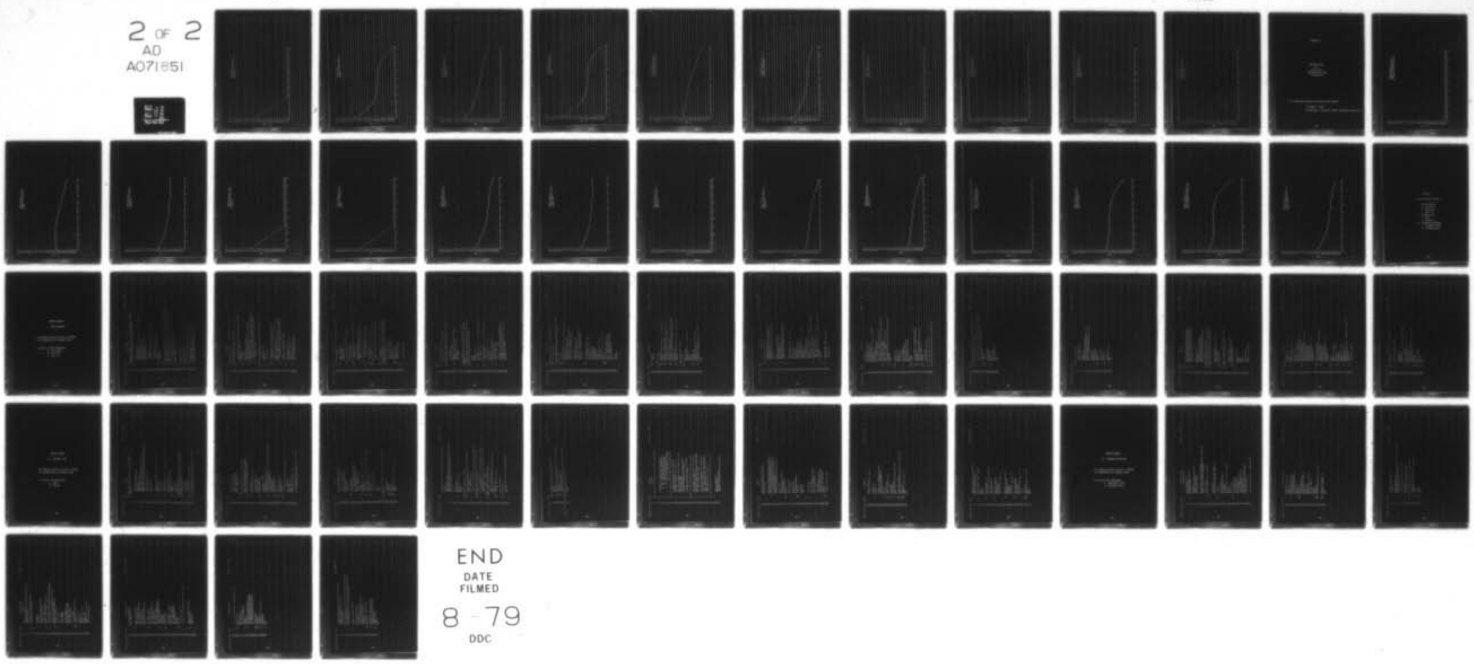

BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 8
PONDS


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 9
CREEK
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
0
10
20
30
40
50
60
70
80
90

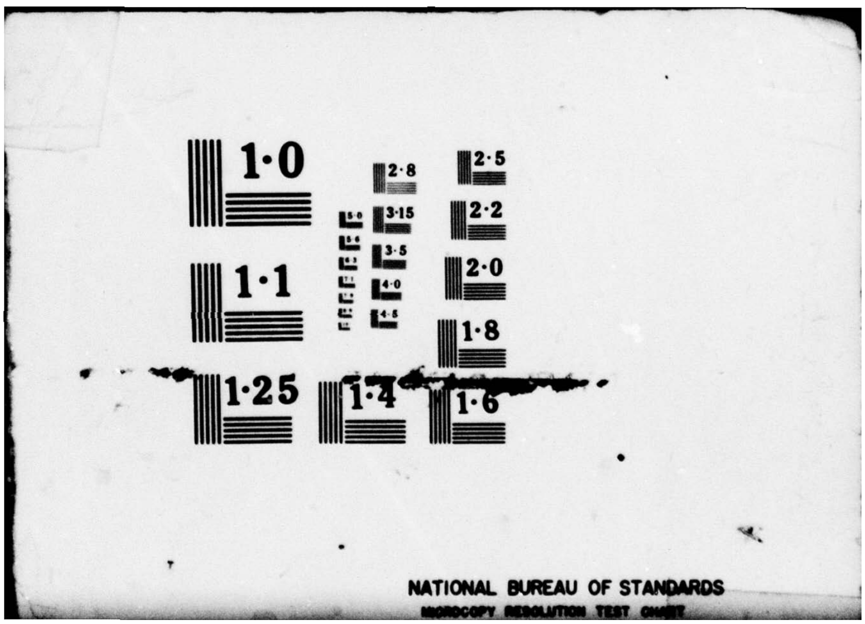

BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 10
RIVER
0
10
20
30
40
50
60
70
80
90

AD-A071 651 KANSAS UNIV/CENTER FOR RESEARCH INC LAWRENCE REMOTE --ETC F/G 17/9
RADAR IMAGE SIMULATION: VALIDATION OF THE POINT SCATTERING METH--ETC(U)
JUN 78 J C HOLTZMAN, J L ABBOTT, V H KAUPP DAAG53-76-C-0154
UNCLASSIFIED RSL-TR-319-31 ETL-0155 NL

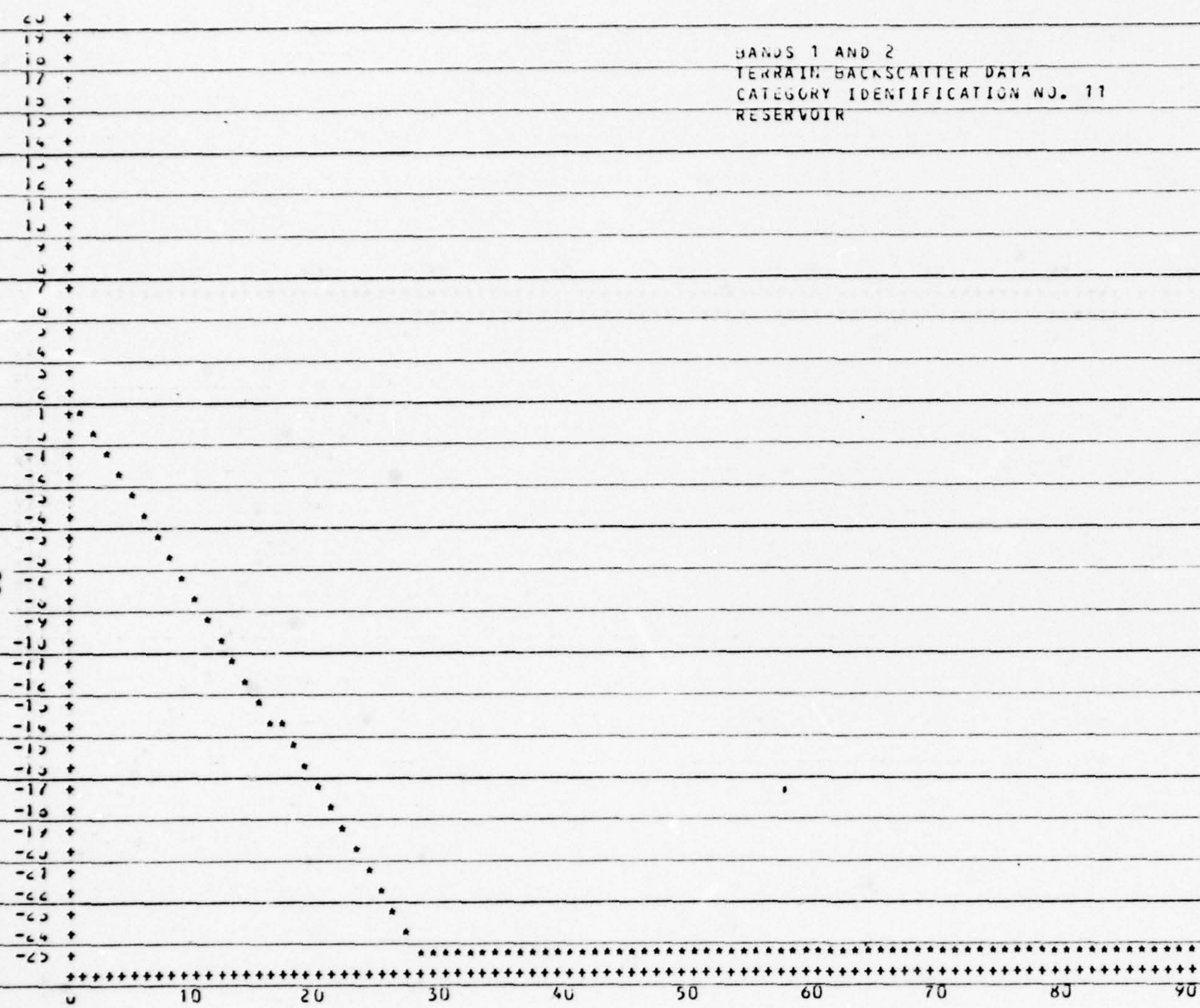
2 OF 2
AD
A071651

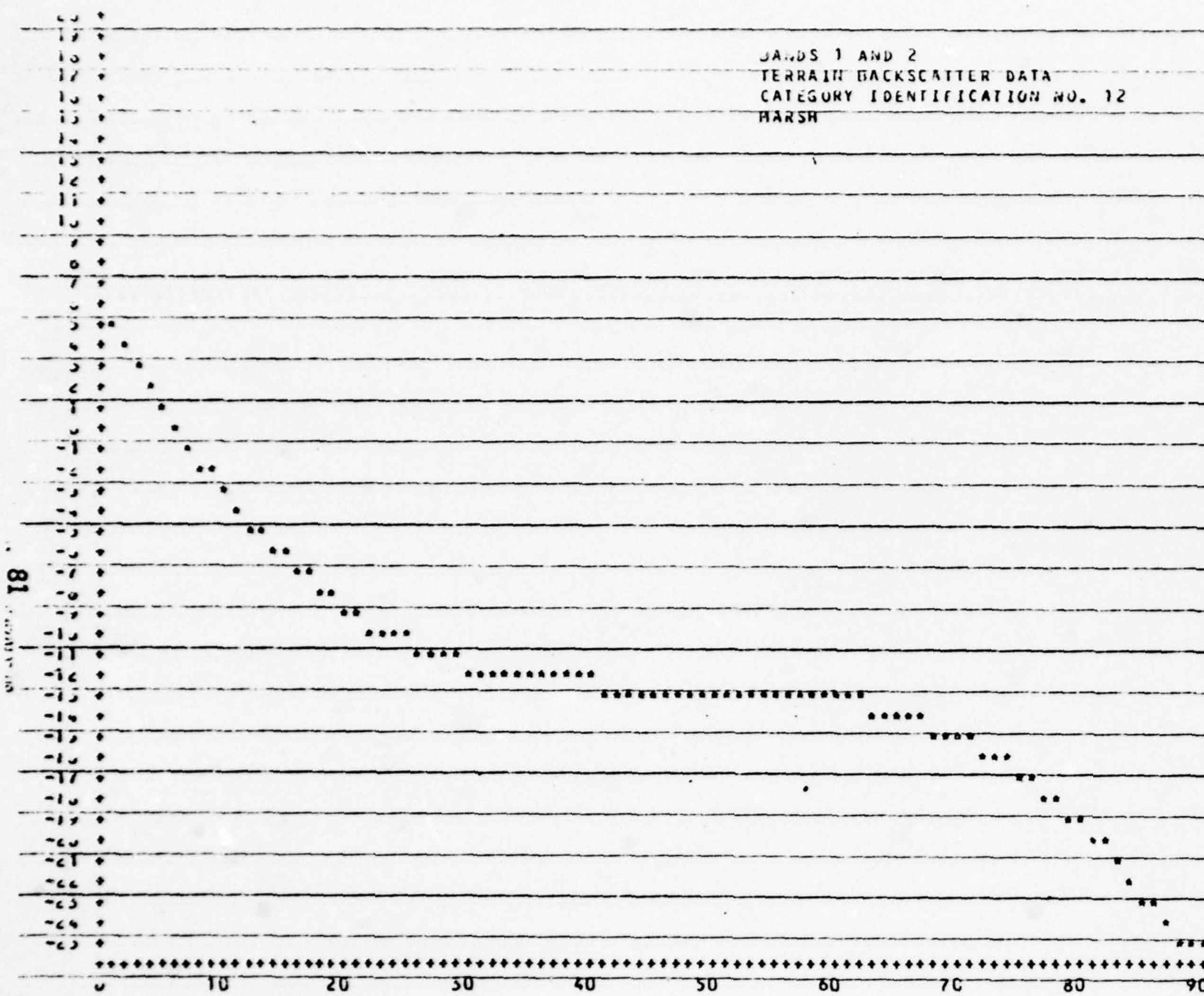


END
DATE
FILMED
8-79
DDC


1·0
1·1
1·25
1·4
1·6
1·8
2·0
2·2
2·5
2·8
3·15
3·5
4·0
4·5
NATIONAL BUREAU OF STANDARDS
MICROCOPY RESOLUTION TEST CHART

BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 11
RESERVOIR




BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 12
MARSH
0
10
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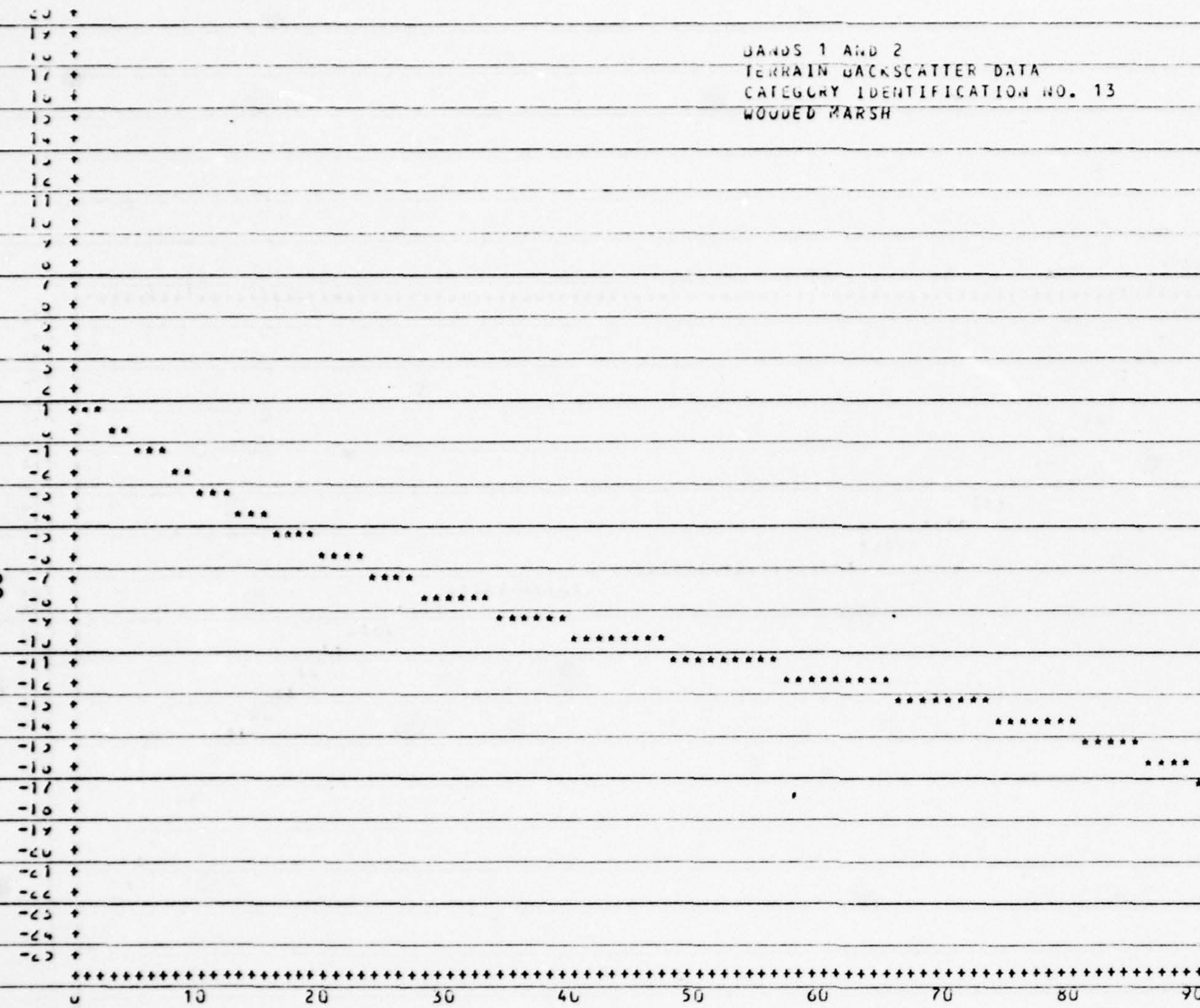
BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 13
WOODED MARSH
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10
0
-10
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50
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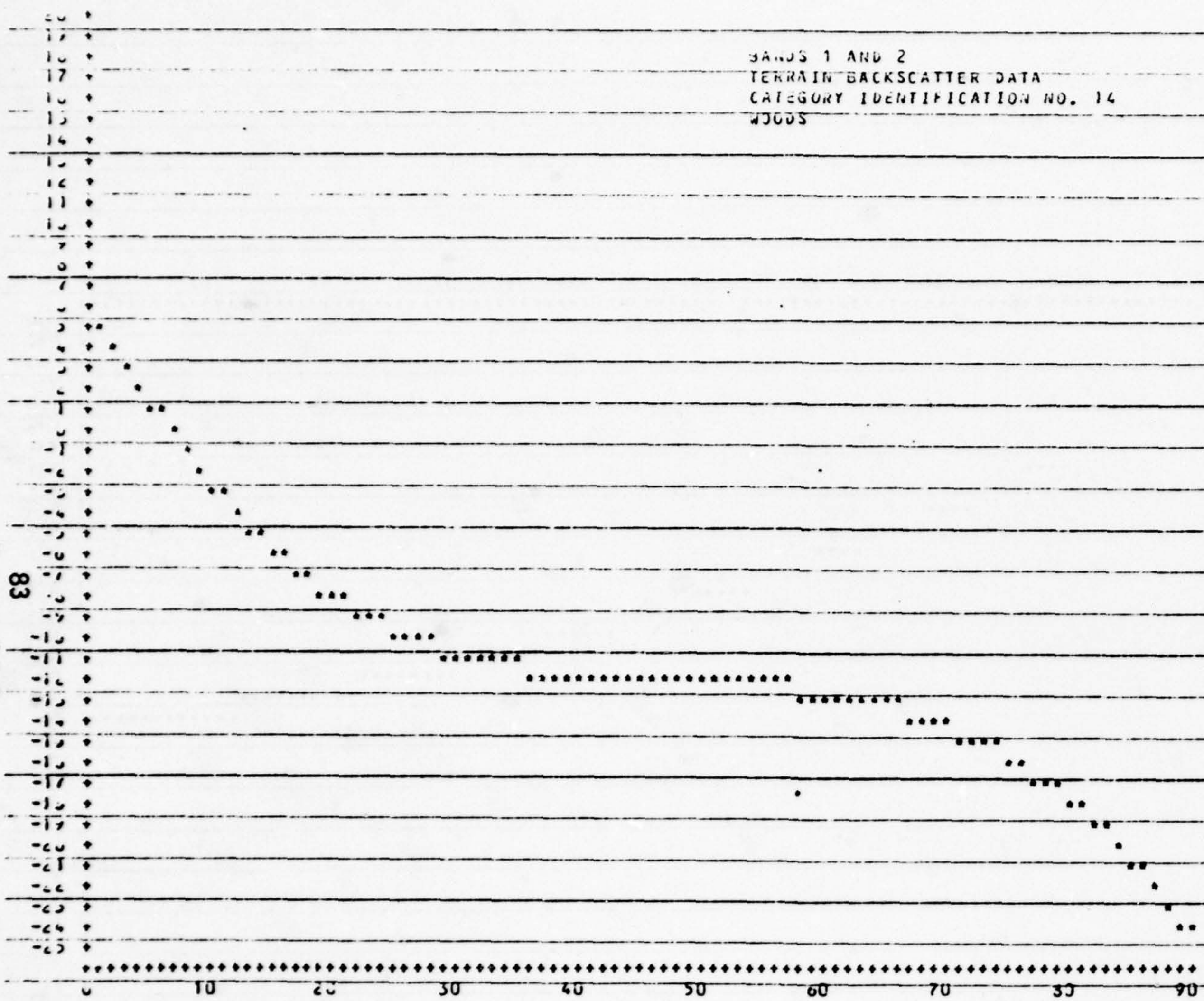
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 14
WOODS
0
10
20
30
40
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80
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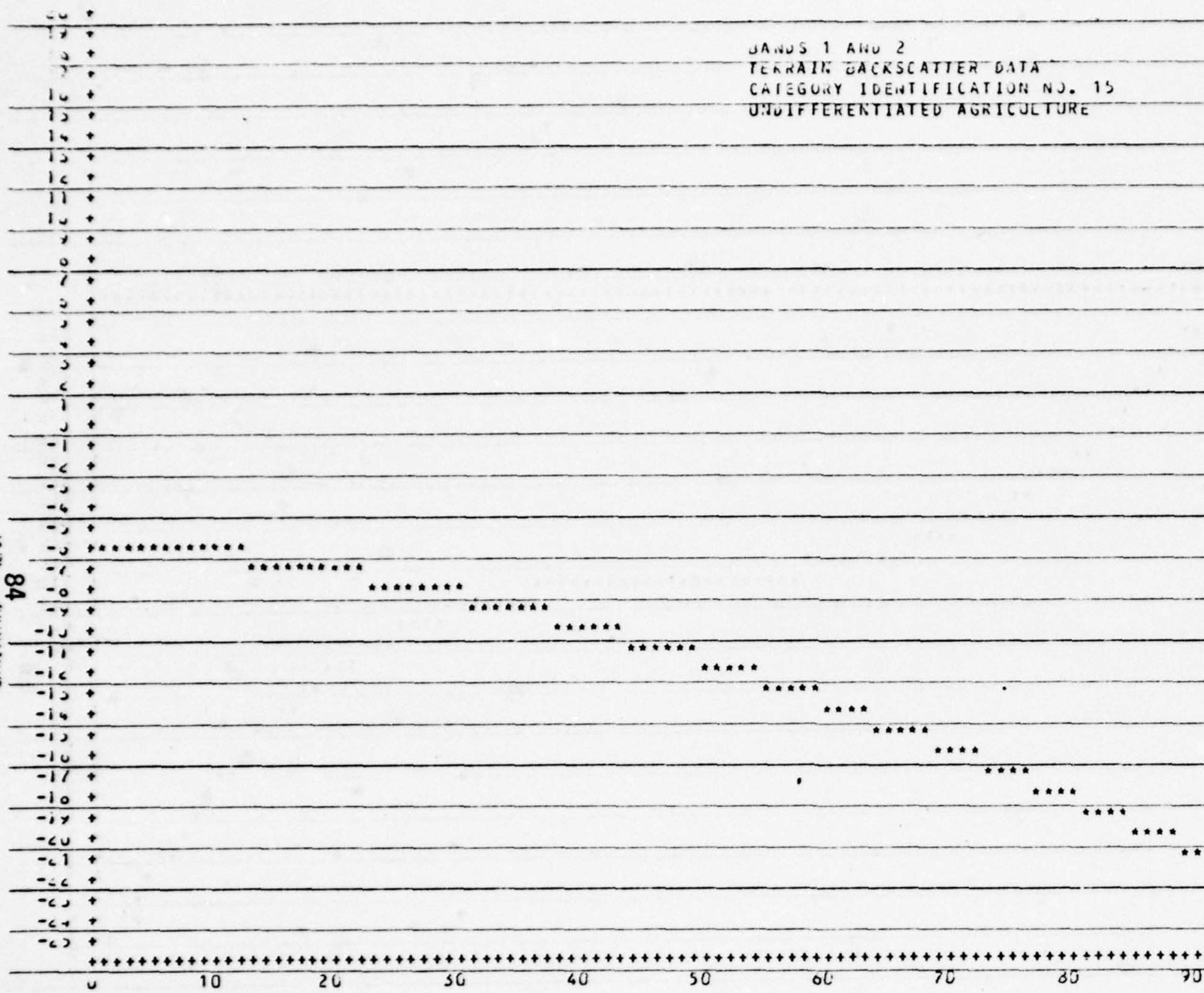
BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 15
UNDIFFERENTIATED AGRICULTURE
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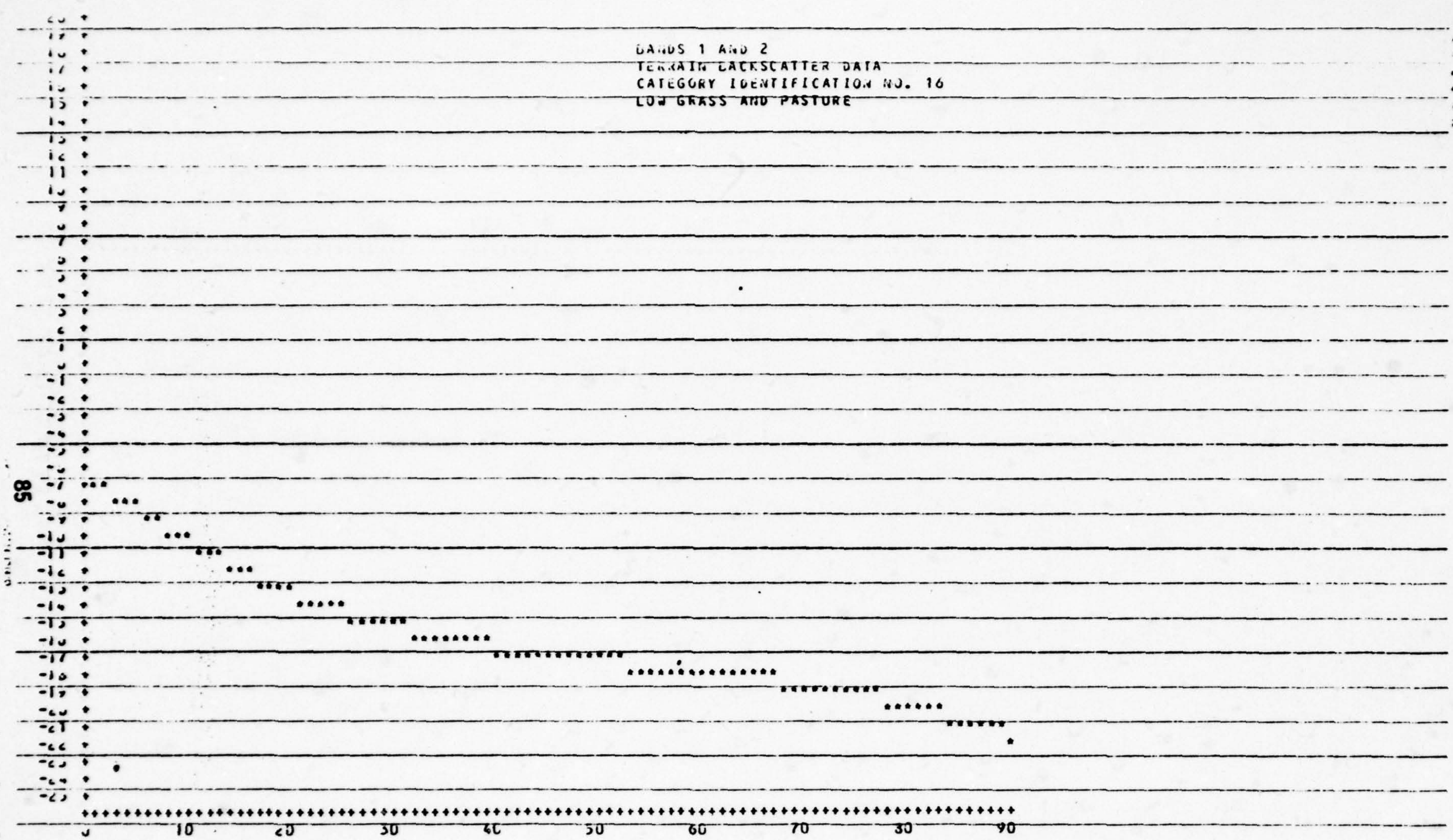
BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 16
LOW GRASS AND PASTURE
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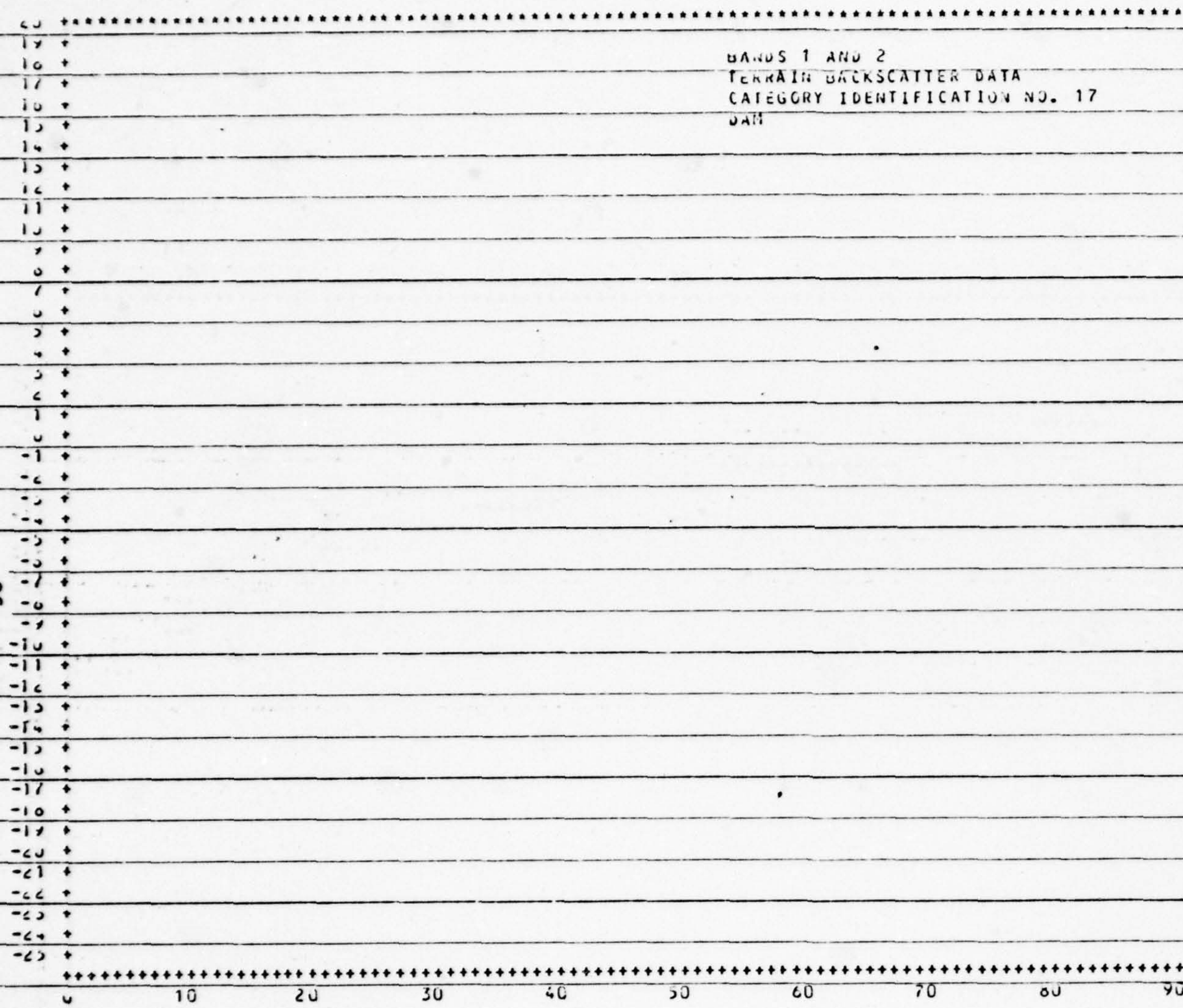
20
30
40
50
60
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 17
DAM
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
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-10
-11
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-13
-14
-15
-16
-17
-18
-19
-20
-21
-22
-23
-24
-25
0
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40
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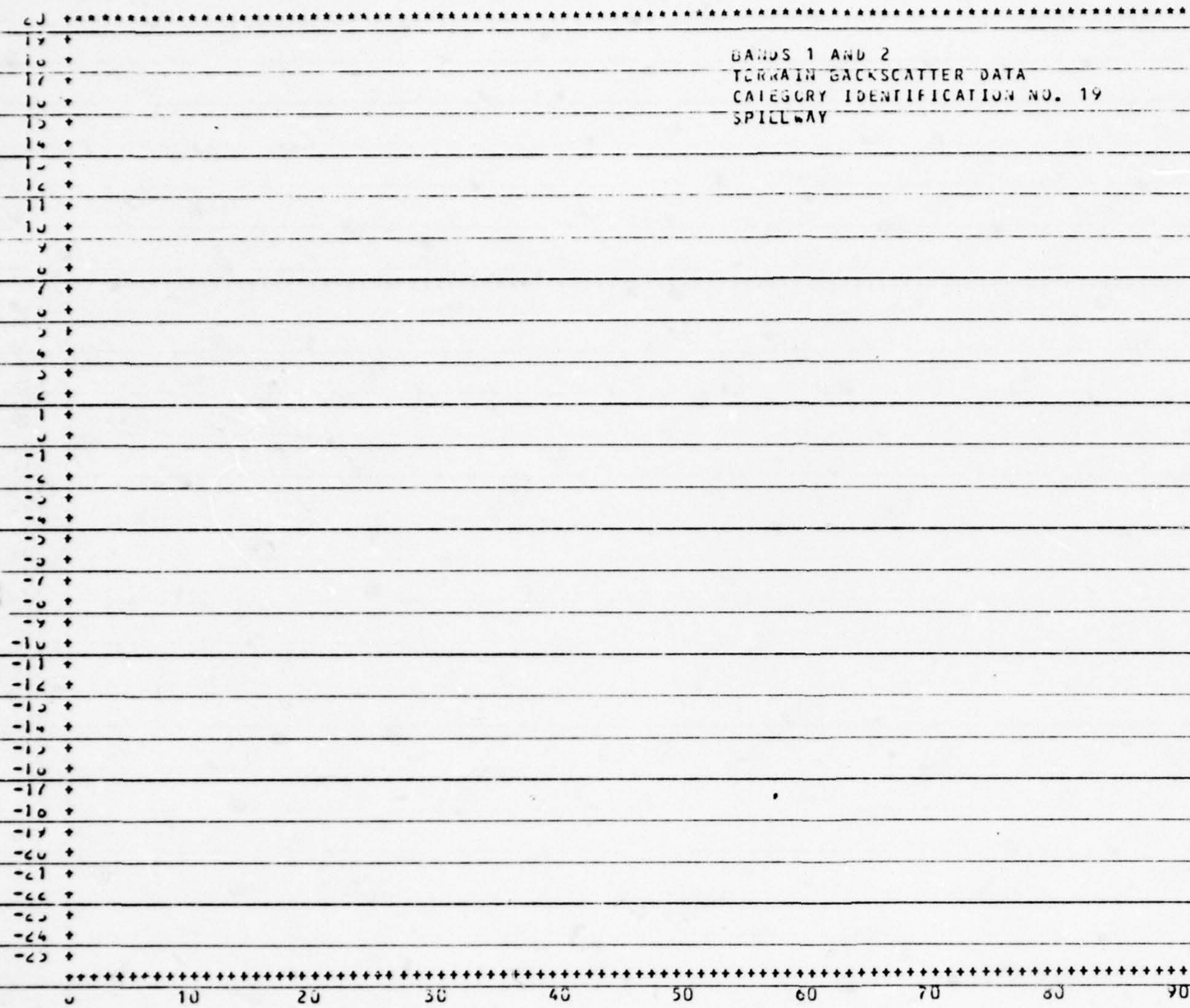
BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 13
BLOCKHOUSE
0
10
20
30
40
50
60
70
80
90


BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 19
SPILLWAY
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
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3
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-24
-25
0
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BANDS 1 AND 2
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 20
HOUSES - SMALL
0
10
20
30
40
50
60
70
80
90

APPENDIX B

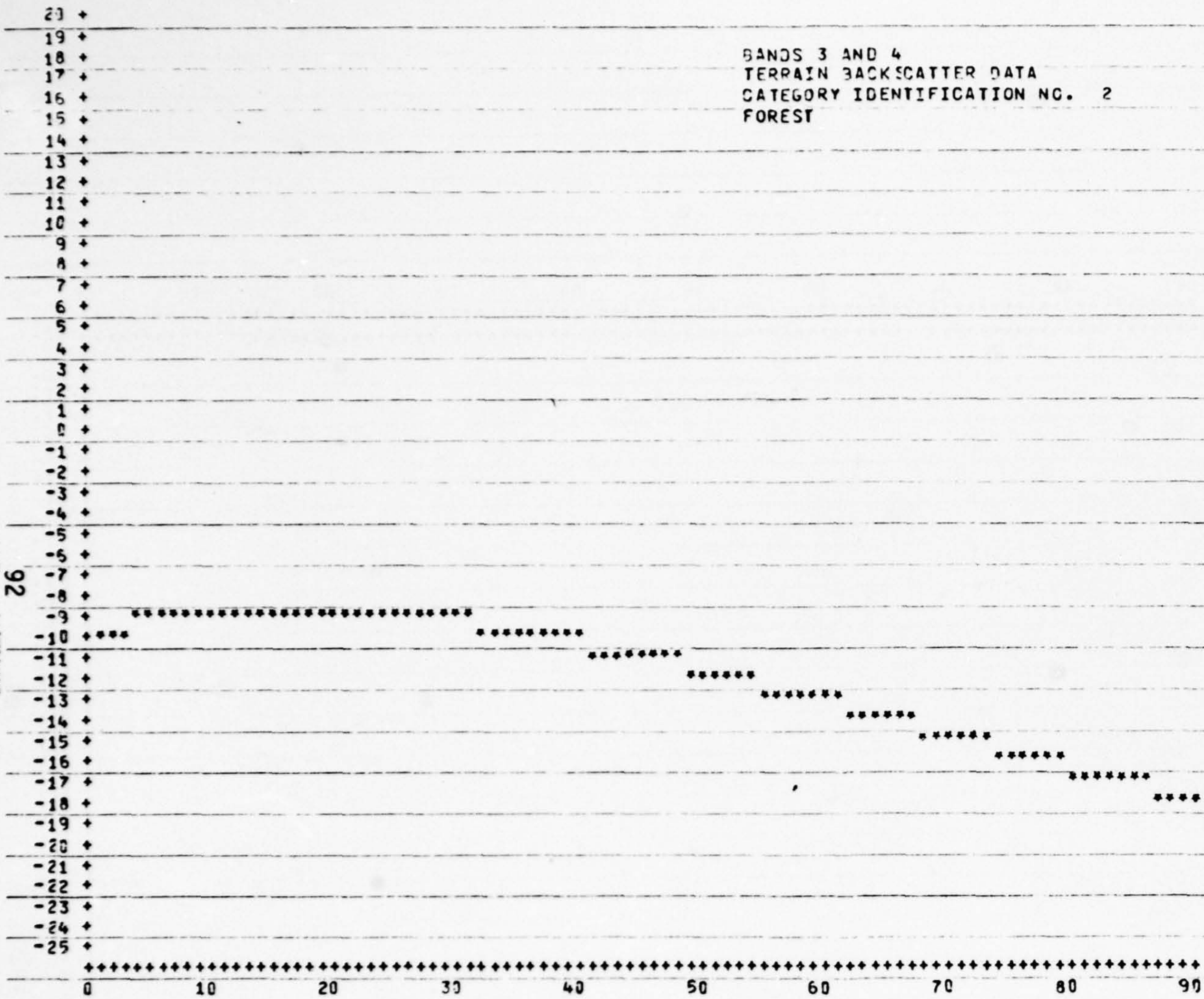
Backscatter Data
for
Bands 3 and 4
Reference Radar Scenes
Pickwick Site

All of these data represent the following radar paramters:

1) Frequency - X-band

2) Polarization - Horizontal Transmit, Horizontal receive (HH)

BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 1
NO CATEGORY (OUTSIDE DATABASE)


BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 2
FOREST
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
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-1
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-11
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-15
-16
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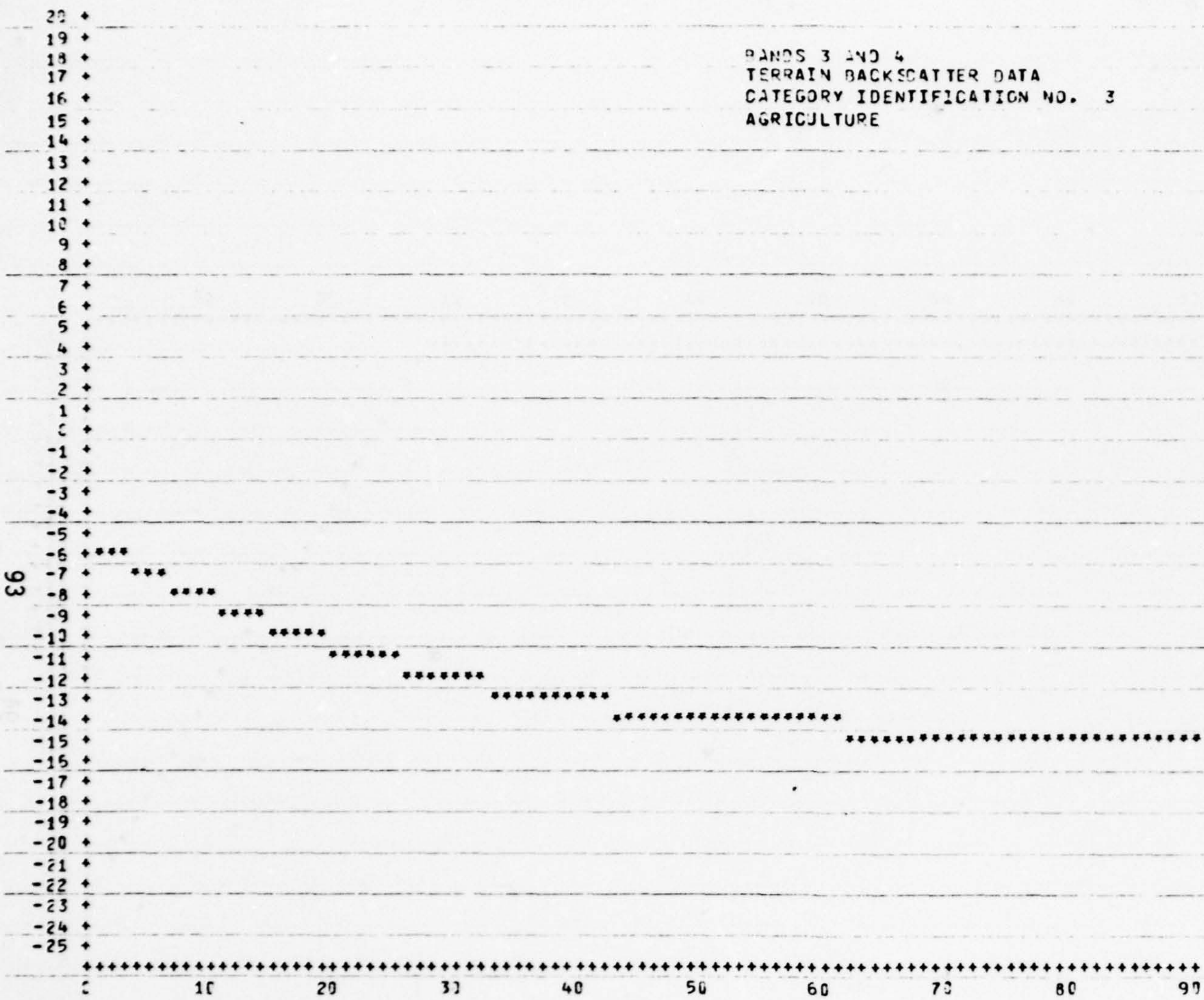
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 3
AGRICULTURE
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18
17
16
15
14
13
12
11
10
9
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7
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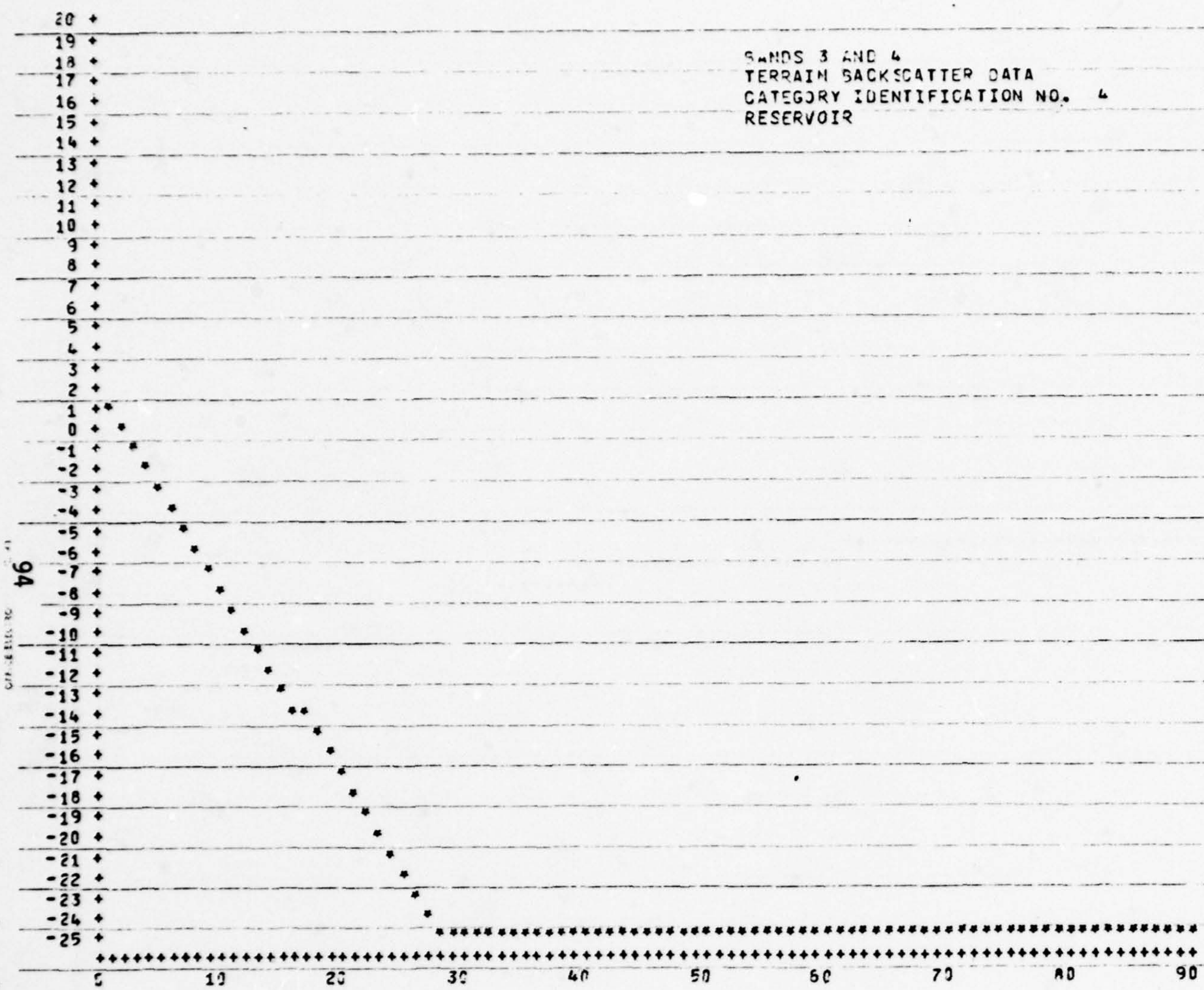

BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 4
RESERVOIR
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
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-1
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-19
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-21
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-23
-24
-25
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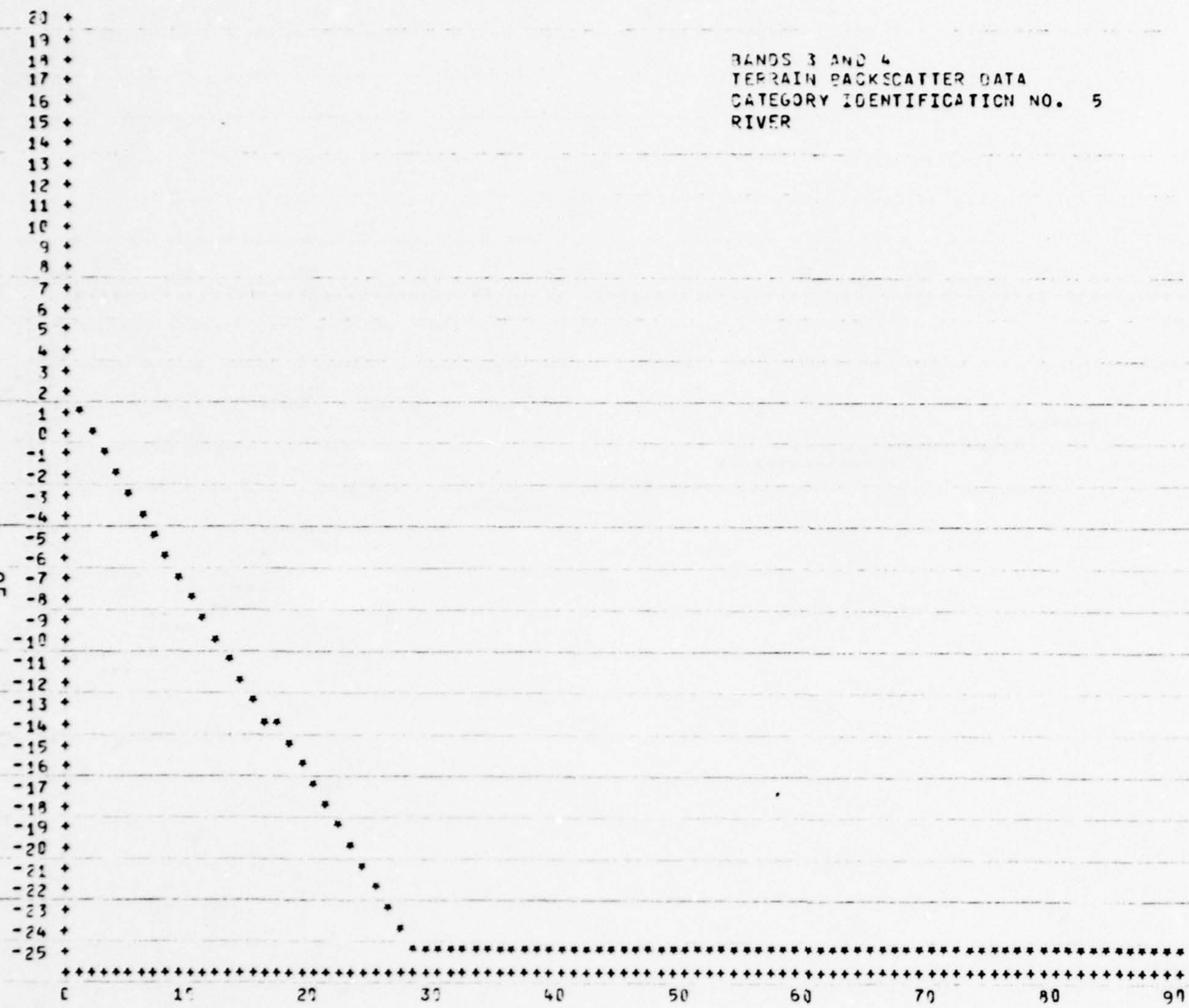
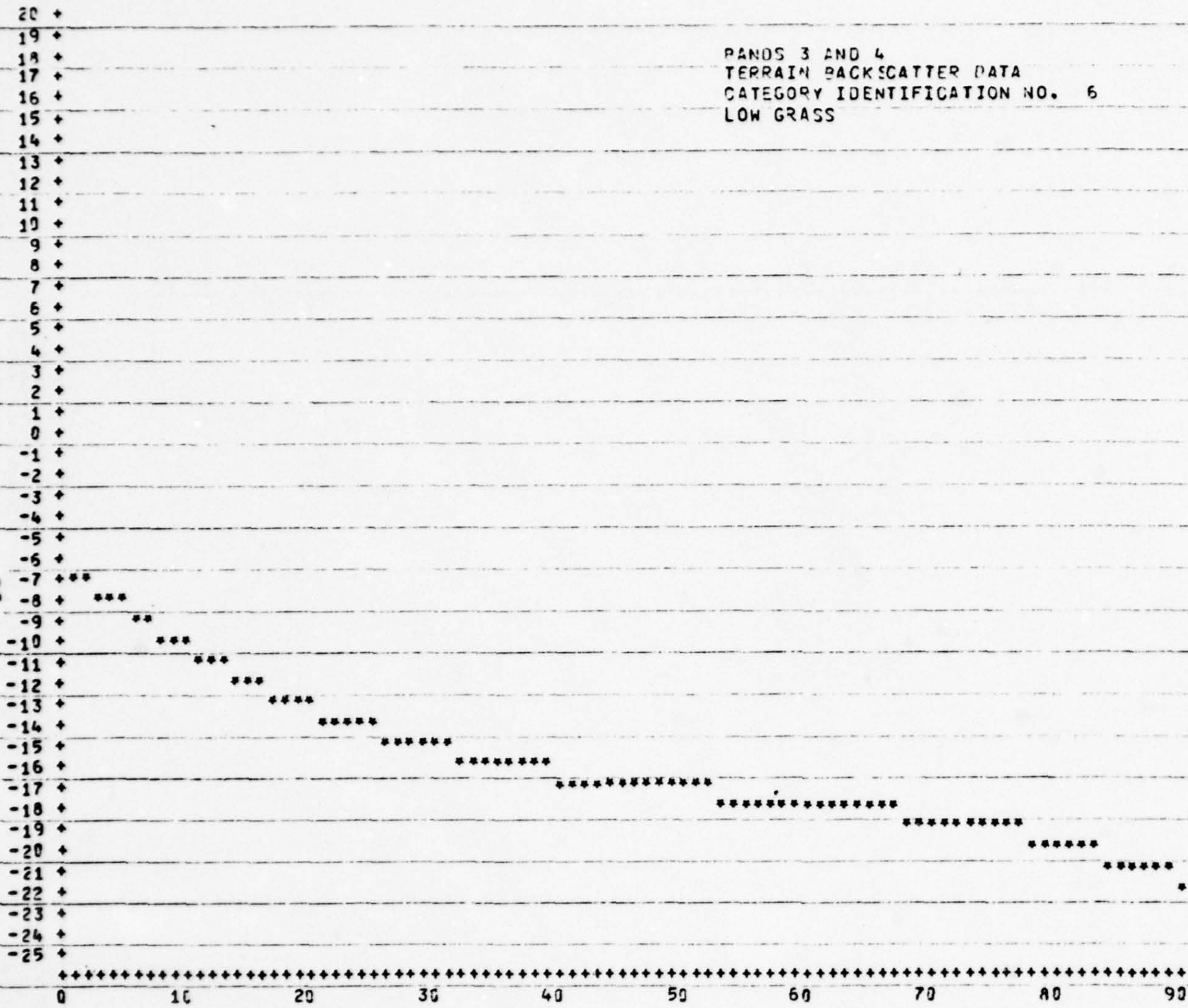
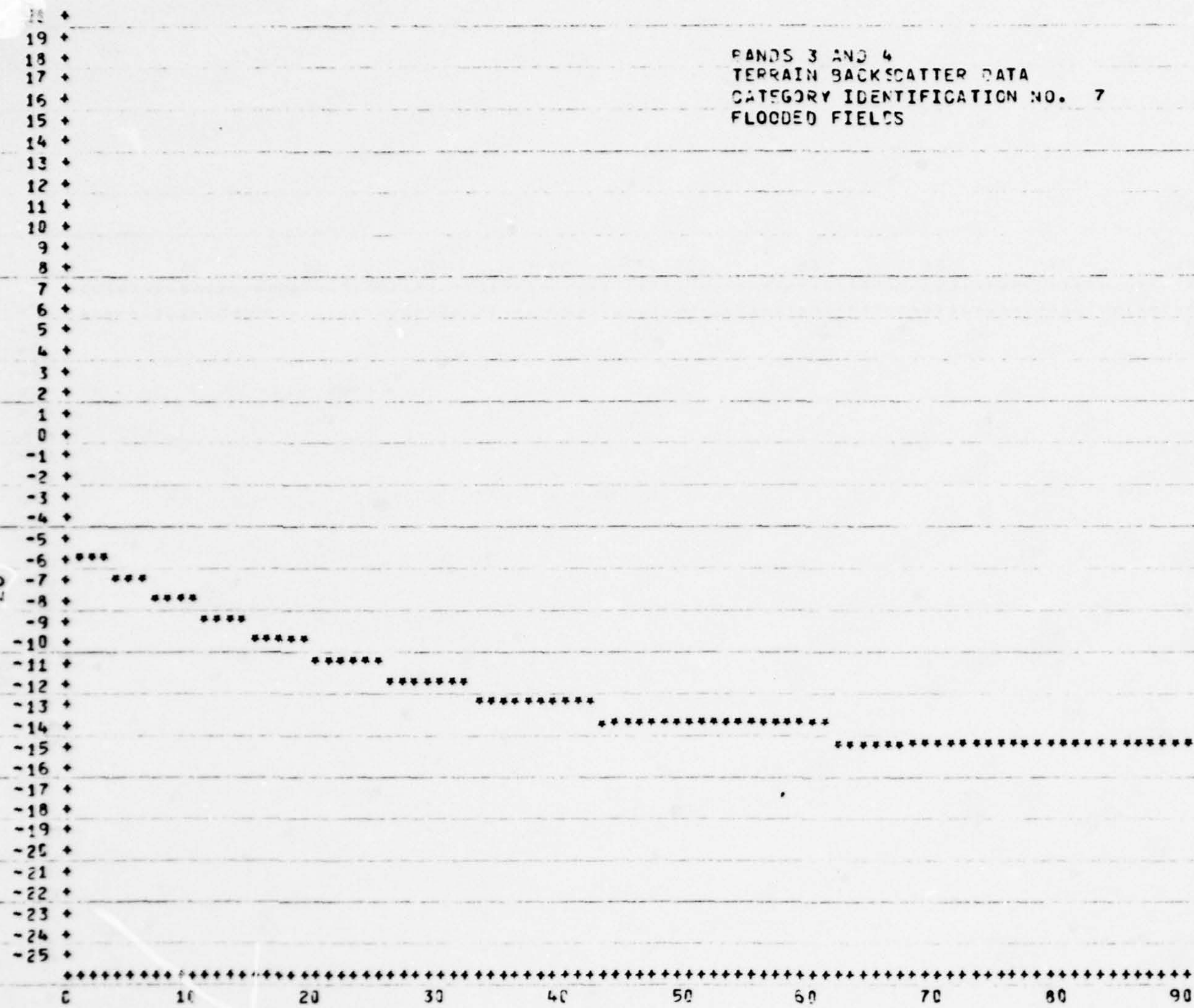
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 5
RIVER



BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 6
LOW GRASS




BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 7
FLOODED FIELDS
19
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17
16
15
14
13
12
11
10
9
8
7
6
5
4
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1
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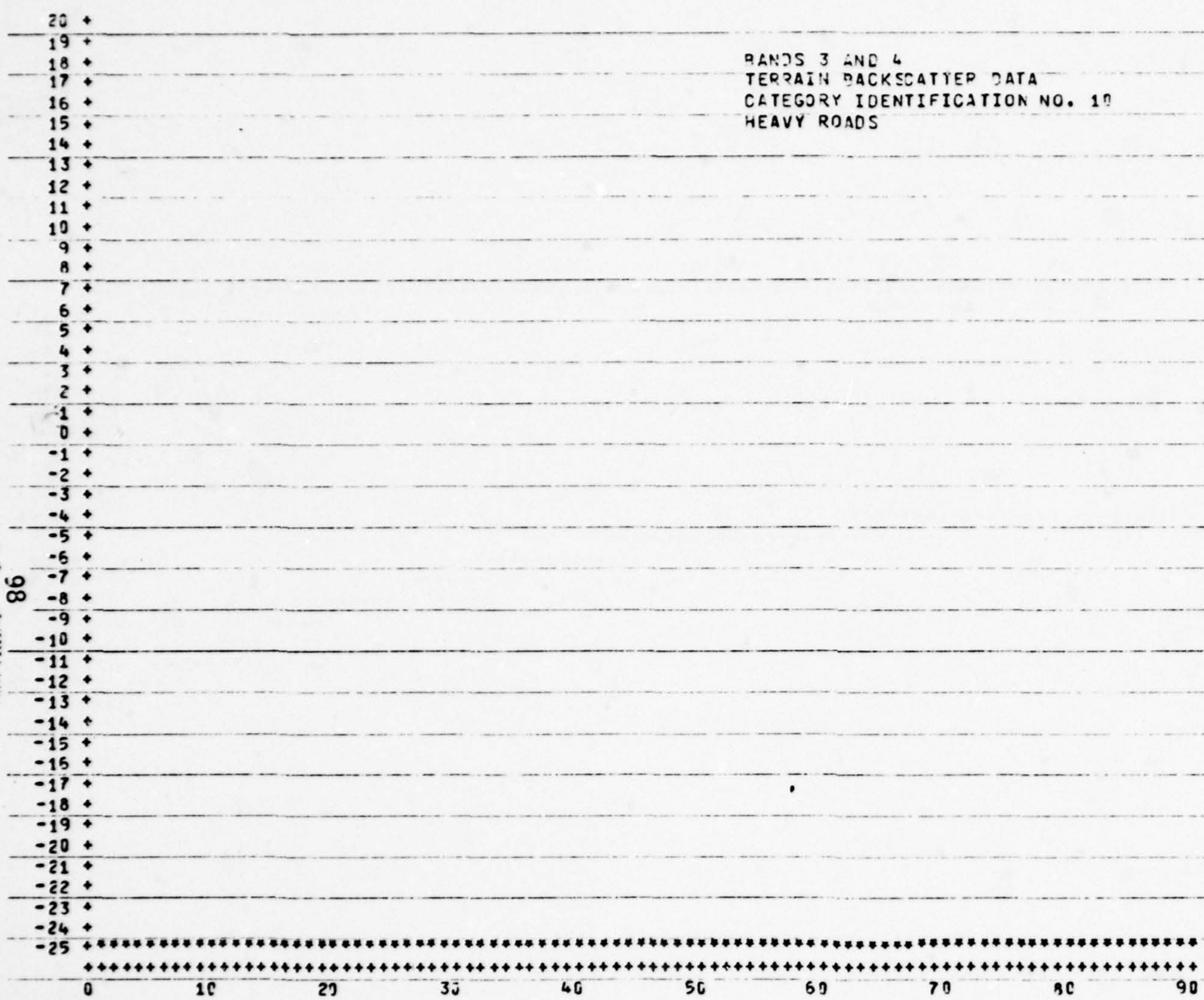
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 10
HEAVY ROADS
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18
17
16
15
14
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12
11
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9
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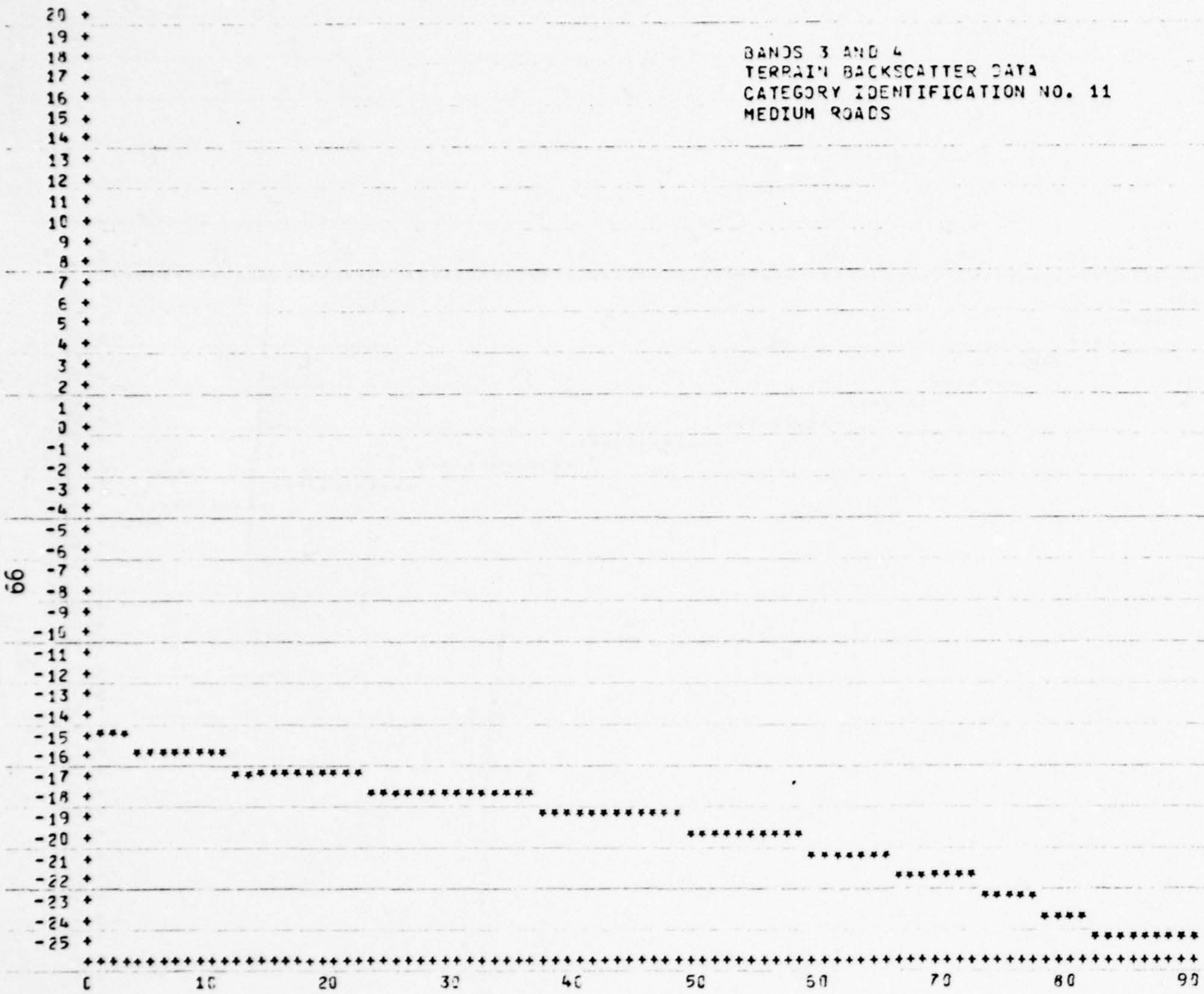
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 11
MEDIUM ROADS
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
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-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
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-15
-16
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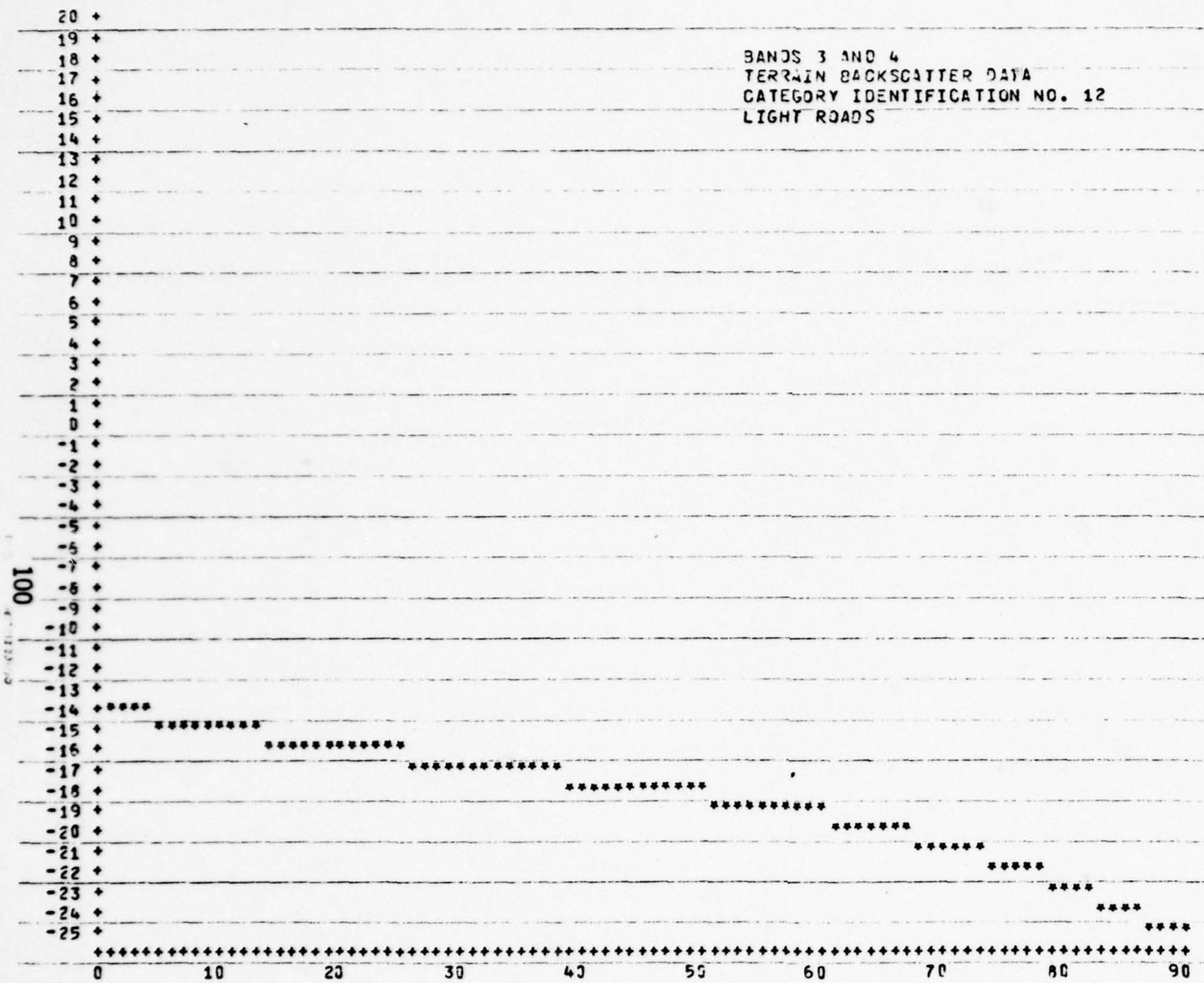
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 12
LIGHT ROADS
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14
13
12
11
10
9
8
7
6
5
4
3
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1
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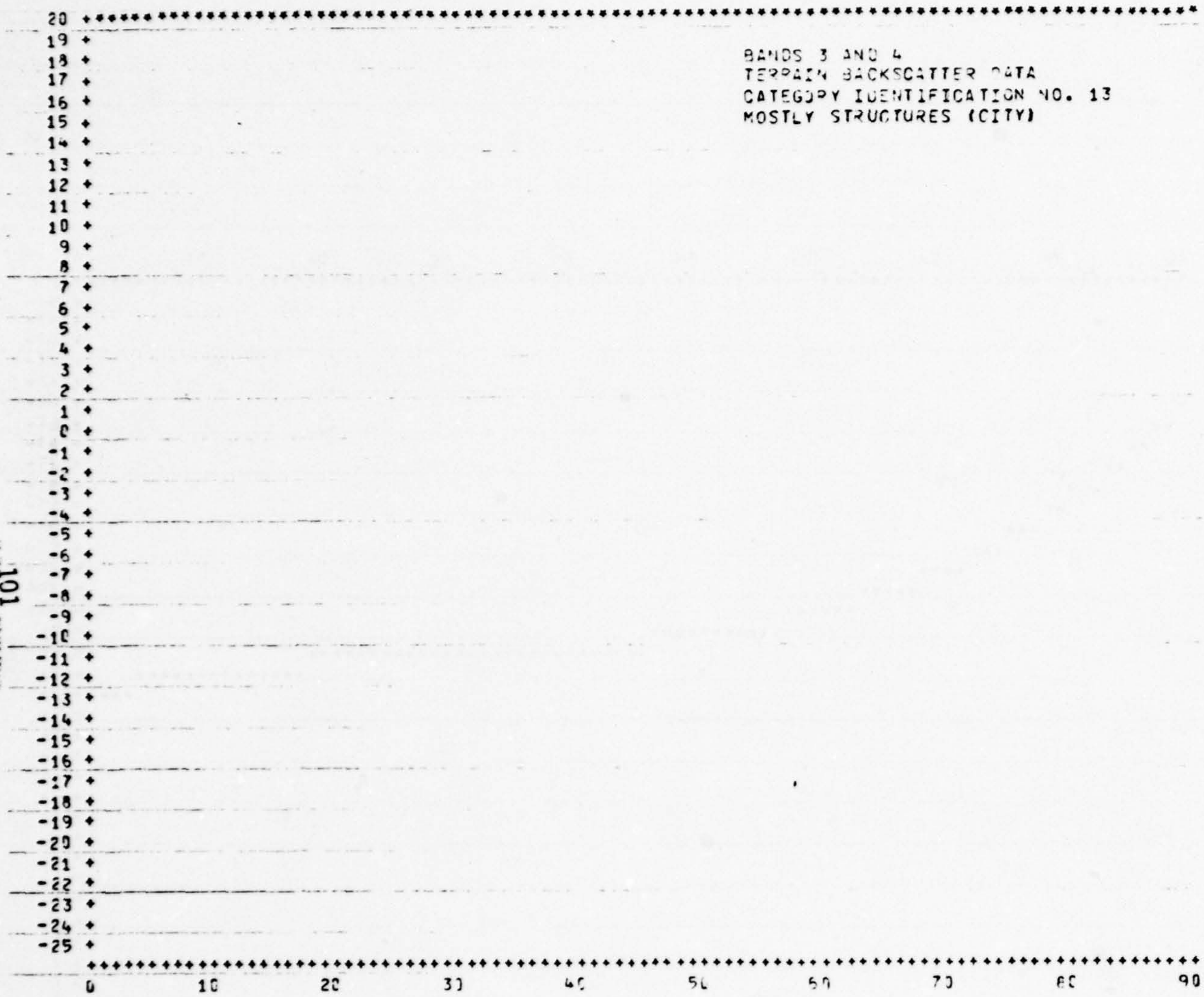
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 13
MOSTLY STRUCTURES (CITY)
20
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15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
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-12
-13
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-15
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-20
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-22
-23
-24
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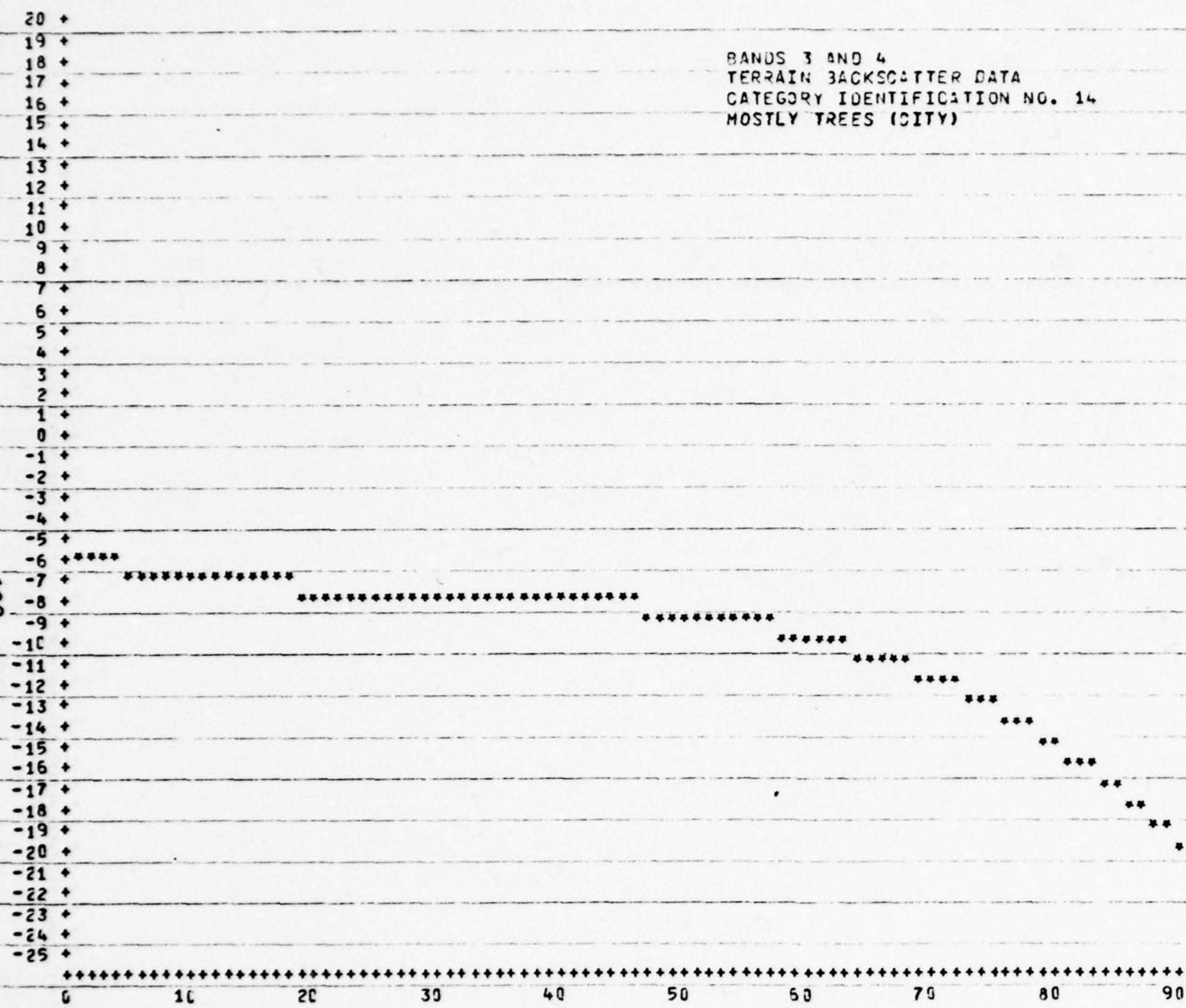
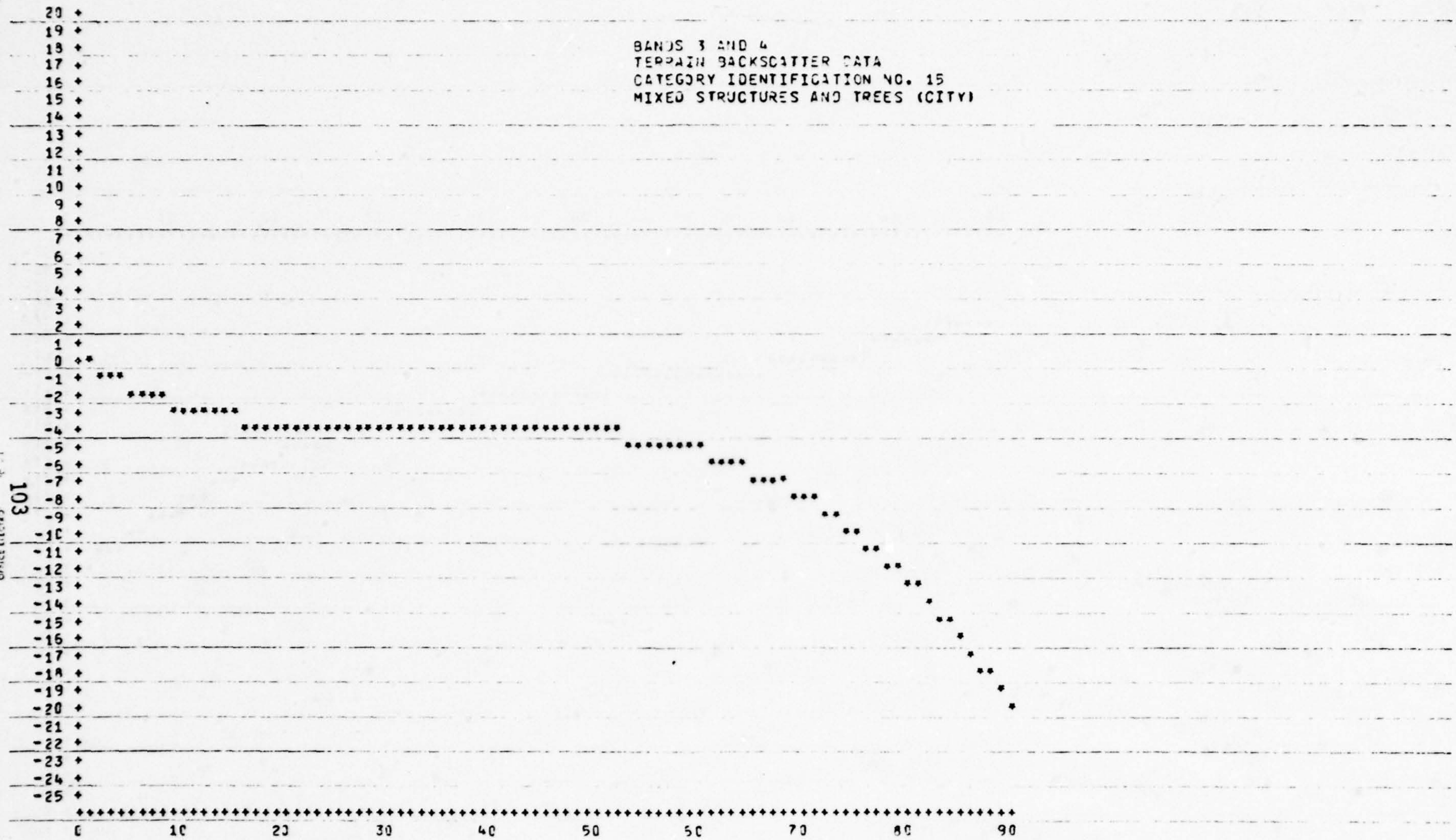
BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 14
MOSTLY TREES (CITY)




BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 15
MIXED STRUCTURES AND TREES (CITY)
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
-15
-16
-17
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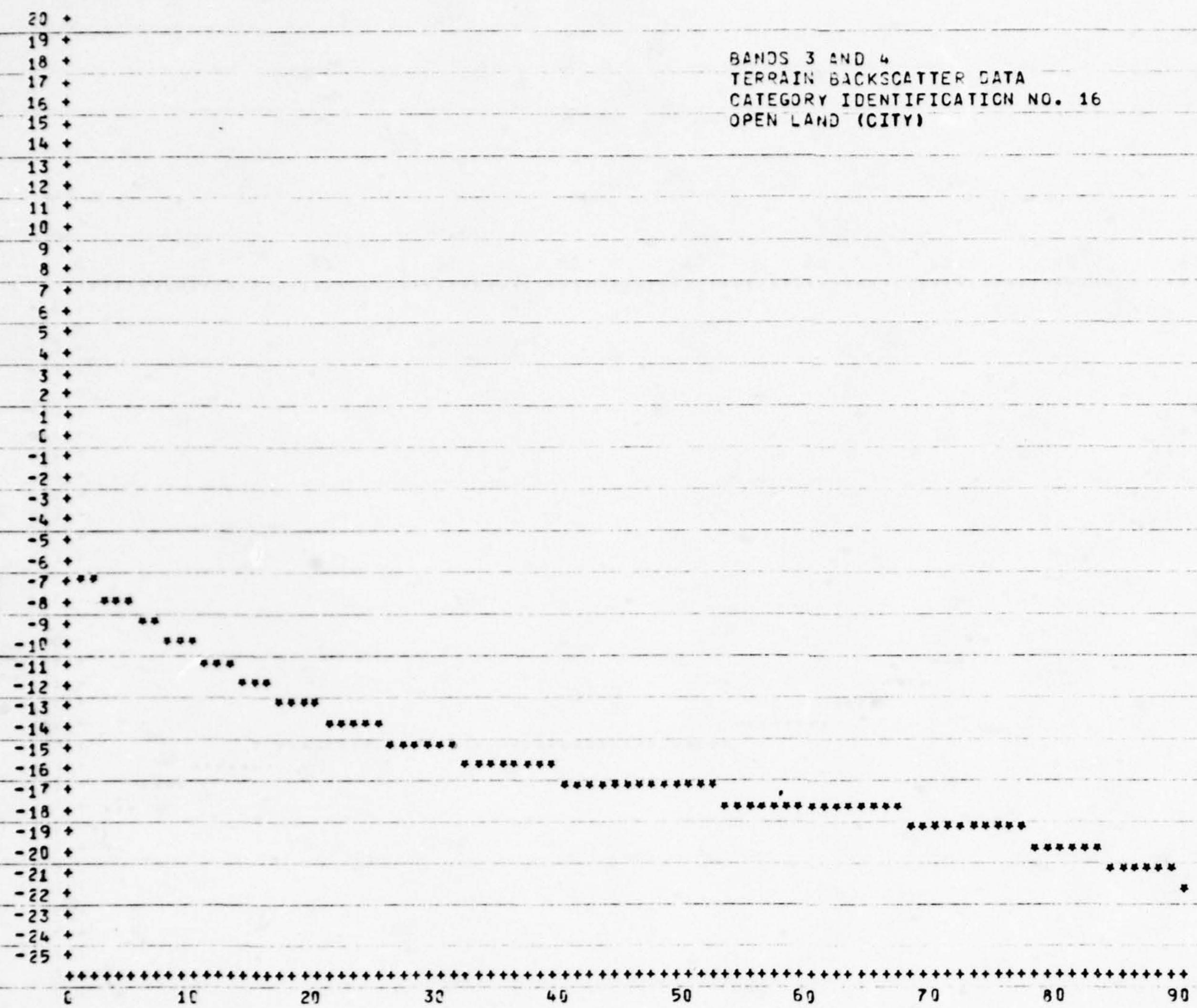

BANDS 3 AND 4
TERRAIN BACKSCATTER DATA
CATEGORY IDENTIFICATION NO. 16
OPEN LAND (CITY)
20
19
18
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16
15
14
13
12
11
10
9
8
7
6
5
4
3
2
1
0
-1
-2
-3
-4
-5
-6
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-8
-9
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-11
-12
-13
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-15
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-17
-18
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-20
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-25
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APPENDIX C

LISTING OF COMPUTER PROGRAMS

I. POLAR CONVERSION
   - A. POLAR CREATE
   - B. POLAR ARRAY
   - C. ARRAY FIX

II. REFERENCE SCENE
   - A. POWER
   - B. GREYTONE

III. RECTANGULAR CONVERSION
   - A. RECTANGULAR CREATE
   - B. RECTANGULAR ARRAY

COMPUTER PROGRAM

I. POLAR CONVERSION

This computer program was written in FORTRAN for implementation on a Honeywell 66/60.

It consists of three subprograms:

A. Polar Create

B. Polar Array

C. Array Fix

```
C                    POLAR CREATE
C
C  THIS PROGRAM ACCEPTS DATA POINTS (RECTANGULAR FORMAT) FOR INPUT
C  AND CREATES THE RESOLUTION CELL SIZE MATRIX IN POLAR COORDINATES
C  TO BE USED AS DATA BASE FOR THE SIMULATION PROGRAM
C
C
         IMPLICIT INTEGER (A-Y)
         REAL ARCOS,FLOAT
         DIMENSION PRIOR(16,16),RECORD(3000),TABLE(1000),OT(4,300)
         DATA HALF,STRT/0,1/
         DATA CNT,NUMB/1,0/
         DATA OCT8,OCT7/0100000000,01007
         DATA NUMCAT,HOLEFIX /16,50/
         DATA MSKCAT /077/
C
         WRITE(6,7)
   7     FORMAT(20X,'PRIORITY MATRIX FOR CATEGORIES')
         WRITE(02)NUMCAT,HOLEFIX,MSKCAT
C
         DO 95 I=1,NUMCAT
         READ(05,5) (PRIOR(I,J),J=1,NUMCAT)
         WRITE(02)(PRIOR(I,J),J=1,NUMCAT)
         WRITE(6,5) (PRIOR(I,J),J=1,NUMCAT)
  95     CONTINUE
   5     FORMAT(16I3)
C
C
C  MIDX = DISTANCE (FEET) FROM LEFT EDGE OF DATA BASE TO TARGET CENTER       R
C  MIDY = DISTANCE (FEET) FROM BOTTOM EDGE OF DATA BASE TO TARGET CENTER     TER
C  RADIUS = RADIUS (IN FEET) OF SIMULATION DESIRED <= MIN(MIDX,MIDY)
C  CELSIZ = SIZE (IN FEET) REPRESENTED BY DATA POINTS - ASSUMED SQUARE
C  NUMPT = NUMBER OF DATA POINTS PER RECORD ON INPUT TAPE
C  NUMREC = NUMBER OF RECORDS ON INPUT TAPE
C        EACH RECORD GOES FROM SOUTH TO NORTH.  RECORDS ON TAPE IN
C        A WEST TO EAST ORDER
C  WIDTH = FIXED SIZE FOR RANGE RESOLUTION
C  ZBMWD = BEAMWIDTH (IN RADIANS)
C
C
C  INPUT FOR PICKWICK 6 MILE RADIUS (7/ /77)
C  31690 31690 29156 20 3169 3169 1 [illegible] .25
C
C  INPUT FOR PICKWICK 52000 FT ALTITUDE (11/ /77)
C  126,280 121,934  58,512  82  2.83  2.82  327 16000 .00875  .25
C
C  ************MODIFICATION***************(10/14/78)
C
C  ONE HAS THE OPTION TO MAKE RANGE RESOLUTION FIXED
C  LET WIDTH = DESIRED RESOLUTION
C  OR TO HAVE RANGE RESOLUTION VARY WITH RANGE
C  LET WIDTH = 0 AND INPUT VALUE FOR PULSEWIDTH
```

```
C  (FACTOR OF E-06 ASSUMED -- SO INPUT PARAMETER WILL LIKELY
C  BE BETWEEN .1 AND 2.)
C
C  INPUT PARAMETERS FOR FICKWICK (10/14/76)
C  31690  31690  26400  20  3169  3169 0  4000  .0175  .25
C
C
      READ(05,10) MIDX,MIDY,RADIUS,CELSIZ,NUMPT,NUMREC,WIDTH,ALT
      READ(05,11) ZBMWD,ZPULS
   10 FORMAT(8I9)
   11 FORMAT(2F10.6)
C
      WRITE(6,21)
   21 FORMAT(//,30X,'INPUT PARAMETERS')
      WRITE(6,22) MIDX,MIDY,RADIUS,CELSIZ,NUMPT,NUMREC,
     &  WIDTH,ALT,ZBMWD,ZPULS
   22 FORMAT(' X,Y DIST TO TARGET CENTER',2I10,//,' SIMULATION'
     & ' RADIUS',I10,//,' DATABASE RESOLUTION ',I8,//,' NUMBER OF'
     & ' POINTS PER RECORD AND # OF RECORDS',2I8,//,' RANGE '
     & ' RESOLUTION AND ALTITUDE ',2I10,//,' BEAMWIDTH AND '
     & ' PULSE WIDTH ',2F12.7)
C
C
C  QUARTER = FLAG TO DO ONLY ONE QUADRANT OF DATA BASE >0 YES
C        <=0 DO FULL 360
C
      READ(05,15) QUARTER
   15 FORMAT(I2)
C
      ALT2 = ALT*ALT
C
C
C  NUMR - MAXIMUM NUMBER OF CELLS IN RANGE DIRECTION IN
C        RESOLUTION CELL MATRIX BEING CONSTRUCTED
C
      IF(MIDX .GT. RADIUS .AND. MIDY .GT. RADIUS) GOTO 80
      WRITE(6,62) RADIUS,MIDX,MIDY
   62 FORMAT('  WARNING - DATA BASE TOO SMALL FOR DESIRED
     &  SCENE, LARGEST CIRCLE POSSIBLE WILL BE SIMULATED',//,
     &  ' INPUT PARAMETERS WERE RADIUS,MIDX,MIDY=',3I8)
C
      IF(MIDX .LT. RADIUS) RADIUS = MIDX
      IF(MIDY .LT. RADIUS) RADIUS = MIDY
C
   80 IF(WIDTH .EQ. 0) GOTO 85
      NUMR = RADIUS/WIDTH
      ZCW = FLOAT(CELSIZ)/FLOAT(WIDTH)
      GOTO 86
   85 ZCTAU = 983.57*ZPULS/2.
      MXSR = SQRT(RADIUS**2 + ALT**2)
      NUMR = FLOAT(MXSR - ALT)/ZCTAU
C
```

```
C  NUMANG - NUMBER OF ANGLE BINS TO BE CREATED IN RESOLUTION
C         CELL MATRIX
C
 86     N90 = 1.57/Z6MWD + 1
        N180 = N90*2 + 1
        NUMANG = N90*4
        IF(NUMANG .GT. 720) GOTO 815
C
C  X AND Y COORDINATES OF CENTER OF DATA BASE
C
        CENTRX = MIDX/CELSIZ
        CENTRY = MIDY/CELSIZ
C
C  RAD - NUMBER OF DATA CELLS FROM CENTER TO EDGE OF
C         SIMULATION AREA
C
        RAD = RADIUS/CELSIZ
        WRITE(6,73) NUMR,NUMANG,CENTRX,CENTRY,RAD
 73     FORMAT(7/' INITIAL PARAMETERS ',5I8//)
        IF(RAD .GT. CENTRX .OR. RAD .GT. CENTRY) GOTO 810
C
C  TABLE = TABLE LOOK UP FOR ANGLE
C          USE 1000 TIMES COSINE OF ANGLE AS INDEX
C          RESULT IS PROPER ANGLE BIN FOR THE POINT
C
        DO 100 I=1,1000
 100    TABLE(I)=ARCOS(FLOAT(I)/1000.)/Z3MWD + 1
C
C  WRITE PARAMETERS TO TAPE FOR DATA TO NEXT STEP
C
        WRITE(02) NUMR,NUMANG,RADIUS,WIDTH,N90,ALT,ZETAU
C
C
C  BEGIN - FIRST LINE OF DATA BASE TO BE USED IN THIS
C         SIMULATION
C  IN CASE ONE WISHES TO SIMULATE ONLY A SEGMENT OF THE
C  ENTIRE DATA BASE SOME LINES OF THE DATA BASE WILL BE
C  UNUSED.  THIS LOOP POSITIONS THE USER AT THE FIRST LINE
C  OF THE INPUT WHICH IS TO BE USED
C
        BEGIN = CENTRX - RAD
        ENDREC = CENTRX + RAD +10
        IF(BEGIN .EQ. 0) GOTO 115
        DO 110 I=1,BEGIN
 110    READ(01)
 115    BEGIN = BEGIN+1
        WRITE(6,67) BEGIN
 67     FORMAT(' BEGIN =',I5//)
C
C
C
        DO 200 I=BEGIN,ENDREC
```

```
      C
      C  READ IN NEW LINE OF INPUT
      C
             READ(01,END=800) (RECORD(N),N=1,NUMPT)
      C
      C  NX - DISTANCE (IN NUMBER OF CELLS) IN X DIRECTION FROM
      C  THE CENTER TO THE CURRENT LINE OF INPUT
      C
             NX = I-CENTRX
             IF( NX .EQ. 0) NX = 1
             IF(NX .GE. 0) HALF = 1
             IF(NX .GE. 0 .AND. OTF .EQ. 0) GOTO 600
        105  IF(QUARTER .GT. 0 .AND. NX .GE. 0) GOTO 500
             IF(NX .GT. CENTRX) GOTO 500
             NX2 = NX * NX
             ZX = ABS(NX)
      C
      C
      C  PLACE EACH POINT OF THE CURRENT INPUT LINE INTO THE
      C  APPROPRIATE CELL OF THE RESOLUTION CELL MATRIX BEING
      C  CREATED
      C  EACH PASS THROUGH THIS LOOP PROCESSES TWO POINTS OF THE
      C  LINE -- THE ONE J CELLS ABOVE THE CENTER LINE
      C  AND THE ONE J CELLS BELOW THE CENTER LINE
      C
             TCAT=0
             BCAT=0
             OLDR=0
             DO 180 JJ=1,RAD+1
             J = JJ-1
      C      IF( QUARTER .GT. 0 .AND. J .GT. IABS(NX)) GOTO 200
             NY2 = J*J
             ZR = SQRT(NX2 +NY2)
      C
      C  R - DISTANCE (IN NUMBER OF CELLS) FROM CENTER POINT TO
      C      THE CURRENT POINT
      C
             IF(WIDTH .EQ. 0) GOTO 113
             R = ZR*ZCW + 1.
             GOTO 313
        113  SR = SQRT(ALT2 + (ZR*CELSIZ)**2) - ALT
             IF(SR .LT. 0) GOTO 180
             R = SR/ZCTAU + 1.
        313  IF(R .GT. NUMR) GOTO 200
             COSANG = ZX/ZR * 1000.
      C
             IF(COSANG .LT. 0) WRITE(6,69) COSANG,I,NX,J,R
             IF(COSANG .GT. 1000) WRITE(6,69) COSANG,I,NX,J,R
         69  FORMAT(//' **ERROR - COS > 1',5I8/)
             IF(COSANG .GT. 10 .AND. COSANG .LT. 990) GOTO 117
             ANG= ARCOS(ZX/ZR)/ZBMWD + 1
             GOTO 118
```

```
C
C ANG - APPROPRIATE ANGLE BIN FOR THE CURRENT POINT
C
 117   ANG = TABLE(COSANG)
C
C  HALF=1  IMPLIES RIGHT HALF OF THE SCENE IS BEING PROCESSED
C  SO THE VARIABLE ANG IS MODIFIED APPROPRIATELY
C
 118   CONTINUE
C
 120   INDEX = CENTRY + J
       IF(OLDR .NE. R .OR. OLDANG .NE. ANG) GOTO 150
       CNT = CNT + 1
       CAT=AND(RECORD(INDEX),MSK(AT)
       IF(CAT .GT. NUMCAT) GOTO 820
       IF(TCAT .EQ. 0 .AND. CAT .GT. 0) TCAT=CAT
       IF(CAT .GT. 0) TCAT=PRIOR(TCAT,CAT)
       TELV = TELV + IRL(RECORD(INDEX),6)
C
       INDEX = CENTRY - J
       CAT=AND(RECORD(INDEX),MSK(AT)
       IF(CAT .GT. NUMCAT) GOTO 820
       IF(BCAT .EQ. 0 .AND. CAT .GT. 0) BCAT=CAT
       IF(CAT .GT. 0) BCAT=PRIOR(BCAT,CAT)
       BELV = BELV + IRL(RECORD(INDEX),6)
       GOTO 180
C
C
 150   IF(OLDR .EQ. 0) GOTO 158
       TELV = TELV/CNT + OCT2 + TCAT
       BELV = BELV/CNT + OCT2 + BCAT
       NUMB=NUMB+1
       OT(1,NUMB)=OLDR
       OT(2,NUMB)=OLDANG
       OT(3,NUMB)=TELV
       OT(4,NUMB)=BELV
       OLDR = R
       OLDANG = ANG
       IF(NUMB .LT. 250) GOTO 157
       WRITE(02) NUMB
       WRITE(02) ((OT(L,M), L=1,4),M=1,NUMB)
       NUMB=0
 157   SUM = SUM+1
 158   TELV = IRL(RECORD(CENTRY +J),6)
       BELV = IRL(RECORD(CENTRY -J),6)
       TCAT = AND(RECORD(CENTRY+J),MSKCAT)
       BCAT = AND(RECORD(CENTRY-J),MSKCAT)
       TOTCNT = TOTCNT + CNT
       CNT = 1
C
       OLDR=R
       OLDANG=ANG
```

```
  130   CONTINUE
  200   CONTINUE
        GOTO 900
C
C
C  ERROR MESSAGES
C
  800   WRITE(6,801) I
  801   FORMAT(//'  UNEXPECTED END OF FILE AT RECORD ',I6)
        GOTO 900
  810   WRITE(6,811) RADIUS,MIDX,MIDY
  811   FORMAT(//,'  ***ERROR   RADIUS EXCEEDS DATA BASE
     1    SIZE - RAD=',I8,'  X=',I3,'  Y=',I8)
        GOTO 900
  815   WRITE(6,816) NUMR,RADIUS,WIDTH
  816   FORMAT(//,' ***ERROR - SIZE EXCEEDS DIMENSIONS OF ARRAY
     1   (MAX=160) RANGE CELLS=',I5,'RADIUS=',I8,' WID',I8)
        GOTO 900
  820   WRITE(6,821)CAT,I,J
  821   FORMAT(//,5H*****,'CAT OUT OF RANGE. CAT,I,J ',3I6)
        GOTO 900
C
C  WRITE OUT DATA BASE MATRIX FOR
C  VERIFICATION
C
  600   OTF = 1
        WRITE(02) NUMB
        WRITE(02) ((OT(L,M), L=1,4),M=1,NUMB)
        ENDFILE(02)
        NUMB = 0
        GOTO 105
  500   CONTINUE
  900   WRITE(02) NUMB
        WRITE(02) ((OT(L,M), L=1,4),M=1,NUMB)
        WRITE(6,901) SUM,TOTCNT
  901   FORMAT(10X,'***DONE***',I8,'  RECORDS WRITTEN',
     &     10X,I8,' POINTS PROCESSED') ,
        STOP
        END
```

```
C                         POLAR ARRAY
C
C  PART TWO OF DATA BASE CREATION
C
          IMPLICIT INTEGER (A-Y)
          DIMENSION A(357,181),PRIOR(16,16),DAT(4,300)
          DIMENSION OT(357),C1(357,31),C2(357,31)
          DATA MSKCAT /077/
          DATA OCT2,SHIFT,CTR/0100,0100000,010000000000/
C
          OTF = 0
C
          READ(01) NUMCAT,HOLEFIX,MSKCAT
          WRITE(02)NUMCAT,HOLEFIX,MSKCAT
          DO 412 I=1,NUMCAT
   412    READ(01)(PRIOR(I,J),J=1,NUMCAT)
          READ(01) NUMR,NUMANG,RADIUS,WIDTH,N90,ALT,ZETAU
          WRITE(02) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZETAU
C
C
C
    5     READ(01,END=500) NUMB
          READ(01) ((DAT(L,M),L=1,4),M=1,NUMB)
C
          DO 200 I=1,NUMB
          R = DAT(1,I)
          ANG = DAT(2,I)
          CAT1=AND(DAT(3,I),MSKCAT)
          ELV1=IRL(DAT(3,I),6)
          CAT2=AND(DAT(4,I),MSKCAT)
          ELV2=IRL(DAT(4,I),6)
          A(R,ANG)=ELV1*SHIFT + ELV2 + CTR + A(R,ANG)
          WORD=ANG/6 + 1
          BIT = MOD(ANG,6)*6
          TAG = FLD(BIT,6,C1(R,WORD))
          IF(CAT1 .EQ. 0) GOTO 150
          IF(TAG .EQ. 0) FLD(BIT,6,C1(R,WORD))=CAT1
          IF(TAG .EQ. 0) GOTO 150
          IF(PRIOR(TAG,CAT1) .EQ. CAT1) FLD(BIT,6,C1(R,WORD))=CAT1
   150    TAG = FLD(BIT,6,C2(R,WORD))
          IF(CAT2 .EQ. 0) GOTO 200
          IF(TAG .EQ. 0) FLD(BIT,6,C2(R,WORD))=CAT2
          IF(TAG .EQ. 0) GOTO 200
          IF(PRIOR(TAG,CAT2) .EQ. CAT2) FLD(BIT,6,C2(R,WORD))=CAT2
   200      CONTINUE
          GOTO 5
C
C
    6     READ(01,END=500) NUMB
          READ(01) ((DAT(L,M),L=1,4),M=1,NUMB)
C
          DO 292 I=1,NUMB
```

```
      R = DAT(1,I)
      ANG = DAT(2,I)
      CAT2=AND(DAT(3,I),MSK(CAT)
      ELV2=IRL(DAT(3,I),6)
      CAT1=AND(DAT(4,I),MSK(CAT)
      ELV1=IRL(DAT(4,I),6)
      A(R,ANG)=ELV1*SHIFT + ELV2 + CTR + A(R,ANG)
      WORD=ANG/6 + 1
      BIT = MOD(ANG,6)*6
      TAG = FLD(BIT,6,C1(R,WORD))
      IF(CAT1 .EQ. 0) GOTO 600
      IF(TAG .EQ. 0) FLD(BIT,6,C1(R,WORD))=CAT1
      IF(TAG .EQ. 0) GOTO 600
      IF(PRIOR(TAG,CAT1) .EQ. CAT1) FLD(BIT,6,C1(R,WORD))=CAT1
  600 TAG = FLD(BIT,6,C2(R,WORD))
      IF(CAT2 .EQ. 0) GOTO 292
      IF(TAG .EQ. 0) FLD(BIT,6,C2(R,WORD))=CAT2
      IF(TAG .EQ. 0) GOTO 292
      IF(PRIOR(TAG,CAT2) .EQ. CAT2) FLD(BIT,6,C2(R,WORD))=CAT2
  292   CONTINUE
      GOTO 6
C
C
  500 CONTINUE
      DO 400 II=1,N90
      I= N90 + 1 - II
      WORD=I/6 + 1
      BIT = MOD(I,6)*6
C
      DO 300 J=1,NUMR
      MULT = FLD(0,6,A(J,I))
      IF(MULT .EQ. 0) GOTO 250
      ELV1 = FLD(6,15,A(J,I))/MULT
      ELV2 = FLD(21,15,A(J,I))/MULT
     GOTO 251
  250   ELV1=0
      ELV2=0
C
  251 OT(J)=ILS(ELV2,6) + FLD(BIT,6,C2(J,WORD))
      A(J,I)=ILS(ELV1,6) + FLD(BIT,6,C1(J,WORD))
  300   CONTINUE
      WRITE(02) (OT(K),K=1,NUMR)
      IF(I .LT.4) WRITE(6,21) (OT(K),K=1,NUMR,3)
   21 FORMAT(17(1X,O6))
  400 CONTINUE
C
      DO 420 I=1,N90
      WRITE(02) (A(J,I),J=1,NUMR)
C
C ************************************
C
C SPECIAL CODE TO ROTATE POLAR DATA BASE TO MAGNETIC NORTH
```

```
C  RECTANGULAR DATA BASE IS ROTATED 30 DEGREES FROM NORTH
C
C ****************************************
C
         IF(OTF .GT. 0 .AND. I .GT. 120) WRITE(03) (A(J,I),J=1,NUMR)
C
         IF(I .LT. 4) WRITE(6,21) (A(J,I),J=1,NUMR,3)
         DO 410 J=1,NUMR
  410     A(J,I)=0
  420     CONTINUE
C
         DO 220 L=1,NUMR
         DO 220 L2=1,31
         C1(L,L2)=0
  220    C2(L,L2)=0
         OTF = 1 + OTF
         CALL FCLOSE(01)
         IF(OTF .LT. 2) GOTO 6
         STOP
         END
```

```
      C
      C  WRITE POLAR DATA BASE
      C
             IMPLICIT INTEGER (A-Y)
             DIMENSION IN(355)
      C
             REWIND (03)
             REWIND (02)
             READ(02) NUMCAT,HOLEFIX,MSKCAT
             READ(02) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU
             WRITE(01) NUMCAT,HOLEFIX,MSKCAT
             WRITE(01) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU
      C
             DO 100 I=1,60
             READ(03) IN
             WRITE(6,12) IN
         12  FORMAT(12(1X07))
             WRITE(01) IN
        100  CONTINUE
      C
             DO 110 I=61,720
             READ(02) IN
             WRITE(01) IN
        110  CONTINUE
      C
             WRITE(6,10)
         10  FORMAT(' WE ARE DONE ')
             STOP
             END
```

```
C                    ARRAY FIX
C
C
C        PURPOSE IS TO PATCH UP HOLES IN THE CENTER
C        OF THE POLAR DATA BASE SO EVERY CELL HAS
C        DATA.  HOLES WERE CAUSED IN CONVERSION FROM
C        CARTESIAN TO POLAR COORDINATES.  HOLES WORKS
C        ON THE FIRST 50 CELLS IN EACH RAY RADIATING
C        FROM CENTER OF DATA BASE.
C
C
         IMPLICIT INTEGER (A-Y)
         REAL FLOAT
         DIMENSION BUF(500),IN(720,50)
         DATA OCT2,INTAP,OT /0100,01,02/
         READ(INTAP) NUMCAT,HOLEFIX,MSKCAT
         READ(INTAP)NUMR,NUMANG,RAD,WIDTH,ALT,ZCTAU
C
C   READ IN BAD DATA 1 RAY AT A TIME.
C   FILL "IN" ARRAY WITH FIRST 50 POINTS OF DATA,
C   ALL THE HOLES WILL BE FOUND IN THESE FIRST 50 PTS.
C   "IN" HAS THE FIRST 50 PTS. FOR ALL 720 RAYS.
C   "BUF"  IS ONLY A BUFFER TO READ IN FROM TAPE.
C
C
         DO 100 I=1,NUMANG
       6 READ(INTAP,END=1000)(BUF(J),J=1,NUMR)
         DO 90   J=1,HOLEFIX
    90   IN(I,J)=BUF(J)
   100   CONTINUE
C
C
C   DUMP OUT POINTS AROUND DAM TO FIND WHY SO MANY
C   HOLES GET FILLED WITH RESERVOIR CAT.
C
C
         DO 23 RAY=1,720
         PRINT,'     POINTS FOR RAY ',RAY
    23   PRINT 231,(IN(RAY,CK),CK=1,10)
   231   FORMAT(5X,10(O6,3X))
C
C
         DO 500 I=1,HOLEFIX
         MELV=0
         MLIN=0
         CNT=0
         DIF=0
         ZLOPE=0
C
         DO 150 J=1,NUMANG
         NXT=J
         IF(IN(J,I) .NE. 0)GOTO 160
```

```
  150 CONTINUE
      WRITE(6,12)I
   12 FORMAT(' NO DATA IN LINE ',I4)
      GOTO 500
  160 LAST=0
      REFELV=IN(NXT,I)/OCT2
C
      DO 400 J=1,NUMANG
      CNT=CNT+1
      IF(IN(J,I) .NE. 0)GOTO 350
      IF(LAST .EQ. 0)GOTO 180
      IF((J-LAST) .LT. (NXT-J))GOTO 200
      IF(NXT .GT. NUMANG)GOTO 200
  180 CAT=FLD(30,6,IN(NXT,I))
      IF(CAT .NE. 17)GOTO 190
      IF(LAST .NE. 0)CAT=FLD(30,6,IN(LAST,I))
  190 FLD(30,6,IN(J,I))=CAT
      ELV=REFELV+ZLOPE*CNT
      FLD(18,12,IN(J,I))=ELV
      IF(J .EQ. 1)GOTO 400
      DIF=IABS(ELV-FLD(18,12,IN(J-1,I)))
      MELV=MAX(MELV,DIF)
      GOTO 400
C
  200 CAT=FLD(30,6,IN(LAST,I))
      IF(CAT .NE. 17)GOTO 210
      IF(NXT .LE. NUMANG)CAT=FLD(30,6,IN(NXT,I))
  210 FLD(30,6,IN(J,I))=CAT
      ELV=REFELV+ZLOPE*CNT
      FLD(18,12,IN(J,I))=ELV
      IF(J .EQ. 1)GOTO 400
      DIF=IABS(ELV-FLD(18,12,IN(J-1,I)))
      MELV=MAX(MELV,DIF)
      GOTO 400
C
  350 LAST=NXT
      CNT=0
      DO 370 K=LAST+1,NUMANG
      NXT=K
      IF(IN(K,I) .NE. 0)GOTO 371
  370 CONTINUE
      NXT=NUMANG+1
      ZLOPE=0
      REFELV=IN(LAST,I)/OCT2
      GOTO 400
  371 REFELV=IN(LAST,I)/OCT2
      NUML=NXT-LAST
      ZLOPE=FLOAT(IN(NXT,I)/OCT2 - IN(LAST,I)/OCT2)/FLOAT(NUML)
      MLIN=MAX(MLIN,NUML)
  400 CONTINUE
C
      WRITE(6,60)I,MLIN,MELV
```

```
   60   FORMAT(' RING',I3,'  MLIN AND MELV ',2I6)
  500   CONTINUE
C
C
C       WRITE PATCHED DATABASE TO TAPE
C
C
        REWIND(INTAP)
        READ(INTAP)
        READ(INTAP)
        WRITE(OT)NUMR,NUMANG,RAD,WIDTH,ALT,ZCTAU,NUMCAT
C
        DO 600 I=1,NUMANG
  666   READ(INTAP,END=1001)(BUF(J),J=1,NUMR)
        DO 550 J=1,HOLEFIX
  550   BUF(J)=IN(I,J)
        WRITE(OT)(BUF(J),J=1,NUMR)
        IF(MOD(I,3) .EQ. 1)WRITE(6,70)(BUF(J),J=1,100)
   70   FORMAT(/1G(1X,O6))
  600   CONTINUE
        GOTO 900
 1000   CALL FCLOSE(INTAP)
        GOTO 6
 1001   CALL FCLOSE(INTAP)
        GOTO 656
  900   STOP
        END
```

COMPUTER PROGRAM

II. REFERENCE SCENE

This computer program was written in FORTRAN for implementation on a Honeywell 66/60.

It consists of two subprograms:

A. Power

B. Greytone

```
C                         POWER
C
C   PROGRAM ACCEPTS DATA MATRIX IN POLAR COORDINATES FROM
C   FILECODE 01 (CREATED BY ARRAY FIX) AND PRODUCES A
C   SIMULATION
C
C
          IMPLICIT INTEGER (A-Y)
          REAL FLOAT,SIN,COS,ARCOS,RMS
          LOGICAL TAG
          COMMON /RANDOM/ ISEED
          COMMON ZTAB(1000),ZCF(16,4),ZS(16),LEN(400),TAG
          COMMON /IO/ BASE(400,3),CAT(400,3)
          COMMON /OT/ GT(400),ZGT(400,3),ZDT(400),ZSTRT(400,2)
          COMMON /PARAM/ NUMR,NUMANG,RADIUS,WIDTH,ZALT,ZCTAU,KLAPP,NUMCAT
C
          DATA L1,L2,L3,GTREF/1,2,3,34/
          DATA OCT2/0100/
C
          ISEED = 1231236907
          KLAPP = 0
C
C
          READ(01) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU,NUMCAT
   10     FORMAT(4I8)
          READ(05,10) ALT
C
          ZALT=FLOAT(ALT)
C
          WRITE(6,11)
   11     FORMAT(//,30X,'THIRD ORDER COEFFICIENTS FOR SIGMA O')
C
          DO 100 I=1,NUMCAT
          READ(05,15) (ZCF(I,J),J=1,4)
          WRITE(6,15) (ZCF(I,J),J=1,4)
  100     CONTINUE
   15     FORMAT(4E14.7)
C
          READ(05,2) ZS
    2     FORMAT(10(F6.2))
C   LENGTH OF RESOLUTION CELL IN AZIMUTH INCREASES WITH RANGE
C   THE ARRAY - LEN - CONTAINS THE RESOLUTION CELL LENGTH
C   (TIMES 2) AT EACH RANGE BIN.  USED TO CALCULATE LOCAL
C   ACROSS TRACK SLOPE
C
          R = -WIDTH/2
          DO 105 I=1,NUMR
          R = R + WIDTH
  105     LEN(I)= 3.1416*4. *R/FLOAT(NUMANG) + 1
C
C   WID2 = 2 TIMES WIDTH OF RESOLUTION CELL IN TRACK DIRECTION
C        (A CONSTANT VALUE FOR THIS SIMULATION)
```

```
C
      WID2 = WIDTH + WIDTH
C
      ZCOS35 = COS(35/57.295)
      ZSIN35 = SIN(35./57.295)
      GD35 = ALT*ZSIN35/ZCOS35
      CEL35 = GD35/WIDTH
C
C
C  TRANSFER PARAMETERS TO TAPE FOR OUTPUT ROUTINE
C
      WRITE(02) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU
      WRITE(6,707) NUMR,NUMANG,RADIUS,WIDTH,ALT
  707 FORMAT(' NUMR,NUMANG,RADIUS,WIDTH,ALT=',5I8)
C
C
      DO 110 I=1,1000
  110 ZTAB(I)= ARCOS(FLOAT(I)/1000.)
C
      CALL NEXT(2,IEV)
      IF(IEV .GT. 0) GOTO 800
      DO 120 I=1,NUMR
      BASE(I,1)=BASE(I,2)
  120 CAT(I,1)=CAT(I,2)
C
      DO 300 ANG = 1,NUMANG
      TAG=.FALSE.
      IF(MOD(ANG,30) .EQ. 0) TAG=.TRUE.
      IF (TAG) WRITE(6,23)ANG
   23 FORMAT(1H1,4HANG=,I3,/,4HALOC,7X,3HCAT,4X,5HSIGMAO,10X,5HPOWER,
     1   5X,10HFADE POWER,4H  GT)
      IF(ANG .LT. NUMANG) GOTO 160
      DO 205 I=1,NUMR
      BASE(I,L3)=BASE(I,L2)
  205 CAT(I,L3)=CAT(I,L2)
      GOTO 161
C
  160 CALL NEXT(L3,IEV)
      IF(IEV .GT. 0) GOTO 800
   40 FORMAT(1X,30I4)
  161 CONTINUE
C
      ZM = FLOAT(BASE(CEL35,L2)-ALT)/FLOAT(GD35)
C
      DO 270 ROW=1,NUMR
      ROW1 = ROW -1
      IF(ROW1 .LE. 0) ROW1 = 1
      ROW2 = ROW + 1
      IF(ROW2 .GT. NUMR) ROW2 = NUMR
C
      ZDELT = FLOAT(BASE(ROW2,L2)-BASE(ROW1,L2))/FLOAT(WID2)
      ZY = ABS(BASE(ROW,L3)-BASE(ROW,L1))
```

```
      ZHYP = SQRT(ZY*ZY + LEN(ROW)**2)
      ZRHO = ZY/FLOAT(LEN(ROW))
      ZCOSRHO = FLOAT(LEN(ROW))/ZHYP
C
      NALT = ALT - BASE(ROW,L2)
      IF(ROW .GT. CEL35) GOTO 230
      ZSINTH = ZSIN35
      ZCOSTH = ZCOS35
      GOTO 250
C
 230  ZGDIS = ROW*WIDTH
      Y = ZM*ZGDIS + ALT
      IF( Y .GT. BASE(ROW,L2)) GOTO 270
      ZM = FLOAT(BASE(ROW,L2)-ALT)/ZGDIS
      ZSR = SQRT(ZGDIS**2 + NALT**2)
      ZSINTH = ZGDIS/ZSR
      ZCOSTH = FLOAT(NALT)/ZSR
C
 250  CONTINUE
      IF(ZCF(CAT(ROW,L2),1) .LT.100.) GOTO 251
      ZOT(ROW)=10.
      GOTO 270
 251  CALL RTPWR(ZRHO,ZCOSRHO,ZDELT,NALT,CAT(ROW,L2),ZCOSTH,
     1  ZSINTH,ZPWR)
      ZOT(ROW)= ZOT(ROW)+ZPWR
 270  CONTINUE
C
      WRITE(02) (ZOT(J),J=1,NUMR)
C
      T = L1
      L1=L2
      L2=L3
      L3=T
C
C  OUTPUT LINE OF GREYTONE IMAGE (STILL IN POLAR FORMAT) TO
C  TEMP FILE
C
      DO 290 K=1,NUMR
      ZGT(K,L3)=0
 290  ZOT(K)=0
 300  CONTINUE
      STOP
 800  WRITE(6,801) ANS
 801  FORMAT(' RAN OUT OF DATA AT RECORD ',I5)
      STOP
      END
```

```
      SUBROUTINE RTPWR(RHO,COSRHO,DELT,NALT,ICAT,COSTH,SINTH,PWR)
C
      LOGICAL TAG
      REAL RMS
      COMMON /RANDOM/ ISEED
      COMMON /PARAM/ NUMR,NUMANG,RADIUS,WIDTH,ZALT,ZCTAU,KLAPP,NUMCAT
      COMMON TABLE(1000),CF(16,4),S(16),LEN(400),TAG
      DATA FUDGE /-1.9193/
C
      ITRACE = 1
C
      DATA SIGREF/-.8/
      BASEALT = ZALT
      IF(ICAT .GT. 1) GOTO 505
      PWR = 0
      RETURN
C
C  CALCULATE LOCAL ANGLE OF INCIDENCE
C
 505  ACOS = (COSTH + SINTH*DELT)/SQRT(1.+DELT**2+RHO**2)
      IF(ACOS .LT. 0.) GOTO 800
      NLOC = ACOS*1000.
      ALOC = TABLE(NLOC)*57.295
C
      IF(NLOC .LT. 6 .OR. NLOC .GT. 995) ALOC = ARCOS(ACOS)*57.295
C
C  CALCULATE SIGMA ZERO FOR GIVEN CATAGORY AT THE LOCAL ANGLE
C  OF INCIDENCE JUST CALCULATED
C
      SIGO = ALOC*(ALOC*(ALOC*CF(ICAT,1)+CF(ICAT,2))+CF(ICAT,3))
     &       +CF(ICAT,4)
      IF(KLAPP .EQ. 1)SIGO = S(ICAT) + 10*ALOG10(ACOS) - FUDGE
      SIGO = SIGO/10. - SIGREF
C
C  THDELT = SINE OF ANGLE THETA-DELT
C  WHICH IS NEEDED FOR THE POWER FORMULA
C
      IF(DELT .LT. .05) GOTO 160
      THDELT = ABS((SINTH-COSTH*DELT)/SQRT(1.+DELT**2))
      GOTO 161
 160  THDELT = SINTH
 161  IF(THDELT .LT. .001) GOTO 810
C
C
      ALT = (BASEALT)/NALT
C
C  POWER EQUATION
C
      PWR = (10**SIGO)*(ALT**3)/(2*COSTH*COSRHO*THDELT)
      GOTO 900
C
C
```

```
 800   IF(ITRACE .GT. 3) WRITE(6,801) COSTH,DELT,ACOS
 801   FORMAT(' DELTA IS > THETA ',3F10.4)
       PWR = 0
       GOTO 900
 810   IF(ITRACE .GT. 3) WRITE(6,811) SINTH,COSTH,DELT,RHO,THDELT
 811   FORMAT(' DELTA = THETA',5F12.4)
       PWR = 10.
 900   IF (PWR .LT. .001) PWR=.001
       GT=ALOG10(PWR)*32.+34.
       IF(TAG) WRITE(6,23)IFIX(ALOC),ICAT,SIGO,PWR1,PWR,IFIX(GT)
*****W   412 PWR1 IS NOT DEFINED
  23   FORMAT(I4,I10,F10.2,2E15.4,I4)
       RETURN
       END
```

```
C                 GRAYTONE
C
C*****************************************************************
:
C
C
C      PARAMETERS TO BE ADJUSTED TO RUN THIS PROGRAM
C          1.)  M,N    THE # OF CELLS TO AVERAGE
C          2.)  RES    DETERMINES THE SIZE OF THE IMAGE
C          3.)  NFILE WHICH DETERMINES WHICH RECORD
C                      TO WRITE TO ON THE OUTPUT TAPE
C          4.)  DICO FLAG,  WHICH DETERMINES OUTTAP FORMAT
C                      (DICO=1 FOR DICO FORMAT,0 FOR IDECS).
C
C************************************************************
C
:      A CHANGE OF RESOLUTION CHANGES DIMENSIONS
C      OF ARRAYS RECORD AND OT
C      RECORD(RES) , OT(WORD)  WORD = RES/6 + 1
C
C      MOST OTHER DIMENSIONS DEPEND ON NUMR WHICH IN TURN
C      DEPENDS ON THE RADIUS
C      NUMR = RADIUS/WIDTH
C      ZIN(NUMR),ZPWR(NUMR,12),ZUM(NUMR),IOT(NUMR)
C      ZAVE(NUMR,12),BASE(NUMR,121),IN(NUMR)
C
C      A CHANGE IN DIMENSIONS SHOULD BE ACCOMPANIED
C      BY A CHANGE IN THE LIMITS CARDS
C
C*******************************************************
C
C      IF IDECS OUTPUT IS DESIRED,CHECK THE FOLLOWING
C      DICO=0 IN DATA STATEMENT
C      FFILE ON OUT TAPE INCLUDES ONLY A BUFSIZ SO THAT
C      EACH LOGICAL RECORD IS A SCANLINE. (BUFSIZ=RES+20)
C      PUT A DENS ON OUTPUT TAPE7 CARD
C
C      IF DICO OUTPUT IS DESIRED,CHECK THE FOLLOWING
C      DICO=1 IN DATA STATEMENT
C      FFILE IS PUT IN SPECIFYING NSTDLB,NOSRLS,ETC.
C$      FFILE   02,NSTDLB,NOSRLS,FIXLNG/154,BUFSIZ/154
C      WORD = RES/6 + 1
C      REMOVE DENS FROM OUTPUT TAPE7 CARD
C
C*******************************************************
:
C
C
       IMPLICIT INTEGER (A-Y)
       REAL ALOG10,FLOAT
       COMMON ZIN(360),ZPWR(360,12)
       DIMENSION L(12),ZUM(360),IOT(360),ZAVE(360,12)
```

```
C
      DATA L/1,2,3,4,5,6,7,8,9,10,11,12/
      DATA M,N,NFILE,DICO,RES /1,1,1,1,921/
      DATA GTREF /34/
C
C
      READ(02) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU
      WRITE(6,607) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAJ
  507 FORMAT(' NUMR,NUMANG,RADIUS,WIDTH',4I8,/,
     $     ' ALTITUDE AND PULSE LENGTH ARE ',I5,F10.5)
      WRITE(04)NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAU
      WRITE(04)NFILE,DICO,RES
      WRITE(01) NUMR,NUMANG,RADIUS,WIDTH,ALT,ZCTAJ
C
      DO 100 I=2,12
      DO1 = I
      CALL GETLINE(DO1,N,NUMR,IFV)
      DO 90 J=1,NUMR
   90 ZAVE(J,I-1)=ZPWR(J,I)
  100 CONTINUE
C
      STRT=7 - (M-1)/2
      END = STRT+M-1
C
      DO 150 I=1,NUMR
      ZUM(I)=0.
      DO 140 J=STRT,END
  140 ZUM(I)= ZUM(I)+ZPWR(I,J)
  150 CONTINUE
C
      OLD = STRT-1
      NEW = END
      KOMPLT = 0
C
C
C
    5 PTS = M*(N-1)/2
C
      DO 200 I=1,NUMR
      IF(I .LE. (N+1)/2) PTS = PTS+M
      IF( I .GE. NUMR-N/2) PTS = PTS-M
      IF( PTS .EQ. 0 )PTS=1
C
      ZOT = ZUM(I)/PTS
      IF(ZOT .LT. .001) ZOT=.001
      IOT(I)= ALOG10(ZOT)*32. + GTREF
      IF(IOT(I) .GT. 63) IOT(I)=63
      IF(IOT(I) .LT. 0) IOT(I)=0
  200 CONTINUE
C
      WRITE(01) (IOT(J),J=1,NUMR)
C
```

```
      C
            KOMPLT = KOMPLT+1
            IF(KOMPLT .EQ. NUMANG) GOTO 950
      C
            T = L(1)
            DO 300 I=1,11
  300       L(I)=L(I+1)
            L(12)=T
      C
            IF(KOMPLT .GT. (NUMANG-11)) GOTO 400
            CALL GETLINE(L(12),N,NUMR,IEV)
            IF(IEV .GT. 1) GOTO 900
            GOTO 500
      :
  400       CNT=CNT+1
            DO 410 I=1,NUMR
  410       ZPWR(I,L(12))=ZAVE(I,CNT)
      :
  500       LOLD = L(OLD)
            LNEW=L(NEW)
            DO 510 I=1,NUMR
  510       ZUM(I)= ZUM(I)+ZPWR(I,LNEW)-ZPWR(I,LOLD)
            GOTO 5
      :
  900       WRITE(6,901) IEV,KOMPLT
  901       FORMAT(' ABNORMAL TERMINATION, IEV=',I5,' KOMPLT=',I5)
            STOP
  950       WRITE(6,951)
  951       FORMAT(' *** WE ARE DONE ***')
            STOP
            END
```

```
          SUBROUTINE GETLINE(LINE,NAVG,NUMR,IEV)
          IMPLICIT INTEGER (A-Y)
          COMMON ZIN(360),ZPWR(360,12)
    :
          READ(02,END=900) (ZIN(J),J=1,NUMR)
    C
          ZUM=0.
          IPTR = 1
          OPTR = 1
    :
    100   ZUM = ZIN(IPTR) + ZUM
          IPTR = IPTR+1
          IF(IPTR .LE. (NAVG+1)/2) GOTO 100
    :
          ZPWR(OPTR,LINE)=ZUM
          OPTR = OPTR+1
    C
    120   ZUM = ZUM + ZIN(IPTR)
          ZPWR(OPTR,LINE)= ZUM
          OPTR = OPTR+1
          IPTR = IPTR+1
          IF(IPTR .LE. NAVG) GOTO 120
    :
    C
          BOT = 1
    150   ZUM = ZUM +ZIN(IPTR)-ZIN(BOT)
          ZPWR(OPTR,LINE)=ZUM
          OPTR=OPTR+1
          IPTR=IPTR+1
          BOT = BOT+1
          IF(IPTR .LE. NUMR) GOTO 150
    :
    200   ZUM = ZUM - ZIN(BOT)
          ZPWR(OPTR,LINE)=ZUM
          OPTR = OPTR+1
          BOT = BOT+1
          IF(OPTR .LE. NUMR) GOTO 200
    :
          RETURN
    :
    900   WRITE(6,801)
    801   FORMAT(' UNEXPECTED END OF DATA')
          IEV=1
          RETURN
          END
```

COMPUTER PROGRAM

III. RECTANGULAR CONVERSION

This computer program was written in FORTRAN for implementation on a Honeywell 66/60.

It consists of two subprograms:

A. Rectangular Create

B. Rectangular Array

```
C                          RECTANGULAR CREATE
C
           IMPLICIT INTEGER (A-Y)
           REAL FLOAT,ARCOS
           DIMENSION BUF(600),TABLE(1000)
           DATA ZBMWD/.00875/
C
           REWIND(04)
           READ(04) MAXDIS,MAXANG,RADIUS,WIDTH
           READ(04) NFILE,DICO,RES
           WRITE(03)RES,DICO,NFILE
C
C
           WRITE(6,9) MAXDIS,MAXANG,RADIUS,WIDTH
      9    FORMAT(' INPUT PARAMETERS - MAXDIS,MAXANG,RADIUS,WIDTH=',5I8)
           IF(WIDTH .EQ. 0) WIDTH = RADIUS/MAXDIS
C
           DO 100 I=1,1000
    100    TABLE(I)= ARCOS(FLOAT(I)/1000.)/ZBMWD
C
C
C
           HFRES = RES/2
           IF(2*HFRES .LT. RES) HFRES = HFRES +1
           ZSIZE = FLOAT(2*RADIUS)/FLOAT(RES) - .001
C
    555    CONTINUE
C
           DO 600 I=1,RES
           NX = I*ZSIZE - RADIUS
           IF(NX .EQ. 0) NX = ZSIZE/2
           ZX = ABS(NX)
           NX2 = NX * NX
           IF(NX.LT. 0 .OR. OTF .GT. 0) GOTO 200
           OTF = 1
           NEG = -1
           WRITE(03) NEG
C
    200    DO 575 J=1,RES/2
           NY = J*ZSIZE -ZSIZE/2
           NY2 = NY * NY
           RDIS = SQRT(NX2+NY2)
           R = RDIS/WIDTH
           IF( R. GT. MAXDIS) GOTO 580
           COSANG = ZX/FLOAT(RDIS) * 1000.
           ANG = TABLE(COSANG)
           IF(COSANG .LT. 6 .OR. COSANG .GT. 994)
         & ANG = ARCOS(ZX/FLOAT(RDIS))/ZBMWD
           IF(ANG .EQ. 0) ANG = 1
C
C
           IF(R .EQ. OLDR .AND. ANG .EQ. OLDANG) GOTO 575
```

```
      CNT = CNT+1
      IF(CNT .GT. 1) GOTO 585
      OLDR = R
      OLDANG = ANG
585   IF(CNT .GT. 600) GOTO 800
      FLD(0,10,BUF(CNT))=J-1
      FLD(10,10,BUF(CNT))=OLDR
      FLD(20,10,BUF(CNT))=OLDANG
      OLDR = R
      OLDANG = ANG
575   CONTINUE
580   CNT = CNT + 1
      FLD(0,10,BUF(CNT))=J-1
      FLD(10,10,BUF(CNT))=OLDR
      FLD(20,10,BUF(CNT))=OLDANG
      OLDR = R
      OLDANG = ANG
      WRITE(03) CNT
      WRITE(03) (BUF(I9),I9=1,CNT)
      TOT = TOT + CNT
      MOST = MAX(MOST,CNT)
      CNT = 0
500   CONTINUE
      GOTO 950
800   WRITE(6,805) I
805   FORMAT(' BUFFER OVERFLOW AT LINE',I5)
C
C
950   WRITE(6,951) TOT,MOST
951   FORMAT(' WE ARE DONE ',2I8)
      STOP
      END
```

```
      SUBROUTINE NEXT(LINE,IEV)
      IMPLICIT INTEGER (A-Y)
      REAL RMS
C
      COMMON /RANDOM/ ISEED
      COMMON /PARAM/ NUMR,NUMANG,RADIUS,WIDTH,ZALT,ZCTAU,KLAPP,NUMCAT
      COMMON /IO/ BASE(400,3),CAT(400,3)
      DATA MASK,TREES / 077,2/
C
      READ(01,END=900) (BASE(I,LINE),I=1,NUMR)
C
      DO 100 I=1,NUMR
      CAT(I,LINE) = AND(BASE(I,LINE),MASK)
      BASE(I,LINE) = IRL(BASE(I,LINE),6)
C
C  SPECIAL ELEVEATION ADJUSTMENT FOR TREE CATAGORY
C
      IF(CAT(I,LINE) .NE. TREES) GOTO 100
      BASE(I,LINE) = BASE(I,LINE) + 70 + RMS(ISEED)*10
  100 CONTINUE
C
      RETURN
  900  IEV = 1
      RETURN
      END
```

```
C                   RECTANGULAR ARRAY
C
          IMPLICIT INTEGER (A-Y)
          DIMENSION BASE(360,121),BUF(600),RECORD(921),OT(154)
          DIMENSION IN(360)
C
C         IF DICO OUTPUT IS DESIRED SET DICO=1
C         OTHERWISE IDECS OUTPUT FORMAT
C
C
C
          REWIND(01)
          REWIND(03)
C
          READ(01) NUMR,NUMANG,RADIUS,WIDTH
          READ(03)RES,DICO,NFILE
C
          WRITE(6,141)RES,DICO,NFILE
    141   FORMAT('  RES,DICO,NFILE = ',3I8//)
C
C         POSITION OUTPUT TAPE TO PROPER FILE WITH POST.
C         FILE IS CHOSEN BY SETTING 'NFILE' IN DATA STATEMENT.
C
          IF(NFILE .NE. 1)CALL POST(02,0,NFILE,1,ERR)
          IF(ERR .NE. 0)WRITE(5,223)ERR
    223   FORMAT(' TROUBLE WITH POST ',I5)
          IF (ERR .NE. 0) STOP
C
          HFRES = RES/2
C
          N180 = NUMANG/2
          N90 = NUMANG/4
C
          DO 110 I=1,NUMANG
          READ(01) (IN(J),J=1,NUMR)
          ANG = MOD((I+545),NUMANG)+1
          WORD= (ANG-1)/6 + 1
          BIT = MOD((ANG-1),6)*6
C
          DO 105 J=1,NUMR
    105   FLD(BIT,6,BASE(J,WORD))= IN(J)
    110   CONTINUE
C
      5   DO 500 I=1,RES
          NUM = 1
          READ(03) CNT
          IF(CNT .GT. 0) GOTO 7
          OTF = 1
          READ(03) CNT
      7   READ(03) (BUF(I9),I9=1,CNT)
          STRT = 1
          END = FLD(0,10,BUF(1))
```

```
           R = FLD(10,10,BUF(1))
           ANG = FLD(20,10,BUF(1))
           ANG = N90+1-ANG
     :
     C
     120   IF(OTF .GT. 0) GOTO 300
           WORD = (ANG-1)/6 + 1
           BIT = MOD((ANG-1),6)*6
           LEFT = FLD(BIT,6,BASE(R,WORD))
           TH = N180-ANG + 1
           WORD = (TH-1)/6 + 1
           BIT = MOD((TH-1),6)*6
           RGT = FLD(BIT,6,BASE(R,WORD))
           GOTO 121
     :
     300   TH = NUMANG - ANG + 1
           WORD = (TH-1)/6 + 1
           BIT = MOD((TH-1),6)*6
           LEFT = FLD(BIT,6,BASE(R,WORD))
           TH = N180 + ANG
           WORD = (TH-1)/6 + 1
           BIT = MOD((TH-1),6)*6
           RGT = FLD(BIT,6,BASE(R,WORD))
     121   IF(NUM .EQ. 1) RECORD(HFRES)=RGT
           DO 200 J=STRT,END
           J1=HFRES+J
           J2 = HFRES-J
           RECORD(J1)=RGT
     200   RECORD(J2)=LEFT
     :
           NUM = NUM+1
           IF(NUM .GT. CNT) GOTO 400
           STRT = END+1
           END = FLD(0,10,BUF(NUM))
           R = FLD(10,10,BUF(NUM))
           ANG = FLD(20,10,BUF(NUM))
           ANG = N90+1-ANG
           GOTO 120
     400   CONTINUE
     C
           IF(DICO .EQ. 1)GOTO 420
     :
     C     **********  THIS SECTION WRITES TO IDECS  ********
     C
     C
     C
           WRITE(02) (RECORD(I9),I9=1,RES)
     22    FORMAT(1X,25I3)
     23    FORMAT(1X,123I1)
           GOTO 401
     :
     C
```

```
      C
      C
      C     ***** THIS SECTION WRITES IN DICO FORMAT *****
      C
  420       DO 444 K=1,RES
            KK=K-1
            WORD = KK/6 + 1
            BIT = MOD(KK,6)*6
            DATA = 63 -  RECORD(K)
            FLD(BIT,6,OT(WORD))=DATA
  444       CONTINUE
            WRITE(02) OT
  401       IF(MOD(I,4) .NE. 0)GOTO 450
            CALL GREYMAP(RECORD,0,63,001,240,2,06)
            CALL GREYMAP(RECORD,0,63,241,480,2,10)
            CALL GREYMAP(RECORD,0,63,481,720,2,11)
            CALL GREYMAP(RECORD,0,63,721,921,2,12)
      :
  450       DO 490 M=1,RES
  490       RECORD(M)=0
  500       CONTINUE
            WRITE(6,501)
  501       FORMAT(//,' THAT IS ALL FOLKS')
            ENDFILE (02)
            WRITE(02)RES
  900       STOP
            END
```

```
      SUBROUTINE GREYMAP(ARRAY,MIN,MAX,START,STOP,STEP,FC)
      IMPLICIT INTEGER (A-Y)
      CHARACTER LINE(3,125),DENSITY(3,13)
      DIMENSION ARRAY(1)
C
      DATA (DENSITY(1,J),J=1,13) /1H ,1H.,1H',1H:,1H+,1H=,1H+,1HX,1HX,
     &  1HM,1HT,1HM,1HM/
      DATA (DENSITY(2,J),J=1,13) /6*1H ,1H(,1H.,1H=,1H=,1HN,1HW,1HW/
      DATA (DENSITY(3,J),J=1,13) / 10*1H ,1H(,1HS,1H$/
C
C
      ZQUANT = FLOAT(MAX - MIN)/13.
C
      CNT = 0
      DO 100 I=START,STOP,STEP
      CNT = CNT+1
      IF(CNT .GT. 125) GOTO 200
      VALUE = FLOAT(ARRAY(I)-MIN)/ZQUANT + 1
      IF(VALUE .LE. 0) VALUE = 1
      IF(VALUE .GT. 13) VALUE = 13
      DO 90 J=1,3
   90 LINE(J,CNT) = DENSITY(J,VALUE)
  100 CONTINUE
C
  200 WRITE(FC,10) (LINE(1,J),J=1,CNT)
      WRITE(FC,12) (LINE(2,J),J=1,CNT)
      WRITE(FC,12) (LINE(3,J),J=1,CNT)
   10 FORMAT(1X,125A1)
   12 FORMAT(1H+,125A1)
      RETURN
      END
```