59



The UTILITY OF RADAR AND OTHER REMOTE SENSORS IN THEMATIC LAND USE MAPPING FROM SPACECRAFT, 2d Annual Report

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D.S. Simonett

48

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# THE UTILITY OF RADAR AND OTHER REMOTE SENSORS IN THEMATIC LAND USE MAPPING FROM SPACECRAFT

June 1969

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(This report covers the period May 1, 1968 to May 31, 1969)

PAGINATION PROCEDURE

The primary pagination of this report, at the lower center of each page, unifies the introductory material and the appendices. Since it may be desirable to reproduce each appendix separately, a secondary internal pagination of each is provided at the top center of each page.

TABLE OF CONTENTS

## INTRODUCTION

This is the second annual report on U.S.G.S. Contract 14-08-0001-10848 and covers the period May 1, 1968, through May 31, 1969. This represents the second phase of a study documenting the potentials and problems of thematic land use mapping from remote sensor imagery, especially photography and radar imagery, obtained from aircraft and spacecraft.

Seven papers fully or partially supported by this U.S.G.S. Contract were published during the year and two others are in press. The annual report does not attempt to cover the areas given in detail in these papers. Rather, the treatment adopted has been first, to outline the general objectives of the study; second, to succinctly note the research during the period May 1, 1968, to May 31, 1969, and to note new research objectives for the third year of the study; third, to list the published and in-press documents generated on the project; fourth, to summarize the investigations at field study sites and work with the IDECS system; and, finally, to attach as appendices several studies, some which are not yet far enough along to be in publishable form but for which some interesting results are at hand, and others which are close to being in publishable form.

## 1. GENERAL OBJECTIVES OF STUDY

Before considering the general objectives of this study, it is appropriate first to briefly discuss the meaning intended by thematic land use mapping. As used here thematic land use mapping has an obvious or primary use involving the preparation of such clear cut land use maps as those showing plowed versus uncultivated land, cleared versus uncleared, urban versus rural, transportation nets, and so on. It is feasible, however, to study land use out of the context of the physical environment and we also examine certain secondary land use related maps which aid in the interpretation of land use, hence are supportive in a balanced program of land use mapping. Such secondary land use related maps would include slope maps, maps of major structural linears (of importance because of their relation to mineral ore emplacement) distribution of sink holes in limestone areas, coastal landform types such as plains and terraces, (which may be of ultimate significance in land use) and so on. In addition to considering these static elements of the landscape in the form of land forms, it is also to be understood that the dynamic element of change in man's use of the land and the adequate detection of change constitutes part of this concept of thematic land use mapping.

The five principal objectives of this study as outlined in the original proposal are given below:

1. To evaluate for a number of different climatic environments in the U.S.A. and Puerto Rico, the various ways in which spacecraft and aircraft-borne radar imagery, color and false color photography, and high resolution television, complement and supplement one another for the potential production of thematic land use maps.

2. To evaluate the capability of multi-frequency, poly-polarization radars as devices for obtaining on-demand data for the construction of thematic land use maps. This objective is based on the consideration that an on-demand system requires all-weather capabilities coupled with high resolution. Only synthetic aperture radar can satisfy this need from spacecraft if data are needed within very narrow time constraints.

3. To evaluate various color combining and image enhancement techniques as means of handling multiple images. This portion of the study is based primarily on the use of the IDECS (Image Discrimination Enhancement Combination and Sampling) system at the University of Kansas.

4. To evaluate the potential of spacecraft high resolution sensors as research tools in land use studies.

5. To develop general recommendations on the ways of using these various space-borne imaging devices for preparing thematic maps in different climatic environments.

## 2. RESEARCH PROGRESS

Research During the Period May 1, 1968 - May 31, 1969

During the first year of this contract it became obvious that a number of practical matters on thematic land use mapping required attention. In particular, an analysis was needed of the character and uses of existing thematic land use maps of various scales, and of the potential uses of those to be made from spacecraft data. Also, a preliminary analysis was necessary of the problems and potentials of developing thematic maps from spacecraft data. Consequently among the objectives of the second study phase which concluded May 31, 1969 were: 1) to examine the types of conventional and new thematic maps capable of being constructed with spacecraft data, 2) to determine the uses of the present equivalents of such maps, 3) to prepare estimates of their operational and institutional utility, 4) to analyze the problems and potentials of obtaining a variety of thematic maps from spacecraft.

Attention was also given to 1) evaluating the utility of various forms of change-detection, up-dating between censuses, 2) estimating the utility of space derived data in terms of its uniformity or lack of uniformity as a data-base, and 3) determining the information available as a function of resolution in land use mapping, especially those resolutions lying between 50 feet and 250 feet which have both been proposed for spacecraft missions.

Color (spectral) separation was used on Gemini and Apollo space photographs, particularly that obtained of the Dallas-Fort Worth area, and of the Alice Springs area, Central Australia. Manipulations using false color combinations, level slicing, and signature selection were employed with the expanded IDECS capability on Phase II of this contract, using in particular multiband imagery of Horsefly Mountain, Oregon, and Alice Springs Gemini photography.

Detailed work was continued at the following sites: Horsefly Mountain, Oregon; Garden City, Kansas; and Lawrence, Kansas. Ground data was collected in support of NASA aircraft-missions at the latter two. Unfortunately the processing of scatterometer data of these sites has been plagued with difficulties and the comparative study of radar and photographic returns has been delayed. No work was possible in Puerto Rico because no NASA flights were scheduled. However, work in Puerto Rico will begin in June, 1969, to coincide with a NASA flight. Work was also commenced on the Dallas-Fort Worth area, employing an Apollo space photograph. Field and laboratory studies were also commenced on the evaluation of Gemini IV Alice Springs, Australia space photography in land-type mapping.

A study of the meteorological-climatic problems of obtaining data with visible-light sensors and imaging radar systems was made to evaluate the effects of cloud cover and rain and to some degree, haze and smog in preparing thematic maps of the U.S.A., and of other areas.

Research to be Undertaken May 1, 1969 - August 31, 1970

During the present research period a number of additional considerations in the use of space photography have arisen which will be investigated during the next phase of the research, June 1, 1969 - May 31, 1970. These include: 1) Tests of the consistency with which area-extensive and point and line land use categories may be delineated on space photography of the same area, but of different dates, sun angle, film type, etc. The areas in which these studies will be carried out include Central Texas (Dallas-Fort Worth, Midland-Odessa) and Central Australia (Alice Springs). 2)Tests of the consistency with which area-extensive and point and line land use categories may be delineated on photography of differing resolution (involving steps at 10, 30, 100, and 300 foot resolution). 3) Tests of the information versus noise level in 120 color separated Gemini and Apollo photographs. The red, green, and blue channels will simulate the range of possible variations in different environments of a multi-channel TV type system. These will be studied for the intelligence they provide on land use mapping employing a minimum of eight elements or categories, namely: settlement, cultivated, pasture, trees, brush, bare, water, snow and ice. More complex categories will also be studied.

In addition to these studies, Task 1 of the present contract year will be continued, namely a systems analysis of the potentials and problems of developing thematic maps under various subject matter and space constraints. Emphasis will also be given to 4) Thematic mapping studies in

Puerto Rico, 5) Quantitative studies with existing color photography and RB-57 high altitude color and false color in land use category mapping in the Douglas County, Kansas test site, and at Dallas-Fort Worth, and 6) Comparisons to be made of space photography, radar imaging, and simulated vidicon imagery.

## 3. STUDIES PUBLISHED, SUBMITTED FOR PUBLICATION, AND IN PREPARATION, JUNE, 1969

### Published

The following seven papers have been published or have been issued as Interagency Reports. Items 1, 2, 3, and 4 were wholly supported by the U.S.G.S. Contract. The remainder were partially supported by this contract.

1. Schwarz, D. E. and F. Caspall (1968) "The Use of Radar in the Discrimination and Identification of Agricultural Land Use," Proceedings, Fifth Symposium on Remote Sensing of Environment, University of Michigan, 233-248.

2. Simonett, D. S. (1968) "Potential of Radar Remote Sensors as Tools in Reconnaissance Geomorphic, Vegetation, and Soil Mapping," Transactions, 9th International Congress of Soil Science, IV: 271-280.

3. Simonett, D. S. (1968) "Land Evaluation Studies with Remote Sensors in the Infrared and Radar Regions," A Chapter in Land Evaluation, (ed. G. A. Stewart) MacMillan (Australia), pp. 349-366.

4. Cochrane, G. R., (1968) "False Color Film Fails in Practice," Photogrammetric Engineering, vol. XXXIV, 11:1142-1146.

5. Simonett, D. S., et al., (1968) "The Utility of Radar and Other Remote Sensors in Thematic Land Use Mapping from Spacecraft," Interagency Report NASA-140.

6. Lewis, A. J. (1968) "Evaluation of Multiple Polarized Radar Imagery for the Detection of Selected Cultural Features," Interagency Report NASA-130.

7. Walters, R. L. (1968) "Radar Bibliography for Geoscientists," CRES Report 61-30, Center for Research in Engineering Science, The University of Kansas.

## Submitted for Publication

The following three papers or contributions partially supported by the U.S.G.S. Contract, have been submitted for publication:

1. Peterson, R. M., G. R. Cochrane, S. A. Morain, and D. S. Simonett, (1969) "A Multi-Sensor Study of Plant Community Densities and Boundaries at Horsefly Mountain, Oregon," A Chapter in Remote Sensing in Biology, (ed. P. L. Johnson) University of Georgia Press.

2. Haralick, R. M., F. Caspall, and D. S. Simonett, (1969) "A Conditional Probability and Statistical Study of Crop Discrimination Using Radar Images," Submitted to Remote Sensing of Environment.

3. Simonett, D. S., Contribution to Multispectral Sensing of Agricultural Resources, (J. R. Shay and M. R. Holter, eds.) National Academy of Sciences, National Research Council, in press.

## Reports in Preparation

The following five studies, wholly supported by the U.S.G.S. Contract, are attached to this report as appendices. They are in various stages of completion.

1. Schwarz, D. E., D. S. Simonett, G. F. Jenks, and J. Ratzlaff, "The Construction of Thematic Land Use Maps with Spacecraft Photography."

2. Simonett, D. S., G. R. Cochrane, D. E. Egbert, and S. A. Morain, "Environment Mapping with Spacecraft Photography: A Central Australian Example."

3. Simonett, D. S. and F. M. Henderson, "On the Use of Space Photography for Identifying Transportation Routes: A Summary of Problems."

4. Simonett, D. S., J. R. Eagleman, J. Marshall, and S. A. Morain, "A Comparison of Cloudiness and Other Weather Effects on Photographic and Radar Imaging."

5. Simonett, D. S. and W. G. Brooner, "Crop-Type Discrimination with Color Infrared Photography: Preliminary Results in Douglas County, Kansas."

## 4. INVESTIGATIONS AT FIELD TEST SITES AND WITH THE IDECS SYSTEM

Field Investigations

The field test sites where studies were carried out during the past year include Garden City, Kansas; Horsefly Mountain, Oregon; Lawrence, Kansas; Dallas-Fort Worth, Texas, and the Alice Springs area, Central Australia.

Garden City, Kansas: The radar imagery obtained with the AN/APQ-97 multiple polarization K-band radar is being re-analyzed by Mssrs. F. Caspall and D. Simonett. The material will be in publishable form in the fall of 1969.

Scatterometry data and photography was obtained by NASA/MSC aircraft and field data was collected during June, August, and October, 1968. No analysis of this or earlier scatterometer data has proved feasible during the contract year because of problems in debugging the scatterometer output. At the close of the contract year most of these appeared to have been resolved, and analysis will begin in the fall, 1969. Some of the photography from June, 1968 flights were used in studies or predictions using the IDECS and appears in Dalke and Estes (1968).

Horsefly Mountain, Oregon: Dr. Rex M. Peterson and Professor G. R. Cochrane carried out field work at the Horsefly Mountain site in May - June, 1968. The field study included evaluation of numerous IDECS color combinations of radar or other images. A paper was read at the Ecological Society of America meetings in June at Madison, Wisconsin, and is in press (University of Georgia Press).

Lawrence, Kansas: The Lawrence and vicinity test site was flown June 18, 1968 (Mission 74). Scatterometry has not been evaluated because of the problems mentioned above. Analysis of some of the photography for Mission 74, June 1968, appears in Dalke and Estes (1968). Analysis of color infrared photography for Mission 54 has begun and is appended to this report.

Puerto Rico: Since no aircraft missions were carried out in Puerto Rico, no field studies were made. Preparation was made for flights in June, 1969, by the NASA/MSC P3A aircraft.

Dallas-Fort Worth, Texas: Portions of this area were flown by the NASA Convair 240A in October, 1968, at the time of the Apollo 7 mission, and in March, 1969, coincident with the Apollo 9 mission. Field work was carried out during late March - early April, 1969, after the Apollo 9 photography was inspected at MSC and cloud-free areas of overlap between SO 65 and hand held photography were delineated.

Alice Springs, Australia: Field studies and low altitude aerial oblique photography were obtained by D. Simonett prior to attendence at the 9th International Congress of Soil Science, August, 1968. Professor G. R. Cochrane commenced 6 weeks field work on the Alice Springs area in early May, 1969. Included in this study is evaluation of IDECS color combinations of selected areas.

## The Status of the IDECS System

The IDECS System developed at the Center for Research in Engineering Science at the University of Kansas continues to undergo constant improvements and modifications. Since May, 1968, however, the IDECS System has been kept in full operational capacity while further modifications are carried out. In its third generation, the IDECS System now has the following capabilities, which were discussed in detail and illustrated with examples in Peterson et al. (1969) and Dalke and Estes (1968):

1. Four image synchronous flying spot scanners are now operationally mounted in a cabinet along with their power supply. The scanners are modified Tektronix oscilloscopes which scan each image by moving a dot of light across the images along each of 525 parallel lines. By measuring the variation of intensity of the transmitted light at each instant, a signal is obtained in which time variation corresponds to position on the image. The IDECS System can simultaneously scan up to four images or photo-optically transformed images.

2. Combination and Enhancement -- Consists of a 6 x 4 matrix unit, level selection devices, and differentiation circuitry. Processing capabilities include: straight color combinations of up to four images; differences between four image pairs; edges enhanced

in various colors; level selected portions of four images shown in color; and category identification and display.

3. Signature Selector -- consists of a series of pin-board matrices. It can be used separately or in series with the color matrix for greater flexibility. The signature selector identifies selected categories in the image set.

4. The position framing and synchronization devices which control the location, timing, and registry of images.

5. Image flicker which alternately displays two images and allows detection of (1) differences in tone and shape between images and (2) non-registry between images.

6. General-purpose decision device which takes the output from the four flying spot scanners and at each instant selects and displays the most likely category for this output in a map-like color image.

7. Line selector, used to select a line across an image and to give a "graphical" representation of photographic density along the line (i.e. the X axis gives location, the Y axis of the display represents intensity).

8. Monitor display (3-D Line Scan Modulation Display), shows in isometric projection combinations of the horizontal and vertical sweeps to the X and Y inputs of the CRT display, resulting in an overall image density profile.

Within the next two months, several additional improvements will be made on the IDECS. These include:

1. Linkage of a digital interface disk unit.

2. Signature selector modifications to supplement the pin-boards with eight potentiometers. The IDECS will then be capable of "freezing" a selected category by placing it on one of 24 channels on the memory disk and then simultaneously displaying up to 24 categories on the color video display.

3. New image framing device with a joy-stick control to move a variable-sized frame to any part of the image. This will be used as a gating signal for category selection.

4. Automatic area integrator and area measuring device with scale calibration.

During the present study phase (June, 1969 to May, 1970) the IDECS System will be most fully employed in land use studies in the Dallas-Fort Worth area using both spacecraft and high altitude aircraft multiband photography.

## REFERENCES

Dalke, G. W. and J. E. Estes (1968), Multi-image correlation systems study for MGI; Final Report (U), Included in Phase II report on U.S. Army Topographic Laboratories, Fort Belvoir, Va., Contract No. DAAK02-67-C-0435, CRES, University of Kansas, 166-186.

Peterson, R. M., G. R. Cochrane, S. A. Morain, and D. S. Simonett (1969), A Multi-sensor study of plant community densities and boundaries at Horsefly Mountain, Oregon, A Chapter in Remote Sensing in Biology, (ed. P. L. Johnson) University of Georgia Press.

# APPENDIX 1

## THE CONSTRUCTION OF THEMATIC LAND USE MAPS WITH SPACECRAFT PHOTOGRAPHY

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# THE CONSTRUCTION OF THEMATIC LAND USE MAPS WITH SPACECRAFT PHOTOGRAPHY

by

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TABLE OF CONTENTS

# INTRODUCTION

The elements making up the earth's surface commonly are so distributed in both time and space as to affect the character of thematic maps of such areas. In addition when we produce generalizations of areal phenomena in thematic maps we may generalize and organize the data in a variety of ways: any phenomenon or combination of phenomena may be included in a given thematic map. In short, thematic maps reflect the peculiarities of their locales and the idiosyncracies of their compilers as well as the diversity of their data sources. It is consequently rare to find existing thematic land use[1] maps in a form appropriate for spacecraft duplication: the systematic constraint of a single data source or the restriction exclusively to visible phenomena has never applied during their compilation, nor has the necessity for developing a classification of general rather than particular application, based upon remote sensors, been faced. It should come as no surprise to the reader therefore to find in this study on the potentials and problems of constructing thematic land use maps with spacecraft photography, that virtually every aspect of the study has proven to be a virgin area requiring definition and re-definition of problems, approaches, data congruence and so on. Thus we have found that:

1. Very few existing land use maps could be duplicated using spacecraft photography.
2. The problems of inconsistency in the meaning to be attached to photographic tones in different locales markedly constrains the land use categories into very general entities.
3. A given resolution does not convey the same information in all environments, i.e., information transfer is environmentally modulated.

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[1] In this study the definition of "land use" is not restricted to man's use of land. Our view is that broader concept which includes natural phenomena as well as human activities to be "land uses." For example, a forest is a forest whether or not it is lumbered, and a land use map or a vegetation map will have much in common.

4. A ground resolution of 100 feet or less will be necessary to determine other than the most generalized land uses from space.
5. Most present land use classifications will not be proper when considering space data sources.
6. The necessity for doing field work, i.e., of obtaining "ground truth," will not be obviated by spacecraft sensing.
7. The human interpreter should be more efficient than scanning devices or other automatic processors in the making of most land use decisions, at least for some time to come.

The evidence which forms the basis for these conclusions will be reviewed at length in the following pages. It is appropriate now however to touch briefly on some of the consequences for thematic mapping with spacecraft photography if our assertions stand the test of closer analysis.

1. Our lack of knowledge of the environments which we will be sensing from space poses a severe problem for mapping from such data. The types, intensities and intermixtures of landscape elements are so diverse that identification and regional classification of land uses are difficult even from the ground.
2. The basic size and arrangement of landscape units is not stable from environment to environment. The character of a physical and cultural environment is partially expressed in simply spatial terms. This implies not only that a system of a given resolution will not always provide a uniform level of land use information, but that the shape and frequency of landscape elements themselves tend to be indicators of regional types.
3. Spatial changes occur at different rates. The characteristic appearance of a particular land use on a space photograph may or may not be the same for a similar land use a mile, ten miles or a thousand miles away. This "distance-decay function" is highly variable and must especially be considered in any undertaking of automated image analysis.
4. The land use assemblages which will be interpretable from space will not be identical to those categories now commonly employed.

A new understanding of the way things are "put-together" on the earth's surface should become apparent from space vantages. Appropriate land use classifications must be devised, and the meaning of new "land use regions" which appear on space photography must be understood.

5. Considerable thought must be given to practical techniques of interpretation and mapping from space data. The capability for automatic scanning devices to make accurate land use determinations does not seem entirely feasible at the present when we consider the problems of environmental complexity and the distance-decay functions which must be understood before proper implementation of automatic interpretive devices is possible. We must learn how best to train the human interpreter and to serve him with devices to make his job simpler and more accurate.

Having made these assertions and touched lightly on their implications we may now turn respectively to documenting the evidence for the former and probing the consequences of the latter more thoroughly.

## DATA QUALITY AND UNIFORMITY

Neither the standard data collection techniques nor satellite sensing are without shortcomings. A common problem is the non-uniformity of data, though the type and degree of non-uniformity differ. Clawson (1965), Baker (1968), and the International Geographical Union's Committee on a World Land Use Map (Van Valkenburg, 1950) clearly indicate that most land use maps of medium to small scales are presently pieced together from the best available data. The non-uniformity may arise from not employing standardized techniques throughout the mapped area, improper or inadequate sampling, combining data from several sources, ignoring seasonal or greater time disparaties, interpreter bias, accepting estimates, or other factors.

Not all of these shortcomings are eliminated by using space data though several advantages appear at first sight to inhere with its use, and these may prove on close study to be real.

It has been said that orbital sensing will provide a more uniform data base. To some extent this is true. Satellite data will be consistent in that complete coverage may be obtained by a single instrument (or instrument package) over a reasonably short period of time. Field data collected over an extensive area will tend to show individual investigator bias, will involve the employment of inconsistent techniques, or will otherwise tend to produce data of an uneven quality. Aircraft-mounted sensors tend to provide more uniform data, but their individual coverage is limited, and near-simultaneous coverage of broad areas is impossible or requires the utilization of several aircraft and the increasing probability of error. In fact, aircraft sensing over broad areas tends to be incomplete, unequal in quality, or compounded of several segments often collected years apart and of non-uniform quality and scale.

Space data have no value judgments attached and errors made necessary by piecing together data of wide disparity of collection date or from several systems are minimized. Certainly the time required to amass a body of data over a large area will be so diminished that seasonal variations within a single data set will be virtually eliminated. On the other hand the repeated sensing of phenomena at discrete significant intervals allows the seasonal variations of phenomena to be compared for each data set. Thus, changes through time become an added tool for discrimination rather than "noise" and an interpretive liability. Monitoring of change on all but a local scale is not possible by conventional means.

Though some of the constraints of time can be eliminated by satellite sensing, data quality and uniformity are still notably influenced by local and regional environmental variations. Local weather conditions obviously have a pronounced effect on the collection of most remotely-sensed data. Since satellites will provide repeated coverage at relatively short intervals, acceptable imagery can be obtained for areas of nonpermanent cloud cover especially if seasonal advantages are taken into account. Areas which are perpetually cloud-shrouded or polar areas where proper illumination for photographic sensing is not available for large parts of the year will need to rely more on the longer wavelength sensors, notably radar, to fill the data gaps (MacDonald and Lewis, 1969).

The color photographs obtained during Gemini and Apollo missions show that acceptable weather conditions for excellent photographic sensing can be expected with a high probability only in the desert or semi-desert regions of the earth at any given moment (Simonett et al., 1969). To extract necessary data from other regions will require the proper seasonal and diurnal timing of the use of photographic sensors, the utilization of sensors operating in spectral regions not affected to such a degree by cloudiness or darkness, and the use of proper sampling techniques in unavoidable cases of spotty coverage or to key the good bits of photography to the other sensor data.

Not only do local atmospheric variations influence the quality of imagery but they may also cause the desired information to be inconsistent in its spectral location. Preliminary work with spectral separations (red, green, and blue regions) of Gemini photographs at the University of Kansas indicates that these color layers contribute varying degrees of information apparently dependent on local atmospheric conditions.

If problems of image distortion, non-uniform illumination and others inherent in the photographic process are added, it can readily be seen that raw satellite data will not truly be as uniform in quality as at first glance we might suppose. Most of these problems, however, are common to both satellite and aircraft based sensing and are therefore in part amenable to corrections already devised for the latter. The major problems which remain to be investigated concerning quality and uniformity of space data are the limitations imposed by two factors: 1) diminished scale and resolution, and 2) the effects of the atmospheric mass. The remainder of this report will concentrate on the effect of diminished resolution, with special attention being given to 1) comparisons of conventionally-produced or existing thematic land use maps with those potentially constructed from space data, 2) information and mis-information as a function of resolution, and 3) problems of generalizing land use data. In a companion report (Simonett, et al., 1969) the effects of the atmosphere will be examined further.

## GENERALIZED TYPES OF THEMATIC LAND USE MAPS AND THEIR RELATION TO SPACE DATA SOURCES

Spacecraft sensing will provide a more nearly uniform mapping and data base for the construction of thematic land use maps than ever before. However, it does not follow from this that our problems of uniformity are solved, or that all maps will be constructed with equal ease. The capability for constructing a particular thematic map is directly related to the phenomenon or phenomena displayed on that map. That is, the nature of certain phenomena — their areal extent, their geometry, their contrast, etc. — influences their detectability and identification. For example, a map of gross landforms will require an imaging system which will reveal the general shape of the earth's surface but will not require the detail of resolution necessary to distinguish crop types or soil types. Reconnaissance maps will be more readily obtained than maps of detailed phenomena.

Certain system requirements may be desirable or necessary to accomplish special mapping tasks. Some phenomena, notably vegetation, exhibit marked seasonal variations. If these variations are monitored throughout the year, the time, rate and nature of the changes serve to allow discriminations which otherwise will not be possible. In other instances, notably in geologic or geomorphic mapping, a preferred illumination angle or direction of imaging, especially in the case of side-looking radar, aids in distinguishing critical slopes or other elements of the landform pattern which are required for their identification. In still other instances, while adequate mapping may not be possible using only space data, a minimum of ground truth or low altitude photography may key the interpretation and make broad-scale mapping from the space data feasible.

Table I gives our judgment at this time of the desirable data for making a few selected types of thematic maps from space-derived data. Note that the critical resolution break has been made at 100 feet, for reasons outlined later in this report. This is better ground resolution than that of the space photography studied to date which normally falls in the 250 to 350 feet range. Further estimates of space capabilities outlined in this report will assume spatial resolutions on the order of 100 feet, which appears to be the best resolution immediately forthcoming in satellite sensing of non-military nature (Gerlach, 1968).

Reconnaissance maps or maps of a generalized nature may normally be constructed from satellite data with a resolution of about 100 feet. Maps of a detailed nature, such as those showing intricate vegetation patterns or crop type or detailed geologic mapping, can be expected to require finer resolution systems. Table I indicates also the areas, primarily vegetation, where seasonal monitoring is needed, and where multiple look directions or preferred angles of illumination are most desirable. It is especially important to note that some ground truth information (especially field work at the time of the photography rather than existing data) will prove essential in most instances for keying the identification on the broader scale. Our present level of understanding of environmental variability in the several sciences is such that unlike categories may be confused in space photographs, and field work is essential for calibration of this variability.

## CLASSIFICATION OF THEMATIC LAND USE MAPS

No systematic study of thematic land use maps has ever really been attempted. The utility of existing maps is usually not clearly stated nor is it apparent from the map itself. A rational classification of such maps is also lacking and perhaps infeasible to produce. In our preliminary study of thematic maps we also found that no systematic relationship existed between either the scale or subject matter of maps and their complexity. We struggled with alternative classifications and finally devised one based on the generalized nature of the elements making up land use maps and the ordering of such elements. This tentative classification at least attempts to structure the relations between land use maps in such a way as to aid in our assessment of the problems they will pose for spacecraft production.

The classification is as follows:

I. SINGLE ELEMENT MAPS

A. Absolute presence or absence of one element. Example: Cultivated land is mapped; the remaining area has only the certain characteristic of not being cultivated land.

B. Percent presence of one elemment. Example: Areas with over 20 per cent of [a given unit] area cultivated are mapped; remaining area has 20 per cent or less of its area in cultivated land.

II. SINGLE MAJOR ELEMENT MAPS WITH MULTIPLE SUB-DIVISION

A. Qualitative sub-divisions. Example: Major element is forest with sub-types such as rainforest, tropical deciduous, commercial, etc.

B. Quantitative sub-divisions. Example: Major element is cultivated land broken down into 0-19 per cent of area cultivated, 20-39 per cent cultivated, and 40 per cent or over cultivated.

C. Qualitative-quantitative sub-divisions. Example: Major element is woodlands broken down into dense or open categories.

III. MULTI-ELEMENT MAPS

A. Simple multi-element maps. Example: Map showing areas of grassland, forest, and cultivated land.

B. Complex multi-element maps.

1. Multiple major elements with sub-categories. Example: Major categories as in example III A but each major category has sub-categories such as individual crop types under cultivated land.

2. Multiple elements in a single category. Example: Crop combination regions, i.e., corn-soybean region, wheat-sorghum-

pasture region, etc.

3. Combination of 1 and 2.

VI. CONCEPTUAL REGION MAPS

These do not simply involve the discrimination of discrete elements nor simple combinations thereof; rather they indicate regions having some conceptual homogeneity. They may integrate the total landscape elements to produce general regions but usually they abstract from reality to produce specialized regions. Quantitative data and techniques are often used as at least a partial basis for regionalization. Examples: Economic regions, land capability classifications, perception regions, or agricultural regions such as intensive subsistence, shifting cultivation, nomadic herding, etc.

V. MIXED MAP TYPES

Many maps will mix two or more of the above-described classes. Example: A map with these categories — commerical-industrial, residential, commercial agriculture with sub-types of crops and livestock, subsistence agriculture, and unproductive land.

A representative sample of twenty-three thematic land use maps was taken from the University of Kansas map library to determine how they related to our classification and the problems of mapping from space data. The makers of the maps, mostly government agencies, do not state the reason for providing such a map in most instances, but the existence of these and similar maps of these types would indicate that they are the types most used in resource studies, regional planning, policy decisions and other economic and governmental functions.

Table II places each of the maps, ordered by scale, into the categorization scheme we have erected. The great majority of maps fell into the "mixed type" category and are therefore further defined by their dominant tendency for one or more of the other classes. About all that can be said of this sampling is that "single element" maps are rare, as are maps that

TABLE II

SAMPLE MAPS CLASSIFIED AND ORDERED BY SCALE

| MAP IDENTIFICATION | | | Single Element | | Single Major Element with Sub-Divisions | | | Multi-Element | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Complex | | | |
| Location | Type | Scale | Absolute Presence | Generalized Presence | Qualitative | Quantitative | Qualitative-Quantitative | Simple | Sub-Categories | Combinations in a Single Category | Conceptual Regions | Mixed Types |
| Isle of Thanet | Land Use | 1:25,000 | | | | | | | √[2] | | | *[1] |
| Craighead Co., Arkansas | Land Use | 1:62,500 | √ | | | | | √ | | | | * |
| North Antrim | Land Use | 1:63,360 | | | | | | √ | | | √ | * |
| Dumbarton and Lammermuir | Land Use | 1:63,360 | | | | | | | √ | √ | | * |
| Israel | Landscape Regions | 1:150,000 | | | | | | | √ | | | * |
| Truro, Nova Scotia | Land Use | 1:250,000 | | | | | | √ | | | | * |
| Great Britain | Land Use | 1:625,000 | | | | | | | | √ | | * |
| Malaya | Land Use | 1:760,320 | | | | | | √ | | | | * |
| Malaya | Forest | 1:760,320 | | | | | | √ | | √ | | * |
| Portugal | Agriculture & Veg. | 1:1,000,000 | | | | | | √ | | | √ | * |
| Kansas | Agriculture | 1:2,000,000 | | | | | | | | | * | |
| Northwest Africa | Agriculture | 1:3,800,000 | | | | | | * | | | | |
| Ecuador | Forest | 1:4,000,000 | | | * | | | | | | | |
| North Africa | Land Use | 1:5,000,000 | | | | | | √ | | | | * |
| Malaysia | Vegetation | 1:5,000,000 | | | * | | | | | | | |
| United States | Agriculture & Veg. | 1:5,000,000 | | | | | | | | √ | √ | * |
| Australia | Land Use | 1:6,000,000 | | | | | | | √ | | √ | * |
| Australia | Vegetation | 1:6,000,000 | | | | | | | * | | | |
| Australia | Forest | 1:6,000,000 | | | √ | | | | | | | * |
| Southern Peru | Land Use | 1:6,000,000 | | | | | | √ | | | √ | * |
| Saõ Paulo | Land Use | 1:6,000,000 | | | √ | | | | | | √ | * |
| China | Agriculture | 1:7,500,000 | | | | * | | | | | | |
| U.S.S.R. | Land Use | 1:50,000,000 | | | | | | * | | | | |

[1]Category into which the listed map properly falls.

[2]A "mixed type" map but having characteristics most like this (these) category.

TABLE III

SAMPLE MAPS CLASSIFIED AND ORDERED BY NUMBER OF CATEGORIES

| MAP IDENTIFICATION | | | Single Element | | Single Major Element with Sub-Divisions | | | Multi-Element | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Complex | | | |
| Location | Type | Number of Categories | Absolute Presence | Generalized Presence | Qualitative | Quantitative | Qualitative-Quantitative | Simple | Sub-Categories | Combinations in a Single Category | Conceptual Regions | Mixed Types |
| China | Agriculture | 2 | | | | * | | | | | | |
| U.S.S.R. | Land Use | 3 | | | | | | * | | | | |
| Craighead Co., Arkansas | Land Use | 3 | √ | | | | | √ | | | | * |
| Northwest Africa | Agriculture | 5 | | | | | | * | | | | |
| North Antrim | Land Use | 6 | | | | | | √ | | | √ | * |
| North Africa | Land Use | 6 | | | | | | √ | | | | * |
| Southern Peru | Land Use | 6 | | | | | | √ | | | √ | * |
| Great Britain | Land Use | 7 | | | | | | | | √ | | * |
| Australia | Forest | 7 | | | √ | | | | | | | * |
| Malaya | Land Use | 8 | | | | | | √ | | | | * |
| Malaya | Forest | 8 | | | | | | √ | | √ | | * |
| Portugal | Agriculture & Veg. | 9 | | | | | | √ | | | √ | * |
| Ecuador | Forest | 9 | | | * | | | | | | | |
| Kansas | Agriculture | 11 | | | | | | | | | * | |
| United States | Agriculture & Veg. | 12 | | | | | | | | √ | √ | * |
| Saõ Paulo | Land Use | 12 | | | √ | | | | | | √ | * |
| Australia | Land Use | 13 | | | | | | | √ | | √ | * |
| Dumbarton and Lammermuir | Land Use | 14 | | | | | | | √ | √ | | * |
| Truro, N.S. | Land Use | 16 | | | | | | √ | | | | * |
| Malaysia | Vegetation | 18 | | | * | | | | | | | |
| Australia | Vegetation | 35 | | | | | | | * | | | |
| Isle of Thanet | Land Use | 37 | | | | | | | √ | | | * |
| Israel | Landscape Regions | 38 | | | | | | | √ | | | * |

[1]Category into which the listed map properly falls.

[2]A "mixed type" map but having characteristics most like this (these) category.

fall clearly into other than the "mixed" category. No meaningful relationships can be drawn between map scale or map type (phenomena mapped) and the classification of the map.

If the maps are ordered by the number of map categories (only areally extensive categories were considered), as in Table III, a slightly more apparent pattern develops. Maps of few categories (in this sample, five or less) tend to be of a pure type and, of course, tend to be rather simple. Maps of more than five categories are usually not purely of one type; that is, they blend several of our classes and therefore fall into the "mixed" category. Maps of up to about ten categories tend to be "simple, multi-element" types. Maps with an increased number of categories have usually begun to include sub-categories. "Conceptual region" maps appear to be mostly in the medium-number-of-category range — in our sample, from six to thirteen categories.

Though in this sample the two maps with fewest categories are also the smallest scale maps, there is no consistent and meaningful relationship of map scale with the number of mapped categories or the type of map.

## PRESENTLY USED THEMATIC LAND USE MAP CATEGORIES AND THE CAPABILITY TO DUPLICATE THEM FROM SPACE

The sample of existing land use maps was broken down into each areal category and these were individually evaluated in terms of the capability to produce similar map categories from space data and to determine the factors which most constrain their reproduction. Our evaluation is subjective but is based on considerable interpreter experience with both photographic and radar imagery. There is no other procedure available at this time. No quantitative studies on which we could lean are in print. As mentioned earlier, the critical resolution used in the evaluation is 100 feet. That is, we have assumed that good quality imagery of such resolution is available for the given area. If it was judged that a finer resolution would be necessary to identify a particular category, then resolution became a major constraining factor. In several cases the precise definition of a category was not clear; in others the nature of the categories was such that it is highly unlikely that they would appear as distinct entities as seen from space. In most cases the evaluation of space potential is conservative, that is, where there is doubt as to feasibility we ruled that it could not be done with space data. The examples in the following tables follow this format:

Column one: Land use category. Taken directly from the map.

Column two: Capability for mapping. The capability of mapping the given category using good quality photographic and radar sensors and assuming a resolution of 100 feet.

1 - Readily done with few and slight errors.
2 - Can be done with moderate but normally "acceptable" error.
3 - Can be done with large, but possibly "acceptable" error.
4 - Unreliable: Can be done only with great difficulty; errors are rarely acceptable.
5 - Cannot be done.

Column three through five: Factors constraining the mapping of the category using space data.

Column three: Inadequate Resolution: requires a resolution finer than 100 feet.

Column four: Abstract (Including Statistical) Category: The category is defined in conceptual terms or as a statistical abstraction. The areas have regional identities in conceptual or statistical terms, though they may not appear as distinct units judging from their physical appearance. The category may also derive from an economic evaluation of the area which in fact is representative of only a small fraction of the surface. Examples: Unproductive land, cattle breeding, mining land.

Column five: Synthetic or Residual Category: The category does not truly describe a region, not even in conceptual terms. It is either arbitrarily defined with no true regard to natural regions or is a category which has no identity other than being a residual or "catch all" category. Examples: Forest reserve, no significant use.

Tables IV through XIII serve to illustrate certain of the things learned from the analysis of the map sample. The remaining evaluations are included in Appendix A. These evaluations should not be interpreted in a strictly quantitative manner for they are judgments open to modification depending on the frame of reference. In short they rest on experience and intuition as do all such evaluations at this time. However, since they force us to confront squarely the disabilities as well as the advantages of spacecraft imaging with 100 foot resolution, the tables are salutary.

The Truro, Nova Scotia land use map (Table IV) illustrates that it is often the intensity of a given major phenomena which is distinguishable, not specification of qualitative sub-categories. Note that a single grassland category and woodland categories such as dense, open, scrub, and cut-over or burnt-over seem moderately feasible for space mapping with 100 foot resolution. Compare these woodland sub-types to those in Tables V and VI, the Malaysia and Australia vegetation maps, where the woodland sub-types are not of an intensity or quantitative nature, but are instead dependent on the identification of species which are often in fact very similar and indistinguishable from satellite altitudes at the given resolution. In such cases quite detailed field work may be required to make distinctions.

Another manner of grouping the land use elements in terms of things which are visually distinct from other categories is illustrated in the land use map of Great Britain (Table VII). This classification of the major landscape elements contains both quite feasible and moderately feasible items using space data. The Dumbarton and Lammermuir map (Table VIII) uses essentially the same major breakdown but adds sub-categories and the

TABLE IV

AREA MAPPED: TRURO, NOVA SCOTIA

SCALE: 1:250,000

Canadian Land Use Series, 1961, No. 11E, Surveys and Mapping Branch, Department of Mines and Technical Surveys, Ottawa

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including statistical) | Synthetic or Residual |
| Industrial and Commercial | 2-3 | X | | |
| Residential | 2-3 | X | | |
| Associated Urban Areas (Non-Agricultural) | 2-3 | X | | |
| Hay | 5[1] | X | | |
| Grain | 5 | X | | |
| Orchards | 3-4 | X | | |
| Horticulture | 5 | X | | |
| Improved Pasture | 4 | X | | |
| Open Grassland and Scrub Grassland | 2-3 | X | | |
| Blueberries | 5 | X | | |
| Dense Woodland | 2-3 | X | | |
| Open Woodland | 2-3 | X | | |
| Scrub Woodland | 2-3 | X | | |
| Cut-Over and Burnt-Over Areas | 2-3 | X | | |
| Swamps and Marshes | 2-3 | X | | |
| Unproductive Land | 4 | X | X | |

[1] Hay will not be readily distinguished from grain but together they may be more readily separated from the remaining categories.

TABLE V

AREA MAPPED: MALAYSIA

SCALE: 1:5,000,000

Vegetation Map of Malaysia, 1958
UNESCO Humid Tropics Research Project

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories | |
| | | | Abstract (Including Statistical) | Synthetic or Residual |
| Rainforest | 2-4 | X | | |
| Dipterocarpaceous Rainforest | 4-5 | X | | |
| Agathis Rainforest | 4-5 | X | | |
| Borneo Ironwood Rainforest | 4-5 | X | | |
| Casuarina Forest | 4-5 | X | | |
| Pinus Forest | 3-5 | X | | |
| Freshwater swamp and Peat Forest | 3-4 | X | | |
| Sago Swamp Forest | 2-4 | X | | |
| Mangrove Forest (Bakau, Mangle) | 2-4 | X | | |
| Secondary Forest | 4-5 | X | | |
| Savannahs | 2-3 | X | | |
| Grassland | 2-3 | X | | |
| Alpine Grassland | 2-3 | X | | |
| Monsoon (or seasonal) Forest | 2-4 | X | | |
| Teak Forest | 3-4 | X | | |
| Wet Rice-Fields | 3-4 | X | | |
| Dry Fields | 3-4 | X | | |
| Plantations | 3-4[1] | X | | |

[1] Depends on size, type of crop and regularity of pattern, and also whether the crop is grown in second or lower level of a forest.

TABLE VI

AREA MAPPED: AUSTRALIA (VEGETATION)

SCALE: 1:6,000,000

Vegetation Regions, 1957, Atlas of Australian Resources
Department of National Development, Canberra

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Grasslands | 2-4 | | | |
| Sclerophyll Hummock Grassland | 4-5 | X | | |
| Semi-arid Tussock Grassland | 4-5 | X | | |
| Tropical Tussock Grassland | 4-5 | X | | |
| Temperate Tussock Grassland | 4-5 | X | | |
| Savannahs | 3-4 | | | |
| Sclerophyll Shrub Savannah | 4-5 | X | | |
| Semi-Arid Shrub Savannah | 4-5 | X | | |
| Sclerophyll Low Tree Savannah | 4-5 | X | | |
| Semi-Arid Low Tree Savannah | 4-5 | X | | |
| Tropical Tall Shrub Savannah | 4-5 | X | | |
| Tropical Tree Savannah | 4-5 | X | | |
| Temperate Tree Savannah | 4-5 | X | | |
| Shrub Communities | 2-3 | | | |
| Shrub Steppe | 3-5 | X | | |
| Arid Scrub | 3-5 | X | | |
| Semi-Arid Mallee | 3-5 | X | | |
| Heath | 3-5 | X | | |
| Sclerophyll Mallee | 3-5 | X | | |
| Layered Scrub | 3-5 | X | | |

(Continued on Following Page)

TABLE VI CONTINUED

AREA MAPPED: AUSTRALIA (VEGETATION)

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories | |
| | | | Abstract (Including Statistical) | Synthetic or Residual |
| Woodlands | 2-3 | | | |
| Low Arid Woodland | 4 | X | | |
| Low Shrub Woodland | 4 | X | | |
| Tropical Deciduous Woodland | 4 | X | | |
| Tropical Woodland (Mixed) | 4 | X | | |
| Tropical Layered Woodland | 4 | X | | |
| Temperate Woodland (Mixed) | 4 | X | | |
| Mixed Coastal Woodland | 4 | X | | |
| Forests | 1-2 | | | |
| Dry Sclerophyll Forest | 2-3 | X | | |
| Wet Sclerophyll Forest | 2-3 | X | | |
| Temperate Rain Forest | 2-3 | X | | |
| Tropical Layered Forest | 2-3 | X | | |
| Sub-Tropical Rain Forest | 2-3 | X | | |
| Tropical Rain Forest | 2-3 | X | | |
| Miscellaneous | 2-3 | | | |
| Sandhill Desert | 2-3 | X | | |
| Sandplain Desert | 2-3 | X | | |
| Stony Desert | 2-3 | X | | |
| Littoral Complex | 2-3 | X | | |
| Alpine Complex | 2-3 | X | | |

TABLE VII

AREA MAPPED: GREAT BRITAIN

SCALE: 1:625,000

Land Utilization Survey of Britain, 1944
Director General, Ordnance Survey

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including statistical) | Synthetic or Residual |
| Forest and Woodland | 1-2 | X | | |
| Arable Land (Including Fallow, Rotation Grass and Market Gardens) | 2 | X | | |
| Meadowland and Permanent Grass | 2-4 | X | | |
| Heathland, Moorland and Rough Pasture | 2-4 | X | | |
| Pasture | 3-4 | X | | |
| Chief Urban Areas | 1 | X | | |
| Orchards and Nursery Gardens | 3-4 | X | | |

### TABLE VIII

### AREA MAPPED: DUMBARTON AND LAMMERMUIR

### SCALE: 1:63,360

Land Utilization Survey of Britain, 1944
Director General, Ordnance Survey

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Forest and Woodland | | | | |
| Deciduous | 2 | X | | |
| Coniferous | 2 | X | | |
| Mixed | 3-4 | X | | |
| New Plantations | 3-4 | X | | |
| Arable Land | 2 | X | | |
| Meadowland and Permanent Grass | 2-4 | X | | |
| Heath and Moorland | 2-4 | | | |
| Heath, Moorland, Commons and rough pasture | 2-4 | X | | |
| Rough Marsh Pasture | 2-4 | X | | |
| Gardens, etc. | | | | |
| Houses with Gardens sufficiently large to be productive of flowers, veg., etc. | 5 | X | | |
| New Housing Areas and Allotments | 4-5 | X | | |
| Orchards | 3-4 | X | | |
| Nursery Gardens | 3-4 | X | | |
| Land Agriculturally Unproductive | | | | |
| Closely Covered with Houses, etc. | 1-2 | X | | |
| Yards, Cemeteries, Pits, Quarries, etc. | 4 | X | | X |

necessity to identify units too small to be defined within the imposed resolution restrictions.

The next example, the Australian land use map (Table IX), illustrates categories for which the imprint across the total landscape is not distinct enough to allow them to be identified. Certainly, the type of animal will not be identified, and the buildings associated with each activity will not be distinct nor dominant enough to betray the land use as given. The actual land surface cover, such as grassland, brush, and the like, could be more readily identified. Some inferences as to man's activities might be drawn from the vegetation, inferred climate, land surface form and other relative location factors, but they would be highly speculative and imprecise. Another way of viewing this is to consider whether, with the statistical sources in hand, the land use map might be improved with spacecraft photography. There is no doubt that the details of some boundaries might be altered. However, for others it is doubtful whether the statistics could act as a useful calibration device. The problem is that there is implied a clear link between the method of farm management and its impress on the landscape. Such an expectation is naive.

The identification of specific crops will remain difficult as shown in Table X, São Paulo, Brazil land use. Crop identification will depend on the nature of the crop, the size and regularity of the individual fields, and the collection of data at critical points during the growing season. For example: plantation agriculture will be more apparent than subsistence agriculture; fields of the size of those in the U. S. Great Plains will be more readily seen than those in southeast Asia; and flooded rice fields will be more readily detected than they will while dry.

Marschner's map of Land Use in the United States (Table XI) is not of a type which could be directly adapted to space data usage. The categories are statistical or mental abstractions of what really exists on the surface and may not represent similar regions as seen from a space vantage. However, similar maps based on visually discrete phenomena could be constructed.

TABLE IX

AREA MAPPED: AUSTRALIA (LAND USE)

SCALE: 1:6,000,000

Dominant Land Use, 1957, Atlas of Australian Resources
Department of National Development, Canberra

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Beef Cattle | 4-5 | | | |
| Breeding | 4-5[1] | X | X | |
| Breeding and Fattening | 4-5[1] | X | X | |
| Intensive Breeding and Fattening | 4-5[1] | X | X | |
| Fattening | 4-5[1] | X | X | |
| Sheep and Cereals | 3-4 | | | |
| Wool | 3-5[1] | X | X | |
| Wheat or Other Cereals with Wool and Fat Lambs | 3-5[1] | X | X | |
| Wool and Fat Lambs | 3-5[1] | X | X | |
| Dairy Cattle | 3-5[1] | X | X | |
| Sugar Cane | 2-3 | X | | |
| Fruits, Vines, Vegetables, Rice, Tobacco, Cotton, etc. | 2-4 | X | | |
| Timber | 1-2 | X | | |
| No Significant Use | 3-4 | | X | X |
| Built-Up Areas | 1-2 | X | | |

[1] Some inferences could be made about the particular livestocking activities depending largely on identification of feed lots, dairy barns, etc., but this is an abstract expression of the area not indicative of its physical nature.

TABLE X

AREA MAPPED: SÃO PAULO, BRAZIL

SCALE: 1:6,000,000

Land Use, Latin America, P. E. James, 1942, p. 482

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Livestock Ranching without Forage Crops | 4 | X | X | |
| Forest Products | 4 | X | | |
| Sedentary Subsistence Agriculture | 3-5 | X | X | |
| Shifting Cultivation | 3-5 | X | X | |
| Coffee | 4-5 | X | | |
| Cotton | 3-4 | X | | |
| Sugar | 2-4[1] | X | | |
| Oranges | 2-4[1] | X | | |
| Bananas | 2-4[1] | X | | |
| Vineyards | 2-4 | X | | |
| Truck Crops | 4-5 | X | | |
| Mixed Crops of Parana Colonies | 4-5 | X | | |

[1] If these are regular-patterned commercial enterprises, they should be fairly well identified; if grown haphazardly they may be even more difficult to identify.

TABLE XI

AREA MAPPED: UNITED STATES

SCALE: 1:5,000,000

Major Land Uses in the United States, 1950
F. J. Marschner, Ag. Handbook 153, USDA

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Cropland and Pastureland | 2-3[1] | X | X | |
| Cropland, Woodland, and Grazing Land | 2-3 | X | X | |
| Irrigated Land | 2-4 | X | | |
| Forest and Woodland Grazed | 4-5 | X | X | |
| Forest and Woodland Mostly Ungrazed | 4-5 | X | X | |
| Sub-Humid Grassland of Semi-Arid Grazing Land | 4-5 | X | X | |
| Open Woodland Grazed | 4-5 | X | X | |
| Desert Shrubland Grazed | 4-5 | X | X | |
| Desert Mostly Ungrazed | 3-4 | X | X | |
| Alpine Meadows and Mount. Peaks above Timberline | 2 | X | | |
| Swamp | 3-4 | X | | |
| Marshland | 3-4 | X | | |

[1]The natural vegetation types, as listed, should be fairly distinct, but to determine whether or not they are grazed would not often be possible. The major categories are generalized from statistical sources.

Table XII is based on Jenks' map of the Geographic Pattern of Kansas Agriculture, 1961. With photographs obtained at two or three critical times during the growing season, wheat, pasture, irrigated areas and the valley bottom intensive categories should be acceptably distinguished. As seen in the footnote to the table there will be some confusion between grain sorghums and corn in areas of overlapping distributions. Photography and radar late in the growing season may make discrimination between these categories acceptable.

A map with such simple, generalized, and visually distinct categories as the land use map of the U.S.S.R. (Table XIII) should be quite readily done from space photography of 100 foot resolution.

Table XIV summarizes the information in the sample selection of maps, especially in that it indicates the mean capability value for mapping categories similar to those listed on each map using space data. Several summary statements can be made. First, there is no direct relationship between the type of map or the scale of the map and the capability to recreate similar maps using space data sources. Map makers do not always, as one might expect, relate scale and the level of generalization of the mapped phenomena. Both large and small scale maps are often highly generalized; either of them may also exhibit rather sophisticated renderings of phenomena distributions. Areal generalization is the compensating factor. Of course the very small scale maps demand a degree of generalization of phenomena, and in the case of the two smallest scale maps in our sample the phenomena categories are extremely simple. However, one map of very large scale consisted of similar very simple categories.

The number of map categories is the factor which tends to correlate best with the ability to recreate the map using satellite data. A limited number of categories tends to correspond with high space data mapping potential while numerous categories tend to belie such potential. This is probably due to the fact, as earlier mentioned, that maps of few categories tend to separate major blocks of very different kinds of things such as forest, grassland, cultivated land, and settlement. Once these major

TABLE XII

AREA MAPPED: KANSAS

SCALE: 1:2,000,000

The Geographic Pattern of Kansas Agriculture
Kansas Ind. Dev. Comm. and G. F. Jenks, 1961

| Map Categories | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories: Abstract (Including statistical) | Nature of Categories: Synthetic or Residual |
| Major Wheat | 2 | X | X | |
| Major Wheat and Minor Pasture | 2 | X | X | |
| Minor Wheat | 2 | X | X | |
| Minor Wheat and Minor Pasture | 2 | X | X | |
| Major Pasture | 2 | X | X | |
| Irrigated | 2 | X | X | |
| Grain Sorghums and Wheat | 2-3[1] | X | X | |
| Kaw Valley Intensive | 1-2 | X | X | |
| Major Corn | 2-4[1] | X | X | |
| Minor Corn | 2-4[1] | X | X | |
| Minor Corn and Minor Pasture | 2-4[1] | X | X | |

[1] Because they have very similar growth and time cycles grain sorghums and corn will be very difficult to discriminate between in areas of overlapping distributions. This accounts for the reduction in capability. If a category coarse-grains were erected the capability would increase substantially.

TABLE XIII

AREA MAPPED: U.S.S.R.

SCALE: 1:50,000,000

General Survey of the U.S.S.R., Land Use Sub-Map
CIA (No Date)

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories | |
| | | | Abstract (Including Statistical) | Synthetic or Residual |
| Forested or Wooded Area | 1 | X | | |
| Principal Cultivated Area | 1 | X | | |
| Other (Tundra, Swamps, Arid Areas, Mountains) | 1 | X | | X |

TABLE XIV

SUMMARY OF CAPABILITY TO DUPLICATE SAMPLED MAPS USING SPACE DATA

| Map Location | Mean Capability to do From Space | Map Type | Number of Categories | Map Scale |
|---|---|---|---|---|
| French North Africa | 1.00 | Land Use | 6 | 1: 5,000,000 |
| China | 1.00 | Agriculture | 2 | 1: 7,500,000 |
| U.S.S.R. | 1.00 | Land Use | 3 | 1:50,000,000 |
| Craighead Co., Ark. | 2.00 | Land Use | 3 | 1: 62,500 |
| Australia | 2.13 | Forest | 7 | 1: 6,000,000 |
| Kansas | 2.27 | Agriculture | 11 | 1: 2,000,000 |
| Ecuador | 2.44 | Forest | 9 | 1: 4,000,000 |
| Great Britain | 2.50 | Land Use | 7 | 1: 625,000 |
| Southern Peru | 2.83 | Land Use | 6 | 1: 6,000,000 |
| Northwest Africa | 2.90 | Agriculture | 5 | 1: 3,800,000 |
| Portugal | 2.94 | Agriculture & Vegetation | 9 | 1: 1,000,000 |
| Israel | 3.08 | Landscape Regions | 38 | 1:150,000 |
| Dumbarton & Lammermuir | 3.13 | Land Use | 14 | 1:63,360 |
| North Antrim | 3.25 | Land Use | 6 | 1:63,360 |
| Truro, Nova Scotia | 3.38 | Land Use | 16 | 1:250,000 |
| Malaysia | 3.53 | Vegetation | 18 | 1: 5,000,000 |
| United States | 3.58 | Agriculture & Vegetation | 12 | 1: 5,000,000 |
| Australia | 3.60 | Land Use | 13 | 1: 6,000,000 |
| Australia | 3.63 | Vegetation | 35 | 1: 6,000,000 |
| Isle of Thanet | 3.64 | Land Use | 37 | 1:25,000 |
| Malaya | 3.69 | Forest | 8 | 1:760,320 |
| Malaya | 3.75 | Land Use | 8 | 1:760,320 |
| Sao Paulo | 3.75 | Land Use | 12 | 1: 6,000,000 |

groupings are assigned, any additional categories are required to separate more alike phenomena and, in fact, are usually sub-categories of the major phenomena.

Very few existing land use maps at any scale could be exactly duplicated from spacecraft data. This arises because practically every map we have inspected mixes some categories which could be observable using space data with others which are non-observable. The non-observable categories may require a) too fine a spatial resolution, b) information which is not obtainable from space, being obtained from statistical sources or inferences, or c) it represents a synthesis of material often from statistical sources.

But this evaluation has been based on traditional types of land use maps and the kinds of categories they have always employed. It is further apparent that no consistent and rational theme of land use categories runs through the maps we have studied. Many of the maps are composed of illogical and inconsistent categorization schemes. Most are biased by the particular area mapped, giving emphasis to land uses which would be of little importance considering the world scale. It seems reasonable to assume that, if the concept of regions and regional identities is correct, then certain patterns of land use which have heretofore been overlooked should be apparent from a space vantage.

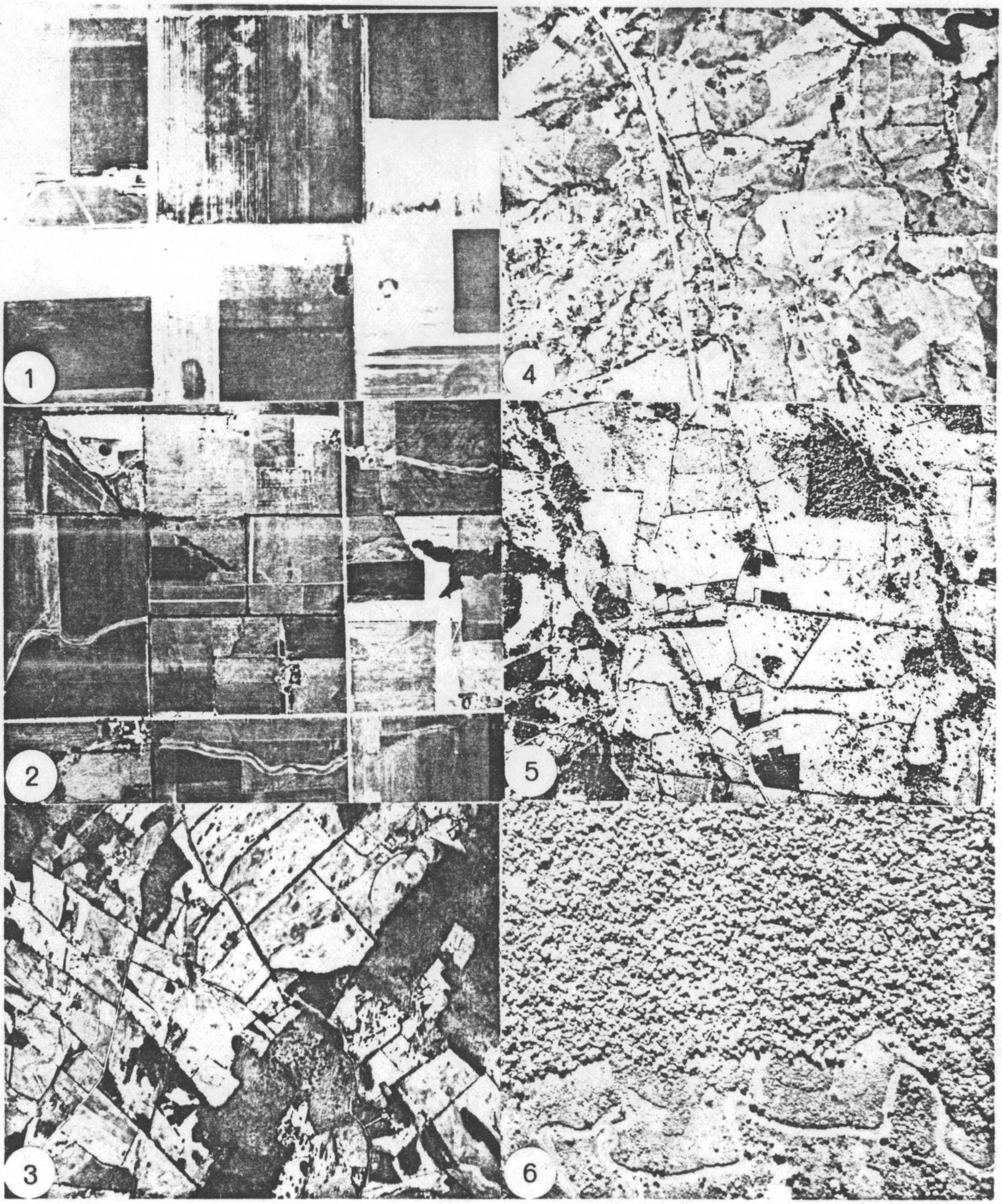
It will be unrealistic to expect that traditional land use categories with all their peculiarities may be mapped from space, and especially not detailed categories. Improved resolutions and modified land use schemes are both required for practical land use mapping from space. Both the role of resolution and testing of various classifications needs much additional study. A preliminary indication of the complexity of the classification problem has been given above. We may now pursue the relations between information and resolution for different environments.

## THE QUESTION OF RESOLUTION IN THEMATIC LAND USE MAPPING

Both nature and man mix land use entities such as cropland and trees in a variety of ways in different environments. Parcels of different sizes and shapes are mixed in quite dissimilar patterns. In the face of such diversity each environment yields a different level of information as a function of a given resolution. This is somewhat contrary to our preliminary estimates of a year ago (Simonett, 1968) and to the statements of Frey (1967). We cannot set rigid resolution requirements indicating that a given type or level of land use information will be equally available for all environments at that resolution. The size, shape, and arrangement of the landscape elements in each environment will affect the optimum resolution/decision cell size for a particular level of land use information in that area.

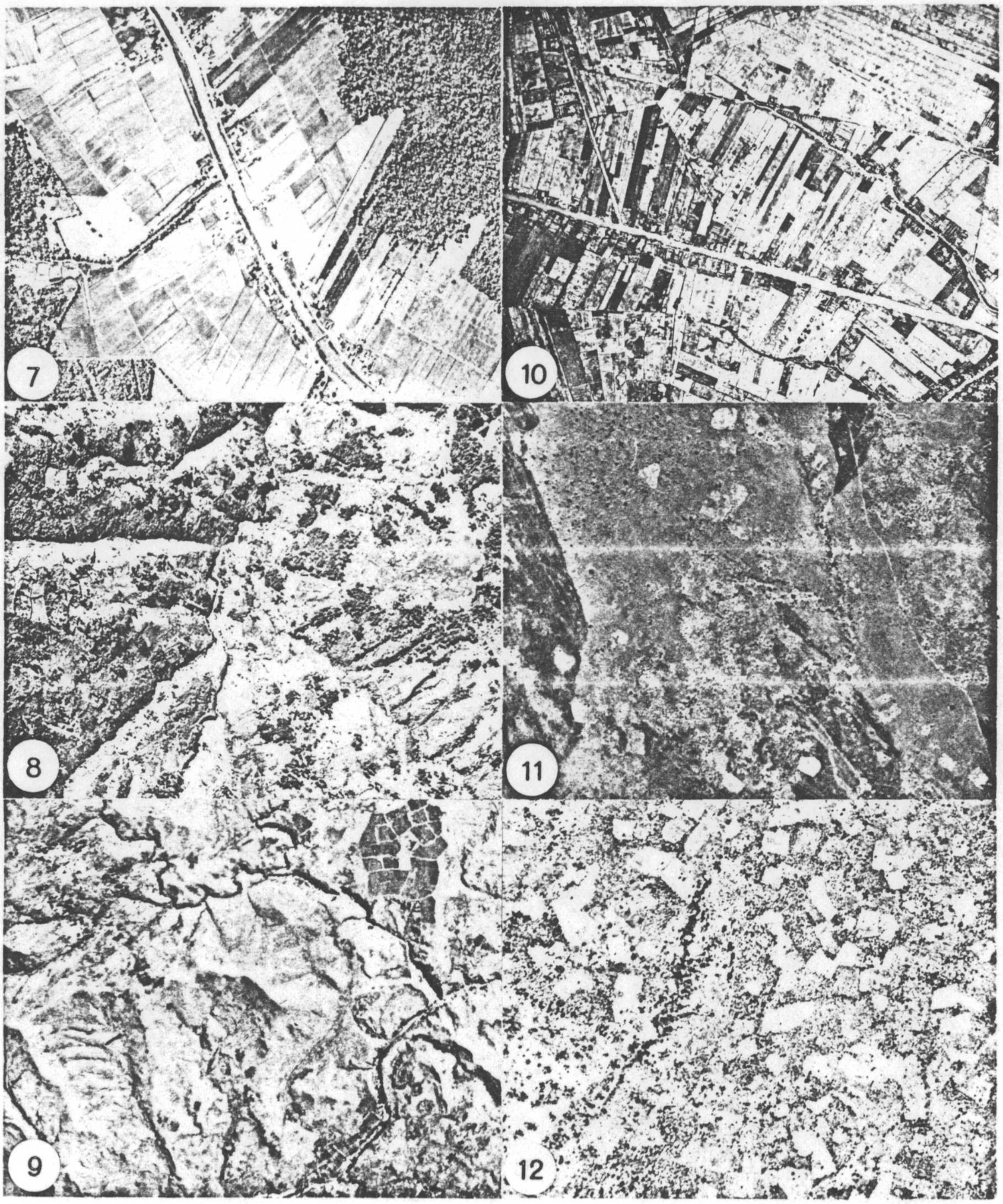
To illustrate that the level of land use information is environmentally modulated, selected areas exhibiting various types of natural and cultural landscapes have been sampled. These include eastern Kansas, western Kansas, eastern Virginia, Costa Rica, Puerto Rico, South Vietnam, Tanzania, and Panama. A sample of the photography used in each area is shown in Figures 1a and 1b. All are shown at a common scale. Only the Houma, Louisiana area is not included among the tabulations in this report. It and other regions representative of many world environments are included in more extensive studies now underway.

The sampling procedure consisted of overlaying large scale aerial photographs with grids representing 1000, 400, 200, 100, and 50 foot resolution/decision cells. These resolution/decision cells are intended to represent the area over which generalizations may have to be made depending on the quality and ground resolution of space data employed in land use studies. It is therefore important to determine the type and degree of integration of land uses which may occur in a cell of each size for diverse environments. The number of different land use categories contained in each cell was tabulated for an entire 9 x 9 inch aerial photo-




| SITE | ORIGINAL SCALE |
|---|---|
| 1. Garden City, Finney County, Kansas | 1:15,000 |
| 2. Lawrence, Douglas County, Kansas | 1:15,000 |
| 3. Gordonsville, Orange County, Virginia | 1:20,000 |
| 4. Caguas, Agua Buenas, Puerto Rico | 1:20,000 |
| 5. Venecia, Alajuela Prov., Costa Rica | 1:43,000 |
| 6. La Palma, Darien Prov., Panama | 1:35,000 |

Figure 1a. The above aerial photographs, brought to a common scale of 1:25,000, illustrate the variations in the size, shape, and arrangement of spatial elements which occur in differing world environments. These sample areas were included in those used in the tabulation of Tables XV through XX.




| | SITE | ORIGINAL SCALE |
|---|---|---|
| 7. | Houma, Terrebonne Co., Louisiana | 1:20,000 |
| 8. | Bena Bena Area, New Guinea I | 1:35,000 |
| 9. | Bena Bena Area, New Guinea II | 1:39,000 |
| 10. | Thuan Dinh Prov., S. Viet Nam | 1:10,000 |
| 11. | Musensi, S. Highlands Prov., Tanzania IV | 1:31,400 |
| 12. | Igamba, S. Highlands Prov., Tanzania III | 1:28,000 |

Figure 1b. The above aerial photographs, brought to a common scale of 1:25,000, illustrate the variations in the size, shape and arrangement of spatial elements which occur in differing world environments. These sample areas were included in those used in the tabulation of Tables XV through XX.

TABLE XV

DECISION/RESOLUTION CELL SAMPLE SIZE

| Site | Cell Size | # Samples | % Photo Sampled |
|---|---|---|---|
| Costa Rica | 1,000' | 826 | 100 |
| | 400' | 900 | 16 |
| | 200' | 900 | 4 |
| | 100' | 900 | 1 |
| New Guinea (I) | 1,000' | 500 | 80 |
| | 400' | 500 | 13 |
| | 200' | 500 | 3 |
| | 100' | 500 | 1 |
| New Guinea (II) | 1,000' | 600 | 90 |
| | 400' | 600 | 14 |
| | 200' | 600 | 3 |
| | 100' | 600 | 1 |
| Tanzania IV | 1,000' | 400 | 100 |
| | 400' | 900 | 36 |
| | 200' | 900 | 9 |
| | 100' | 900 | 2 |
| Tanzania III | 1,000' | 380 | 100 |
| | 400' | 900 | 38 |
| | 200' | 900 | 10 |
| | 100' | 900 | 2 |
| Orange Co. Va. | 1,000' | 196 | 100 |
| | 400' | 400 | 32 |
| | 200' | 400 | 8 |
| | 100' | 400 | 2 |
| | 50' | 400 | 1 |
| Panama | 1,000' | 291 | 27 |
| | 400' | 923 | 24 |
| | 200' | 3600 | 23 |
| | 100' | 900 | 1 |
| Garden City, Ks. | 1,000' | 116 | 100 |
| | 400' | 554 | 74 |
| | 200' | 2149 | 72 |
| | 100' | 7736 | 64 |

(Continued on following page)

TABLE XV CONTINUED
DECISION/RESOLUTION CELL SAMPLE SIZE

| Site | Cell Size | # Samples | % Photo Sampled |
|---|---|---|---|
| Lawrence, Ks. | 1,000' | 119 | 100 |
| | 400' | 576 | 76 |
| | 200' | 2182 | 72 |
| | 100' | 7774 | 64 |
| Puerto Rico | 1,000' | 209 | 100 |
| | 400' | 1021 | 85 |
| | 200' | 3738 | 78 |
| | 100' | 1916 | 10 |
| S. Viet Nam | 1,000' | 56 | 100 |
| | 400' | 324 | 93 |
| | 200' | 891 | 64 |
| | 100' | 1603 | 29 |

graph or a sample of at least 400 cells in each resolution class for each sampled area. Table XV gives the sample sizes and percent of area sampled for each selected photograph. The main land use categories found were woodland, grassland, agricultural fields, shrubs and brush, roads, streams, and settlements. These major categories were additionally broken down where applicable, as will be detailed later.

The areas are grouped according to dominant form of agriculture and presented in Tables XVI, XVII, and XVIII. Table XIX presents results of a natural landscape. These tables indicate that there tends to be a critical resolution size for each environment at which, and for finer resolutions, a high level of detection of a homogenous entity becomes possible. The term, homogenous entity, is relative; it does not mean that only one kind of crop or plant is discriminated. Some generalization is necessary. It implies distinctions between fields, rather than distinctions within a field exhibiting variances of crop growth and vigor or patches of weeds, and distinctions between clumps of trees rather than between different tree species.

If it is desired to obtain photography at which 65-70 per cent of the resolution cells contain only one such category, the resolutions required for the three areas in Table XVI would be 200 feet for irrigation agriculture in Western Kansas, 100 feet for a mixed farming area in eastern Kansas and 50 feet for a mixed farming area in eastern Virginia. In two areas with a mixture of commercial and subsistence agriculture, Costa Rica and Puerto Rico (Table XVII), a resolution of finer than 100 feet would be required in order to detect single categories unambiguously. In South Vietnam (Table XVII) a resolution of less than 50 feet, perhaps as fine as 15 or 20 feet, would be required.

Areas of true subsistence agriculture in New Guinea and Tanzania (Table XVIII), yielded percentage results at the 100 foot resolution size similar to the mixed commercial-subsistence agricultural areas of Costa Rica and Puerto Rico, despite the smaller field sizes in the two former areas. This may be explained by the scattering of fields in New Guinea and Tanzania and the relative homogeneity of the landscape between fields.

TABLE XVI

COMMERCIAL AGRICULTURE

| SITE Type of Agriculture | Resolution Cell/Grid Size | Per Cent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| Western Kansas | 1,000' | 13.8 | 37.9 | 33.6 | 14.7 |
| Irrigated | 400' | 52.0 | 36.5 | 11.2 | 0.4 |
| Area | 200' | 71.5 | 23.7 | 4.8 | -- |
| (Garden City) | 100' | 83.8 | 14.7 | 1.4 | -- |
| Eastern Kansas | 1,000' | 10.1 | 31.9 | 39.5 | 18.5 |
| Mixed | 400' | 35.9 | 37.8 | 21.7 | 4.5 |
| Farming | 200' | 57.9 | 34.0 | 7.7 | 0.4 |
| (Lawrence) | 100' | 84.0 | 15.5 | 0.5 | -- |
| Eastern Virginia | 1,000' | 6.1 | 9.2 | 3.0 | 81.6 |
| Mixed farming | 400' | 10.7 | 15.6 | 17.7 | 56.0 |
| | 200' | 29.0 | 31.0 | 25.0 | 15.0 |
| (Orange County) | 100' | 64.7 | 20.8 | 11.0 | 3.5 |
| | 50' | 77.5 | 17.5 | 4.5 | 0.5 |

TABLE XVII

MIXED COMMERCIAL — SUBSISTENCE AGRICULTURE

| SITE | Resolution Cell/Grid Size | Per Cent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| Costa Rica | 1,000' | 3.0 | 17.2 | 32.9 | 46.9 |
| | 400' | 10.0 | 42.2 | 34.1 | 13.7 |
| | 200' | 21.4 | 68.5 | 10.1 | -- |
| | 100' | 63.7 | 35.4 | 0.9 | -- |
| Puerto Rico (Aguas Buenas) | 1,000' | -- | 2.9 | 4.8 | 92.3 |
| | 400' | 4.7 | 18.5 | 17.5 | 59.3 |
| | 200' | 12.7 | 22.6 | 16.7 | 48.0 |
| | 100' | 47.0 | 39.9 | 11.4 | 1.6 |
| South Vietnam Intensive | 1,000' | -- | -- | -- | 100.0 |
| | 400' | -- | 0.6 | 2.2 | 97.2 |
| | 200' | 6.2 | 21.8 | 37.4 | 34.7 |
| | 100' | 15.0 | 55.0 | 22.0 | 8.0 |
| | 50' | 36.0 | 45.0 | 11.0 | 8.0 |

TABLE XVIII
SUBSISTENCE AGRICULTURE

| SITE | Resolution Cell/Grid Size | Per Cent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| New Guinea II | 1,000' | -- | 19.3 | 58.2 | 22.5 |
| | 400' | 22.2 | 54.2 | 23.3 | 0.3 |
| | 200' | 27.9 | 64.7 | 7.4 | -- |
| | 100' | 45.3 | 49.7 | 5.0 | -- |
| Tanzania IV | 1,000' | -- | 10.5 | 28.3 | 61.2 |
| | 400' | 11.8 | 35.0 | 42.6 | 10.6 |
| | 200' | 40.3 | 57.3 | 2.3 | -- |
| | 100' | 59.4 | 40.6 | -- | -- |
| New Guinea I | 1,000' | 5.4 | 8.2 | 59.0 | 29.4 |
| | 400' | 11.4 | 66.2 | 22.4 | -- |
| | 200' | 17.2 | 68.2 | 14.6 | -- |
| | 100' | 40.4 | 59.2 | 0.4 | -- |

TABLE XIX

TROPICAL RAIN FOREST

| SITE | Resolution Cell/Grid Size | Per Cent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| Panama | 1,000' | 79.7 | 11.7 | 6.5 | 2.1 |
| Darien Province | 400' | 92.4 | 7.4 | 0.2 | -- |
| | 200' | 97.2 | 2.8 | -- | -- |
| | 100' | 97.7 | 2.2 | -- | -- |

The reduction of the cell size from 400 to 100 feet in a rainforest environment in Panama (Table XIX) yielded little improvement with respect to the percentage of cells containing only the one "lumped" category, rainforest. Miller (1960) indicated that "most tropical forests are so mixed that it is not possible to describe or identify them on the basis of one or even a few species". A resolution size of 400 feet, therefore, appears to be quite acceptable for very generalized land use mapping in this area.

Some further implications of this technique may now be explored via the generalization of categories used in Orange Co., Virginia, as shown in Table XX, and the categories used in Tanzania and shown in Table XXI. The groupings under the headings A and B in Orange County are two criteria by which the number of categories in the resolution cells were tallied. Percentages of the cells containing one, two, three, and four or more categories for the two levels of generalization are given. The greatest variance between the two is found in the percentages of cells which contained four or more categories. There is a tendency for the differences between the two levels of generalization to become less as the resolution cell size decreases and for these percentage differences to become nearly uniform at the smaller cell size.

Similarly, we may consider the generalization of categories in Tanzania (Table XXI). The entities under A and B are again the criteria by which categories were grouped or discriminated and counted. The percentages given in Table XXI show wide variations at the 1,000 foot resolution cell size and substantial differences at the 400 foot cell size. The percentages of A and B at a resolution cell of 100 feet are nearly the same. The implication is again clear that the finer resolutions are the more desirable, regardless of the level of generalization. However, it is also clear that much thought must be given to the establishment of meaningful land use categories and to systematic rules for tallying data. Further work in this area will rest on systematic procedures worked out through trial and error in this study.

In concluding this section we may re-affirm our earlier conclusions that when a given resolution is used the information obtained with this

TABLE XX

COMMERCIAL AGRICULTURE

| SITE Type of Agriculture | Resolution Cell/Grid Size | Percent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| Eastern Virginia | 1,000' | 6.1 | 9.2 | 3.0 | 81.6 |
| A (Ungeneralized)[1] | 400' | 10.7 | 15.6 | 17.7 | 56.0 |
| | 200' | 29.0 | 31.0 | 25.0 | 15.0 |
| | 100' | 64.7 | 20.8 | 11.0 | 3.5 |
| | 50' | 77.5 | 17.5 | 4.5 | 0.5 |
| B (Generalized)[2] | 1,000' | 7.1 | 9.2 | 6.6 | 77.1 |
| | 400' | 13.7 | 19.3 | 24.0 | 43.0 |
| | 200' | 32.5 | 40.2 | 23.5 | 3.8 |
| | 100' | 69.2 | 24.5 | 6.3 | ---- |

Levels of Categorization Employed

[1]A (Ungeneralized Level of Categorization)

1) woodland
2) grassland
3) brush
4) individual cultivated fields
5) water bodies
6) roads
7) farmsteads
8) settlement

If several separate clusters of each appeared in a single cell, each cluster was counted as a separate land use entity.

[2]B (Generalized Level of Categorization)

1) All woodland in a cell as a single category.
2) All grassland in a cell as a single category.
3) All brush in a cell as a single category.
4) All cultivated fields.
5) Water bodies.
6) Settlement (including roads and farmsteads).

TABLE XXI

SUBSISTENCE AGRICULTURE

| SITE | Resoultion Cell/Grid Size | Percent of Decision/Resolution Cells Containing Specified Number of Categories | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 or More |
| Tanzania III | 1,000' | -- | 7.6 | 22.4 | 70.0 |
| A (Ungeneralized)[1] | 400' | 12.0 | 39.2 | 40.1 | 8.7 |
| | 200' | 34.4 | 58.7 | 6.9 | -- |
| | 100' | 67.7 | 29.2 | 3.1 | -- |
| Tanzania III | 1,000' | 3.3 | 24.3 | 61.5 | 10.9 |
| B (Generalized)[2] | 400' | 15.0 | 58.0 | 25.3 | 1.7 |
| | 200' | 42.0 | 51.1 | 6.9 | -- |
| | 100' | 69.7 | 28.7 | 1.6 | -- |

Levels of Categorization Employed

[1]A (Ungeneralized Level of Categorization)

Each cluster of a category is treated as a separate entity

1) Woodland - dense clumps of trees, sometimes with minor amounts of scrub or brush.
2) Grassland - clearings, grassy areas, sometimes with isolated, scattered trees; non-continuous trees or scrubs in a grassy matrix.
3) Brushland - predominately intermediate size vegetation when differentiated from trees.
4) Stream courses (including bank vegetation, sand bars, stream bed and stream).
5) Individual agricultural fields (perhaps with some grouping of contiguous fields with the same gray tone.
6) Settlement and roads (paths) when comprising 10% of a cell.

[2]B (Generalized Level of Categorization)

Each category is totaled for a given cell (one entity)

1) All woodland in a cell as a single category.
2) All grassland in a cell as a single category.
3) All brushland in a cell as a single category.
4) All cultivated fields.

resolution will not be consistent from environment to environment and that a resolution of no poorer than 100 feet will be needed for "acceptable" results in most environments. It remains to be seen whether these inconsistencies will be tolerable using space photography with 100 foot resolution for a general land use mapping program.

## ENVIRONMENTAL COMPLEXITY AND THE DISTANCE-DECAY FUNCTION

That there tends to be a particular spatial frequency of land use elements in each type of environment suggests that a particular resolution or decision cell size is adequate for each, but this does not further imply that the use of that cell size will completely solve the ambiguity problems and render each decision cell ready for precise, rapid, automated land use determination. Land use categories, as they are normally conceived, consist of a specialized aspect of the environment, such as the indication of vegetation type, usually with no regard to the remainder of the environmental milieu. To segregrate special characteristics of each environment becomes an especially difficult problem if we consider that our data source will be spacecraft photography or other remotely sensed information. Such data integrate the total environment at each earth location and provide simply a particular photographic tone, color, or texture or combination of these influenced by all elements at that location. The field observer making land use determinations may ignore changes in soil color while concentrating on the mapping of vegetation. On space photography the effects of soil and vegetation will be mixed making it virtually impossible to extract the meaning of one without considering the other. Two major points are relevant:

1. When doing land use mapping from space it will be necessary to restructure our land use categorization schemes. Land uses seen from space will not be necessarily coincident with those mapped from the ground. The view from space will tend to yield groupings of phenomena different from our traditionally-conceived

land use categories, but they should be equally valid categories and perhaps even more accurate pictures of reality at the more generalized levels of land use.

2. Field work will always be desirable and probably absolutely necessary for the production of good quality land use maps even when using space photography as the primary data source. A ground observer is bound by his narrow field of view which greatly inhibits his ability to integrate land use over broad areas, but he is capable of making point by point determinations with great accuracy. Space sensing will provide the opposite but complementary perspective which integrates the various elements into land use complexes allowing us to "see the forest", while the field worker provides identification keys by "seeing the trees". No incompatability is seen in combining the advantages of using the strengths of each techniques.

We have noted that the frequency of land use elements varies from environment to environment, but we need also to learn more about the nature of environmental change from region to region. The world is not neatly composed of discrete environmental units exhibiting internal homogeneity with sharp delineations from one unit to the next. There is rather a complex interdigitation of these environmental units and the nature of change and its rate and direction is infinitely variable. This is an especially significant factor if we expect ultimately to do automated land use mapping, for if the automated device is "trained" to identify a particular land use in one environment, its ability to predict a similar land use in another area will be profoundly influenced by the environmental similarities or differences between the two areas. It is valid to assume that proximity of the two areas will influence the accuracy of automated predictions but preliminary indications are that automated training and prediction techniques are sometimes not suitably accurate at a distance of only a few miles. Fu et al. (1969), for example, found in the Purdue area that training on one flight line and predicting for an adjacent line 1 1/2 miles away, gave prediction accuracies as follows: oats, 80%; soybeans, 58%; corn, 58%; and wheat, 87%. The data were obtained June 28, 1966 and included twelve spectral channels from .400 to 1.000 nanometers. Similar results are being obtained in our studies near Lawrence, Kansas (Simonett and Brooner, 1969). There are many indications that mid-summer is not the most desirable time for optimum discrimination. Nevertheless, these results give us pause in the search to automatically predict land uses. All rates of change of these "distance-decay functions" will occur and they will also vary with direction of the "predicted area" with respect to the "training area". These distance-decays must be closely analyzed and careful allowance must be made for them before accurate automated interpretation of land use is feasible.

In the next section of this report we explore some practical land use mapping problems which relate to interpretation and cartographic classification and generalizing procedures, as well as to the respective roles of man and machine in mapping.

## SOME PROBLEMS OF INTERPRETATION AND CARTOGRAPHIC GENERALIZATION IN LAND USE MAPPING

In the discussion of the number of categories contained in resolution cells of different sizes it was seen (Table XVI) that with 100 foot resolution some 84 per cent of all cells in the Lawrence (Eastern Kansas) sample contained but a single category and that of the remaining 16 per cent almost all contained two categories. Since it appeared that a 100 foot resolution was suitable for this area, we next examined for the area close to Lawrence — where immediate field checks were feasible — some new problems of interpretation and cartographic generalization.

A simple land use mapping exercise was carried out to study these problems of interpretation and generalization. A portion of eastern Kansas encompassing all of four counties and portions of seven others (Figure 2) was mapped according to an eight category land use scheme at an initial scale of 1:250,000. Standard 1:20,000 panchromatic aerial photography

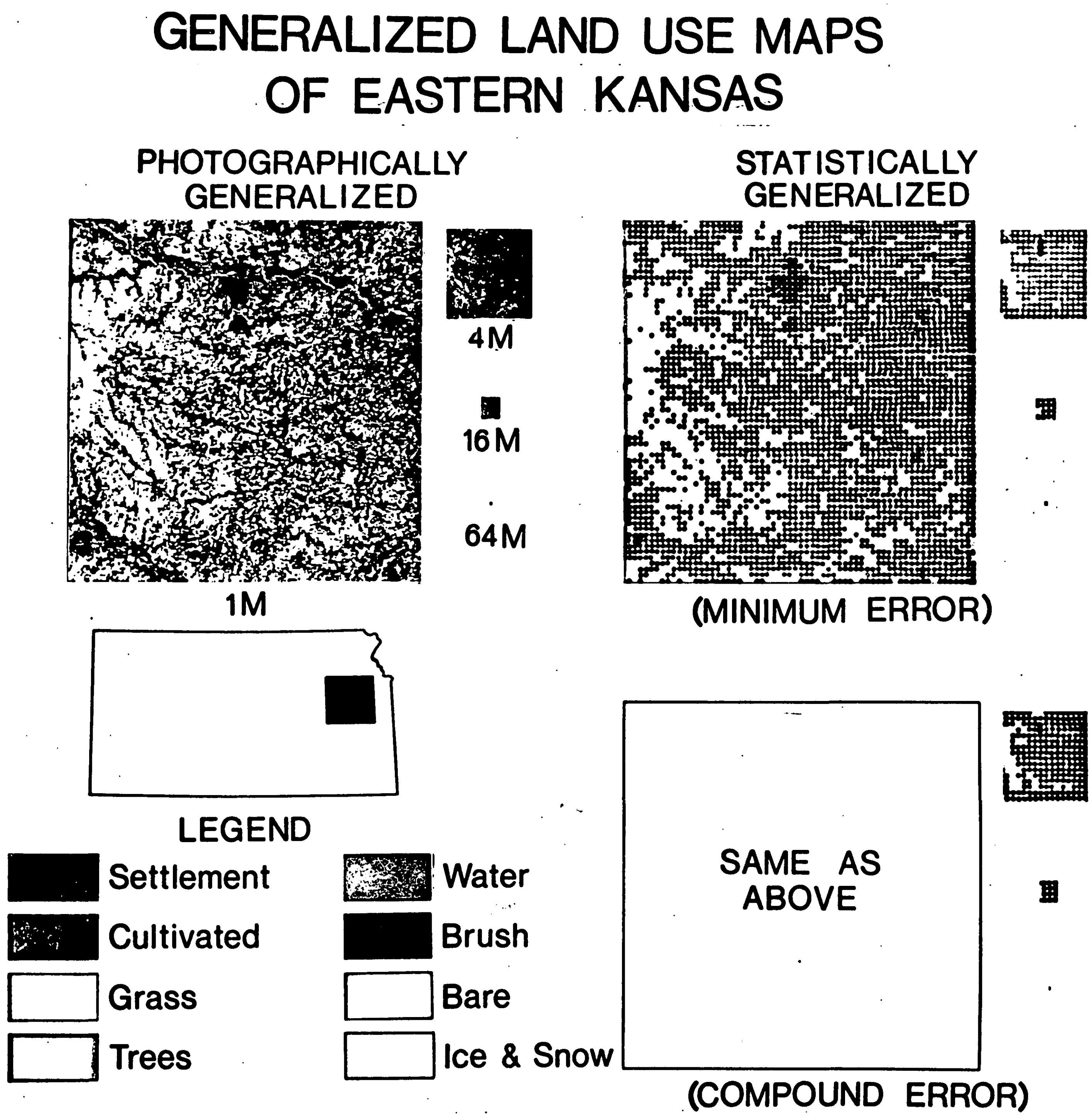



Figure 2. Photographic and statistical generalizations of the eastern Kansas land use map are compared above. Photographic generalization is superior at the larger scales, but the clutter of detail and problems of reproduction may tend to make the use of statistical generalizations more practical at small scales. Note: In preparing this illustration for page-size black and white reproduction, the scales have been altered and much detail has been lost. The scales are approximately 58% of that indicated (the 1:1,000,000 map should be 4 inches on a side at the proper scale). The color legend becomes ambiguous in black and white form; however, the three major categories, comprising nearly 96% of the total area are distinguishable: settlement is dark gray, cultivated is medium gray, and grass is very light gray.

was used as the data base. Certain of the problems encountered using imagery even of this scale and resolution were notable and are relevant to the interpretation and mapping from space data sources.

The mapping done in this exercise was restricted to very simple, broad categories. The ideal categorization scheme would be so-ordered that, first, it encompasses at a major level all conceivable land use types which might be encountered the world over to insure parallel emphasis in varying environments, and second, that it groups these uses into units which are both visually discrete and "meaningful" in land use terms.

Only the most major categorization was attempted in this study because to do a detailed breakdown we would need to know, first, what land use elements exist in the world, second, which of these could be determined with acceptable error using space, and third, what types of land use maps might usefully employ these elements.

In devising our classification therefore we bore in mind these questions of worldwide distributions of phenomena and visual discreteness of image categories, in a classification which attempts a generalized rendition of a hierarchical categorization of phenomena which is appropriate to all scales of mapping. The categories we have used are in a classificatory sense essentially indivisible: more detailed classifications would employ sub-divisions within the categories we have delineated.

The categories are as follows:

1. Settlements and associated non-agricultural land
2. Cropland
3. Grassland
4. Trees
5. Brush
6. Water
7. Naturally bare (bare rock, sand, etc.)
8. Snow and Ice

At the most generalized land use level, any segment of the earth's surface can be characterized as falling into one of the eight categories. Each is representative of an extensive portion of the earth's surface or is of such importance that relative areal coverage is immaterial, as in the case of "settlement".

The eight major categories are also similar to those proposed by the International Geographical Union commission on a world land use survey (Van Valkenburg, 1950). The major IGU categories are: 1) Settlements and associated non-agricultural lands, 2) Horticulture, 3) Tree and other perennial crops, 4) Cropland, 5) Improved pasture, 6) Unimproved grazing land, 7) Woodlands, 8) Swamps and marshes, and 9) Unproductive land. Such a classification is along traditional lines and assumes the intimacy of field work rather than the detachment of remote sensing. Our categories should be distinct enough to be visually separable using space-derived data. The distinctions between "cropland" and "grassland" or "trees" and "brush" involve both careful definition of what belongs in each category and interpreter training, and even with these there will be pertinent problems of identification. However, despite these problems our categories will tend to have less ambiguity for interpretation than distinguishing between "cropland" and "improved pasture" and between "woodlands" and "tree and perennial crops," and between grazing land and non-grazed land as given in the IGU classification. Either classification is appropriate for broad scale thematic land use mapping, but each supposes a different method of data collection. In our judgment the problem of devising classifications suitable for spacecraft mapping is serious and has yet to be faced in the earth resource disciplines.

There are several ways to go about making land use mapping decisions. An interpreter may draw bold lines around photographic areas which he considers to be distinct because of differences in tone, color, texture or pattern. Point by point decisions may also be made based upon the dominant category observed for each predetermined unit area of the photograph. Again the decisions are based on the appearance of the photography, but this time cell by cell. We have chosen to do interpretations using the point by point technique with 40 acres as our basic decision cell size. This method was chosen to most nearly simulate the process which a mechanized system would have to follow. Automatic scanning devices cannot make the kind of textural integrations and intuitive decisions which the human interpreter does in the drawing of his boundaries. By using the point by point technique we can make better decisions on the kinds of maps and mapping problems involved in automatic mapping, and we can also make more direct comparisons between human and machine interpreters.

Decisions must be made at some areal level. Land use determinations for infinitely small portions of land are impractical. The data source and the final map product largely determine which level of areal generalization is appropriate. Though we used large scale photography which had the potential for providing much detail, we used it for purposes of expediency and were otherwise trying to simulate problems of mapping from space data. The final maps which we envisioned were to be, at best, of medium scale (1:250,000) and would range to 1:64,000,000 in scale. Even at the more detailed scale of 1:250,000, the smallest area which can practically be plotted will be on the order of 40 acres. This is a cell of 1320 feet on a side. Systems of 100 feet ground resolutions should allow land use determinations on this order. However, even the extremely simple land use classification which we set up seemed to require finer decision cells for selected environments as documented earlier for Virginia, Puerto Rico, Tanzania and other locations.

To see in practice what the difference would be for the 10 acre and the 40 acre decision cell in Eastern Kansas, a portion of the area was also mapped using a 10 acre decision cell, which corresponds to areas 660 feet on a side. The land use information in this map (Figure 3) proved to be quite similar to that provided by the 40 acre generalization, particularly in regard to major boundaries between predominantly cultivated and predominantly grassland areas.

The same decisions had to be made for the 10 acre cells as were necessary when generalizing over 40 acres. The same problems of identifying phenomena were apparent, for 10 acre cells tend to encompass the same mixtures of trees, grass, cultivated fields or other categories as do the larger cells. A slightly finer-grained pattern was obtained using 10 acres as a base but the gain in the overall map pattern does not appear significant enough to warrant the greatly increased work burden. Thus

# LAND USE MAP INTERPRETATION EXPERIMENTS

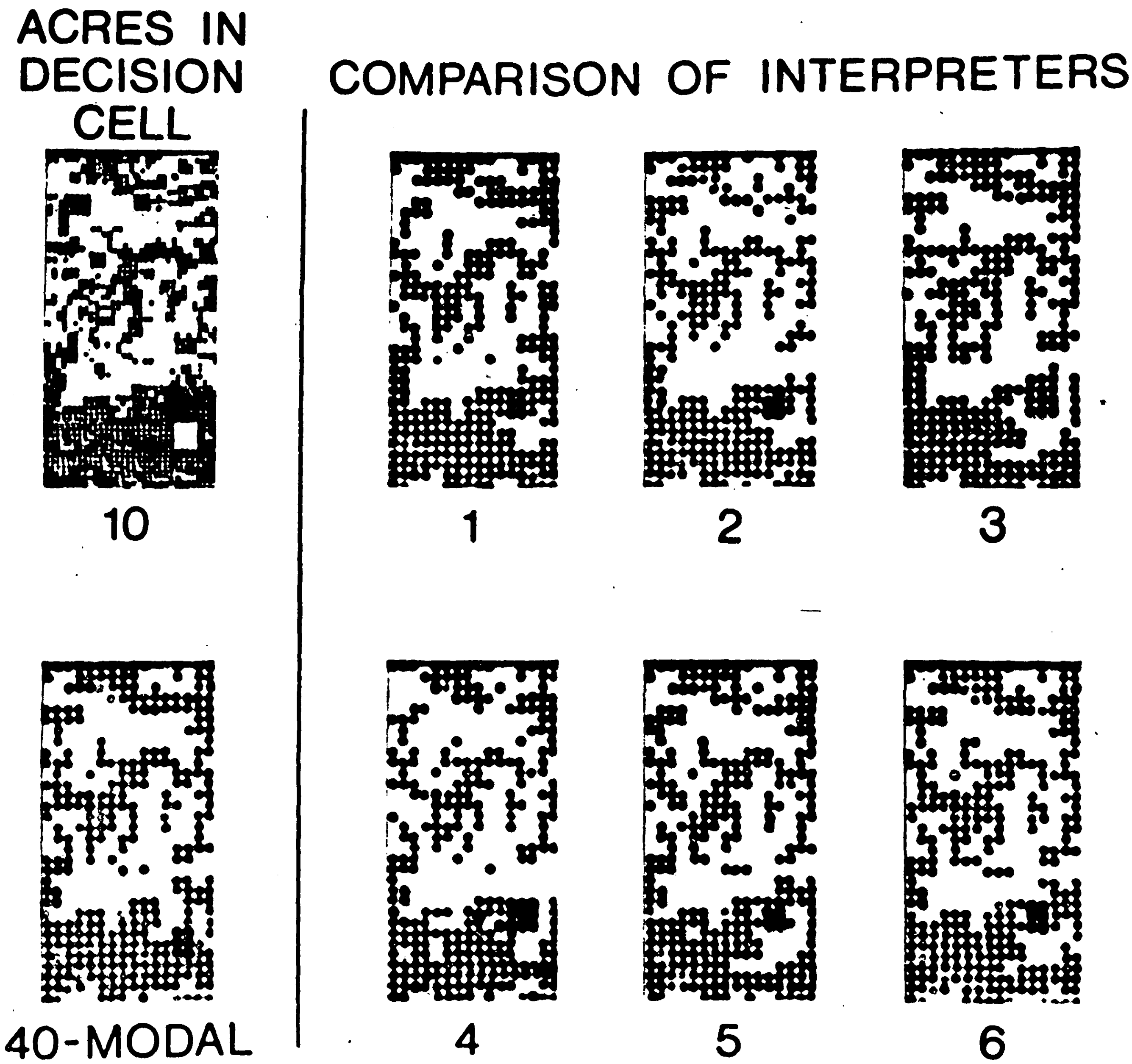



Figure 3. The above maps are of a 32 square mile sub-portion of the eastern Kansas land use map. The six on the right were each done by a different interpreter. The two on the left compare the results using 10 acre versus 40 acre decision cells. Although the details show some variation, the overall patterns are so similar that interpreter error appears to a minimal problem, and the increased time and work load needed for finer generalizations are not sufficiently beneficial to make its use practical.

the grosser generalization was adequate for our purposes at this time considering the map scale and level of category generalization. Further studies are underway on this problem.

Another facet of the areal generalization problem occurs whenever more than one land use category appears in a cell. Once the various land use elements in the cell have been distinguished the entire cell must be generalized and conceded to a single category. For our purposes the following rules were formulated:

1. The category occupying the most area within the cell determines the use of that cell.
2. If two or more categories occupy an equal area within the cell, the one representing the higher order of use determines the use of the cell. (The ordering was predetermined and is that order in which the land use categories were earlier listed).

Our eight category land use map based on forty acre decision cells is shown in Figure 4. The map was constructed at an original scale of 1:250,000. It is shown here at a scale of 1:1,000,000, in black and white thus obscuring some of the color detail. However, the major land uses are apparent: very dark gray is settlement; medium gray is cropland; and the very light gray areas are grassland. At the scale of 1:250,000 each forty acre cell is one-sixteenth inch square on the map.[2] One sixteenth of an inch is considered a reasonable minimum reporducible area on a finished color map requiring screening and careful registration. This simple map even at the 1:1,000,000 scale shows significant settlement and agricultural patterns. From the major city of Topeka to the very small hamlets, the pattern of agglomerated settlement is seen and the influence of the rivers is clear. Though only the Kansas River is wide enough to actually appear in the water category on the map, the courses of others are betrayed, especially in western portion, by the fingering of the medium gray tones of the intensively cropped floodplains into the grassy (very light gray)

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[2]Actually, the map was constructed at 1:125,000 for convenience in plotting the data so that 1/8 inch cells could be colored rather than 1/16 as was required at 1:250,000.

Figure 4. Land use of a 4096 square mile area of eastern Kansas. This map was prepared to simulate the problems and specify the potentials of generalized land use mapping using space data. The map was designed for an original scale of 1:250,000, but is shown here reduced to 1:1 million which still retains much detail. This black and white reproduction of the color map does not sufficiently distinguish all eight categories. But the three major land uses (nearly 96% of the total area) are: Very dark gray is settlement, medium gray is cropland, and very light gray is grassland. Note how the cropped floodplains contrast with the grassy uplands in the left portion, and note also that even the small hamlets are distinct.

uplands. The pattern of dominantly crop agriculture with scattered woodland remnants in the east is seen to give way to the grazing lands of the Flint Hills toward the west. Even this elementary map thus has useful application in resource management. Data for a similar map using space photographs may be within the capabilities of current remote sensors. Tests of this will be carried out in the Dallas-Fort Worth area using resolutions between 10 feet and 300 feet with aircraft and space color photography during the summer and fall of 1969.

Interpreter error became obvious during the compilation of the data. Most of the categories were readily distinguished based on pre-determined definitions. No "snow and ice" was observed but that category should be readily distinguished where it does occur for, with stereoscopy from space, clouds will be separable from snow. A few cells were classed as "bare." These must, by our definition, be naturally occuring barren land such as bare rock, sand dunes, gravel beds and the like. In our area such occurrences large enough to dominate a forty acre cell are usually limited to sandy bars associated with the major streams. Water areas are readily distinguishable as are areas of settlement which were defined, for our purposes, to include all areas evidencing alteration by man, other than crop or pasture land. Thus settlement includes transportation facilities including airports, recreation areas such as parks and golf courses, mines, and so forth. (Obviously with spacecraft resolutions golf courses and parks on the edges of cities will tend to be lumped with grass or cultivation, not settlement.)

The major difficulties of phenomena identification were the grassland-cropland distinction and the tree-brush distinction. Enclosed grassy pastures were classed as grassland for our purposes. It is doubtful that they could be so identified using space data since such definition is not always clear even on the 1:20,000 scale photography used here. Such areas should properly be included with cropland in future studies leaving the grassland category composed of the more open expanses.

The tree-brush distinction requires a clearer definition of the category than was utilized. We recognized that trees were relatively taller than brush and further we decided that if a stand broke up we would classify the areas as brush rather than trees. Whether such distinctions will be more or less readily made from the smaller scale space photographs than from the detailed photos used in our study is still uncertain. A brush or scrub vegetation category is deemed proper due to the broad areas of the world where its various sub-types are prevalent, such as maquis, caatinga, leguminous-myrtaceous scrub, and others.

In order to test the consistency between interpreters a sub-portion of the area was classified and mapped by each of six interpreters as shown in Figure 3. Visually comparing these six indicates that, though some variations are evident, the overall patterns are little different. A more detailed statistical comparison between these interpretations will be made at a later time in connection with a simulation of machine categorization problems.

If similar space-derived map data were available for the world, maps of less detailed scales would be needed to properly consolidate the data at desired smaller scales. The two basic alternatives of scale generalization mechanisms are photographic and statistical reduction. That is, either we may photographically shrink the larger map to allow the coalescence of the data or we may average a given number of cells and replace these by one cell representative of the "average" land use for all those cells. The series of maps and the discussion which follow indicate relative differences in photographic generalization and two types of statistical generalization.

An initial mapping scale of 1:250,000 is appropriate to the quality and resolution of most present space data and to most which will be acquired in the next decade. Smaller scales are required for regional, national, continental and world maps of functional sizes. It is proper, therefore, to plot the data at the most detailed scale possible and then generalize these data by the most appropriate technique.

One method is to statistically generalize the data to compensate for shrinkage of map scale. In our instance, the initial map, at a scale of 1:250,000 had its scale successively quartered to produce maps at scales of 1:1,000,000, 1:4,000,000, 1:16,000,000, and 1:64,000,000. If we desire to retain the same minimum printed unit on each finished map, this requires that the number of cells must be quartered also with each reduction. Thus, where a 160 acre area on the 1:250,000 scale map consisted of four discrete units, with the reduction to 1:1,000,000 scale these four units were averaged and replaced by a single unit. The resultant maps from these successive statistical reductions are shown in the right half of Figure 2. The same criteria for generalization as were employed in the original decision making were used; that is, the land use category with the majority of sub-cells becomes the assigned land use for the generalized cell, if an equal number of cells fall into two or more land use categories the generalized cell is assigned the category of highest use.

Certainly, with each reduction of the data the generalizing on the map becomes coarser. Coarseness must increase as the map scale decreases, but it can be minimized if with each scale reduction we revert back to the original map (where the "map" is regarded as a synonym for the 40 acre decision cells, stored with their geographic coordinates on magnetic tape) as our data source. If the error of each generalization step is compounded; that is, if we reduce the data successively from 1:250,000 to 1:1,000,000 to 1:4,000,000 to 1:16,000,000 to 1:64,000,000, the resultant total error is greater than if each generalization is a reduction of the original map data; that is, from 1:250,000 to 1:1,000,000, from 1:250,000 to 1:4,000,000, from 1:250,000 to 1:16,000,000 and from 1:250,000 to 1:64,000,000. Though the error introduced by compounding does not usually greatly alter the overall pattern it is significant enough and easily enough eliminated that it should be avoided. Comparison of the maps in Figure 2 at a scale of 1:16,000,000, i.e., smaller than the scale of the U. S. National Atlas (1:7,500,000), indicates that the compounding difference alone accounts for a six per cent error in this example.

Photographic reductions of the maps were also made to the same scales as the statistical reductions and are included in Figure 2. The 1:250,000 scale map is too unwieldy to be included in the report and is not necessary to its understanding. Certainly the 1:1,000,000 and 1:4,000,000 scale photographically-generalized maps still contain much detailed information which is lost in either of the statistical generalizations. The latter have dropped out all save the largest city (population of about 125,000 at the time of the photography, 1960) and no stream pattern is evident. The photographically-generalized map clearly retains all cities of about 10,000 population and over, and even smaller ones remain identifiable. The pattern of trees and brush is almost lost but can still be seen though on the statistical reductions it has been averaged out because of its minimal areal importance. Note that the major floodplains are still quite apparent in the photo reduction but have disappeared in the statistical rendering. Further reductions maintain the superiority of the photo reduction for preservation of detail.

It is difficult to envision what a full map at each scale would look like, and such a full view is essential for proper comparison of the data reduction techniques. It does seem obvious that the lesser reductions are best accomplished by photographic techniques. By photographic means one can take the cell size down much smaller than is feasible with plotting. At the scale of 1:1,000,000 and perhaps even 1:4,000,000 the scale is sufficiently large to warrant rather detailed renderings. But there is a cutoff point where the detail becomes so fine that most standard printing processes cannot properly reproduce it. The extreme clutter of detail of a full map reduced to 1/64 or 1/256 of its original scale may minimize its interpretability and the gross patterns may be difficult to abstract. For most very small scale maps some more basic generalization of the data, such as the statistical reduction, might well be proper.

It follows from this analysis that output data for decision cells from future semi-automated space-photograph pattern recognition systems should be made at as fine a resolution as feasible so that optimum decisions or further generalization may be made.

It is appropriate also to emphasize here that weighting functions other than those we used may be employed. Particular items, such as settlement could be so weighted that those occupying as little as 1/16, 1/64, or even 1/256 of a generalization cell could be called out for emphasis. A series of such specialized maps could then be produced to effect a size-filtering of the environment.

The preparation of a series of major generalized maps with a format similar to the eight category land use map introduced above, would not only provide basic inventory maps for planning purposes, but would serve also as a training ground for interpreters and interpretive techniques appropriate to space data. The state of Minnesota is already planning to prepare such a map but it must, of course, use aircraft photography since no Gemini or Apollo space photos are available for the latitude. Aside from attesting to the practicality of such maps, their experience will add further to the determination of appropriate and useful land use categories and to the techniques and problems involved in interpretation.

In our opinion the production of any land use maps from space data, whether specialized or generalized maps, will involve the human interpreter for at least the next decade. Immediate production of such maps would certainly be man oriented with automated processes providing the services they do best — rectification of imagery, the solving of scale and coordinate problems and the like. Thus the interpreter would be provided a visual display with the photograph already rectified, of the desired scale, and with coordinates assigned. He would then determine the land use for each decision cell. A series of coordinatographs would be attached to the display device to coordinate the proper cell location on photographic film, using one sheet of film for each map category. Thus, as each interpretation was made, the operator would press a button to expose the appropriate spot only on that piece of film corresponding to the interpreted land use type. The films would then be available for immediate use and thus there would be no intermediate steps between recognition and having publishable color separation plates immediately available.

The importance of developing an integrated system for decision-making and immediate recording in a form suitable for making separation plates cannot be stressed too much. In our experience the time for decision making has proven to be about one-tenth of that required to make the finished map because of the numerous re-processing steps involved. Our suggestion of the use of coordinatographs can short circuit these redundant steps.

In such a system, half-hour work spells would be needed because of the high rate of fatigue, but it should be possible for a single operator to make decisions at the rate of about 30 a minute. At this rate using 40 acre decision cells, 200 man/days of interpretation would provide a land use map of the United States ready for printing.

## SUMMARY AND CONCLUSIONS

Very few existing land use maps could be exactly duplicated from spacecraft data. However, many existing maps employ such illogical and inconsistent schemes of categorization that it is doubtful that exact reproduction would be useful or desirable. In addition, practically every map we have inspected mixes some categories which would be observable using space data with others which are non-observable. The non-observable categories may require a) too fine a spatial resolution, b) information which is not obtainable from space, being obtained from statistical sources or inferences, or c) it represents a synthesis of material often from statistical sources.

Space data should partially overcome the problem of piecing together information from a variety of non-uniform sources, but to assume that a given resolution will provide a uniform level of land use information regardless of the local environment is spurious. Environmental effects, both physical and cultural, have a profound influence on the size, spacing, and arrangement of even major landscape elements. To discriminate the broad, simple elements of land use in western Kansas can be rather well done by integrating over a resolution or decision cell of about 100 feet, but the intensive agricultural areas of Southeast Asia are not nearly adequately done even at 50 feet.

Careful study must be made of the inconsistency of meanings attached to photographic tones, colors and textures in different locales. Automatic interpretation devices cannot follow a subtle transitional change and keep in mind, as the human interpreter does, that it is but a variation of the same land use. These "distance-decay functions" must be carefully studied to determine how profound their effects are, how their direction and rate of change vary by phenomena and environment, and how well their effects can be calibrated out in order to allow effective automatic interpretation. It appears that because of environmental diversities, the effect of distance-decay, and the innate intuitive advantages that the human interpreter still maintains, the human interpreter will be necessary for at least the next decade, and probably much longer.

The new perspective of the earth provided by spacecraft data requires also that we re-appraise our view of land use elements in terms of how they are arranged, how they are associated, and especially how observable they are from orbital altitudes. New land use categorization schemes which realistically anticipate the limitations of space sensing can still produce quite useful maps.

Using space data for land use mapping will not make field work obsolete. Field work will still be invaluable for keying the identification or for pursuing in detail the study of some distribution brought to light by the use of space imagery. In some cases extensive field work will be necessary to make full use of spacecraft photography.

Broad-scale maps such as the long-proposed International Geographical Union's world land use map are of a type which may reasonably be expected to take fullest advantage of space data. A generalized land use map of a four-county area of Kansas was constructed for this report simulating the problems of space-data usage. Initial indications are that such a map is both practical and useful. Work has now begun using actual photography from the Apollo 9 mission to create a similar map of the Dallas-Ft. Worth, Texas area. Though the ground resolution of the photography to be used is about 300 feet, it is possible that acceptable results may be achieved. Photography with 100 foot resolution is to be obtained in the RB57 program in late September (1969) for the same area. These data will enable us for the first time realistically to anticipate the magnitude of both potentials and problems in land use mapping from space. Judgments in the present study have anticipated imagery of 100 foot resolution. Given that resolution, useful medium to small scale land use maps should be produced from spacecraft data.

## REFERENCES


Baker, S. (1968), An evaluation of crop and land use data in a world sample of countries: Economic Research Service, United States Department of Agriculture, Washington, D. C.

Clawson, M. and C. L. Stewart (1965), Land Use Information: A Critical Survey of U. S. Statistics Including Possibilities for Greater Uniformity: Resources for the Future, Inc., Washington, D. C.

Colwell, R. N. (1968), Determining the usefulness of space photography for natural resources inventory: Proceedings of the Fifth Symposium on Remote Sensing of Environment (April 1968); Institute of Science and Technology, University of Michigan, Ann Arbor, 249-290.

Committee on Geography, Advisory ro the Office of Naval Research (1966), Spacecraft in Geographic Research, Report of a conference on the use of orbiting spacecraft in Geographic research: National Academy of Sciences, National Research Council, Publication 1353, Washington, D. C

Frey, H. T. (1967), Agricultural application of remote sensing -- The potential from space platforms, Agriculture Information Bulletin No. 328, U. S. Department of Agriculture.

Fu, K. S., D. A. Landgrebe and T. L. Phillips (1969), Information processing of remotely sensed agricultural data: Proceedings of the I.E.E.E., 57(4), 639-653.

Gerlach, A. C. (1968), Advances in geographic and thematic applications of remote sensor data: Proceedings of the Fifth Symposium on Remote Sensing of Environment (April 1968); Institute of Science and Technology, University of Michigan, Ann Arbor, 191-196.

MacDonald, H. C. and A. J. Lewis (1969), Interpretation of radar imagery for terrain analysis in tropical environments, Submitted for publication to First International Symposium on Geoscience Electronics, IEEE, Summer, 1969.

Miller, R. G. (1960), The interpretation of tropical vegetation and crops on aerial photographs, Photogrammetria, 16(3), 232-240.

Simonett, D. S. and W. G. Brooner (1969), Crop-type discrimination with color infrared photography: preliminary results in Douglas County, Kansas, Included in second annual report on U.S.G.S. Contract No. 14-08-001-10848, CRES, University of Kansas.

Simonett, D. S., J. R. Eagleman, J. Marshall, and S. A. Morain (1969), The complementary rules of aerial photography and radar imagery related to weather conditions, Included in second annual report on U.S.G.S. Contract No. 14-08-001-10848, CRES, University of Kansas, Lawrence.

Simonett, D. S. (1968), The utility of radar and other remote sensors in thematic land use mapping from spacecraft, First annual report on U.S G.S. Contract No. 14-08-001-10848, CRES, University of Kansas, Lawrence.

Summer Study on Space Applications (1969), Useful applications of earth-oriented satellites: Forestry-Agriculture-Geography Prepared by Panel I of the Summer Study on Space Applications. National Academy of Science.

Van Valkenburg, S., (1950), The world land use survey, Economic Geography, 26(1), 1-5.

## APPENDIX A

TABLES EVALUATING THE CAPABILITY FOR DUPLICATING, FROM SPACE DATA, THE CATEGORIES USED ON SAMPLED MAPS

(Ten such Tables are included in the body of the paper — Tables IV through XIII.)

TABLE B-I

AREA MAPPED: MALAYA (LAND USE)

SCALE: 1:760,320

Malaya Land Utilization Map, 1953
Surveyor General of Malaya

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Rubber | 3-4[1] | X | | |
| Rice | 3[2] | X | | |
| Coconut | 3-4[1] | X | | |
| Oil Palm | 3-4[1] | X | | |
| Pineapple | 4 | X | | |
| Miscellaneous Cultivation | 4[3] | X | | X |
| Mining Land | 2-5[4] | X | X | |
| Forest Reserve | 5 | | | X |

[1] If plantation agriculture with row crops, there is a possibility to distinquish these crops.

[2] Major areas of irrigated rice should be apparent if data are collected at the proper time(s) during the growing season.

[3] Small subsistence plots will be difficult to identify. Other cropped land should be distinguished.

[4] Extensive mining operations should be apparent (2); however to classify and entire area as mining land is only a specialized abstraction of the nature of the area (5).

TABLE B-II

AREA MAPPED: MALAYA (FOREST)

SCALE: 1:760,320

Forest Resources of Malaya, 1954
Surveyor General of Malaya

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Forest Reserves (below 1000') | 2-5[1] | X | | X |
| Mangrove Reserves | 2-5[1] | X | | X |
| Forest Reserves over 1000' to the Gazetted Limit | 5[1] | X | | X |
| All other land over 1000' | 5[1] | X | | X |
| Rubber, Coconut, Oil Palm, and misc. cultivation | 3-4[2] | X | | |
| Pineapple and Rice | 3-4[3] | X | | |
| Mining Land | 2-5[4] | X | X | |
| Coast Deposits and Alluvium | 2 | X | | |

[1] Forest or Mangrove from non-forest distinctions should be fairly clear as should be the approximate delineation of the 1000' contour (2). The reserve in the definition is infeasible (5).

[2] If these are planted in regular patterns, all but the smallest subsistence plots may be distinguished.

[3] Depending on plot size and season of data collection, these crops may be distinguishable.

[4] Extensive mining operations should be apparent (2); however to classify an entire area as mining land is only a specialized abstraction of the nature of the area (5).

TABLE B-III

AREA MAPPED: AUSTRALIA (FOREST)

SCALE: 1:6,000,000

Atlas of Australian Resources, 1959
Dept. Of National Development, Canberra

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories | |
| | | | Abstract (Inclusing Statistical) | Synthetic or Residual |
| Rain Forest | 1-2 | X | | |
| Eucalypt Forest | 1-2 | X | | |
| High Rainfall | 2-3 | X | | |
| Low Rainfall | 2-3 | X | | |
| Cypress Pine Forest | 2-3 | X | | |
| Riverain Forest | 1-2 | X | | |
| Woodland and Savannah Woodland | 2-3 | X | | |
| Mallee | 2-3 | X | | |

TABLE B-IV

AREA MAPPED: ISLE OF THANET

SCALE: 1:25,000

Land Utilization Survey of Britain (2nd Survey) 1958
Director General, Ordnance Survey

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Arable Land | 2-3 | X | | |
| Cereals | 2-4[1] | X | | |
| Ley Legumes | 2-4 | X | | |
| Roots | 2-4 | X | | |
| Green Fodder | 4 | X | | |
| Industrial Crops | 3-4 | X | | |
| Fallow | 4-5 | X | | |
| Market Gardening | | X | | |
| Field Food Crops | 4-5 | X | | |
| Mixed Market Gardening | 4-5 | X | | |
| Nurseries | 4-5 | X | | |
| Allotment Gardens | 4-5 | X | | |
| Flowers | 4-5 | X | | |
| Soft Fruit | 4-5 | X | | |
| Hops | 3-4 | X | | |
| Orchards | 3-4 | X | | |
| With Grass | 5 | X | | |
| With Arable Land | 5 | X | | |
| With Market Gardening | 5 | X | | |
| Grassland | 2-4 | X | | |
| Woodland | 2-3 | X | | |
| Deciduous | 2-3 | X | | |
| Coniferous | 2-3 | X | | |
| Mixed | 2-3 | X | | |
| Coppice | 4 | X | | |
| Coppice with Standards | 4 | X | | |
| Woodland Scrub | 4 | X | | |

(Continued on following page)

TABLE B-IV CONTINUED

AREA MAPPED: ISLE OF THANET

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Heath, Moorland, Rough land | 3-4 | X | | |
| Water and Marsh | 2 | X | | |
| Water | 1[2] | X | | |
| Freshwater Marsh | 2-3 | X | | |
| Saltwater Marsh | 2-3 | X | | |
| Unvegetated | 2 | X | | |
| Settlement | 2 | | | |
| Commercial and Residential | 2 | X | | |
| Caravan Sites | 5 | X | | |
| Open Space | 5 | X | X | |
| Industry | 3-4 | | | |
| Manufacturing | 3-4 | X | | |
| Extractive | 2-4 | X | | |
| Tips | 5 | X | | |
| Public Utilities | 5 | X | | |
| Transport (Port Areas, Airfields, etc.) | 2 | X | | |
| Derelict Land | 5 | X | X | |

[1] At selected times of the year cereal crop may be discriminated at level 2 , generally level 3 is most likely.

[2] Detection of water bodies is dependent on the size of the water body.

TABLE B-V

AREA MAPPED: NORTH ANTRIM

SCALE: 1:63,360

Land Utilization Survey of North Ireland, 1948

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Arable Land | 2-3 | X | | |
| Grasslands | 2-4 | X | | |
| Heath and Moorland | 3-4 | X | | |
| Orchards, Gardens, etc. | 3-5 | X | | |
| Land Agriculturally Unproductive | 2-5 | X | X | |
| Woodlands | 2-4 | X | | |

TABLE B-VI

AREA MAPPED: NORTHWEST AFRICA

SCALE: 1:3,800,000

Types of Farming, 1943
O.S.S., Map No. 2008

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Vineyards | 3[1] | X | | |
| Olives | 4 | X | | |
| Grains Interspersed with Pasture | 3 | X | | |
| Forest | 1-2 | X | | |
| Date Palms | 2-4[2] | X | | |

[1]All these categories have much ambiguity. For example vineyards and olives may be planted together.

[2]Oasis cultivation of dates should be easily detected. Other situations will be ambiguous to various degrees.

TABLE B-VII

AREA MAPPED: PORTUGAL

SCALE: 1:1,000,000

Carta Agricola e Florestal de Portugal, 1958
Direccao-Geral Dos Servicos Agricolas

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Arable Land | 2 | X | | |
| Plantations | 2-4[1] | X | | |
| Natural Grasslands | 2-3 | X | | |
| Horticulture, Gardens, etc. | 4-5 | X | | |
| Woods and Forests | 2 | X | | |
| Uncultivated Agricultural Land | 4[2] | X | X | |
| Inhabited Non-Agricultural Land | 4[2] | | X | |
| Water | 1 | X | | |
| Non-Agricultural Land with Dispersed Settlement | 3-4 | | X | |

[1] Depends on size, type of crop, and regularity of pattern.

[2] The nature of these categories is not really clear. Their distinction appears to be based on an appraisal of the agricultural potential of the land and the density of settlement. The above estimate of the ability to map such areas from space is conservative.

TABLE B-VIII

AREA MAPPED: SOUTHERN PERU

SCALE: 1:6,000,000

Land Use, Latin America, P. E. James, 1942, p. 159

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Shifting Cultivation | 3-4 | X | X | |
| Sedentary Subsistence Agriculture | 3-4 | X | X | |
| Livestock Ranching without Agriculture | 4 | X | X | |
| Irrigated Areas (Oases) | 2 | X | | |
| Permanent Snow | 1 | X | | |
| Wheat | 2-4 | X | | |

TABLE B-IX

AREA MAPPED: ECUADOR

SCALE: 1:4,000,000 (Approx.)

Forest Types, 1958, CIA 38193, 5-63

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories: Abstract (Including Statistical) | Nature of Categories: Synthetic or Residual |
| Tropical Rain Forest | 2-3[1] | X | | |
| Tropical Deciduous Forest | 2-3[1] | X | | |
| Subtropical Rain Forest | 2-3[1] | X | | |
| Mountain Forest | 3 | X | | |
| Mangrove Forest | 2-3 | X | | |
| Dry Forest | 2-3 | X | | |
| Desert | 2 | X | | |
| Inter-Andean Agricultural Land | 2-3 | X | | |
| Paramo | 2 | X | | |

[1] Though it would be difficult to identify the tropical forest sub-types, these three as a single category should be rather easily identified.

TABLE B-X

AREA MAPPED: CRAIGHEAD CO., ARK.

SCALE: 1:62,500

Highway Map with Land Use and Forest Information
Arkansas State Highway Commission, 1936, (With USDA Cooperating)

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Forest | 1-2 | X | | |
| Settlement | 1-4[1] | X | | |
| Other | 1-3 | X | | X |

[1]Towns should be readily distinguished down to populations of a few hundred. Smaller centers and roads will pose severe problems of detection.

TABLE B-XI

AREA MAPPED: FRENCH NORTH AFRICA

SCALE: 1:5,000,000 (Approx.)

Carte Economique (Carte No. 25, No Date)
Service Cartographique, Direction de la Documentation

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories | |
| | | | Abstract (Including Statistical) | Synthetic or Residual |
| Cultural Zones | 1 | X | | |
| Plateaus and Mountains (Steppes) | 1 | X | | |
| Desert | 1 | X | | |
| Erg | 1 | X | | |
| Woods and Forests | 1 | X | | |
| Oasis | 1 | X | | |

TABLE B-XII

AREA MAPPED: ISRAEL

SCALE: 1:150,000

Typical Landscape Regions, Atlas of Israel, 1962

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Buildings | 1-2 | | | |
| Built-Up Areas | 1-2 | X | | |
| Ruins of Abandoned Village | 3-5 | X | | |
| Field Crops | 2-3 | | | |
| Dry Farming | 3 | X | | |
| Dry Framing with Auxiliary Irrigation | 3 | X | | |
| Irrigated Field Crops Inc. vegetables | 2 | X | | |
| Patch Cultivation | 4 | X | | |
| Terracing or Land Amelioration | 4 | X | | |
| Plantations | 2-3 | | | |
| Unspecified, Unirrigated | 5 | X | | X |
| Unirrigated Deciduous | 3-4 | X | | |
| Unirrigated Vineyard | 3-4 | X | | |
| Olive | 3-4 | X | | |
| Unspecified, Irrigated | 5 | X | | X |
| Irrigated Citrus | 3-4 | X | | |
| Irrigated Deciduous | 3-4 | X | | |
| Irrigated Vineyard | 3-4 | X | | |
| Irrigated Banana | 3-4 | X | | |
| Irrigated Sub-tropical Fruit | 3-4 | X | | |
| Dates | 3-4 | X | | |
| Abandoned | 5 | X | | |

(Continued on following page)

TABLE B-XII CONTINUED

AREA MAPPED: ISRAEL

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | Inadequate Resolution | Nature of Categories: Abstract (Including Statistical) | Nature of Categories: Synthetic or Residual |
| Forest and Scrub | 2-3 | | | |
| Forest and Afforestation | 1-2 | X | | |
| Wood | 2-3 | X | | |
| Scattered Trees | 4 | X | | |
| Low Bushes | 3 | X | | |
| Water Bodies | 1[1] | | | |
| Lake or Reservoir | 1 | X | | |
| Seasonal Reservoir | 1[2] | X | | |
| Fish Pond | 4 | X | | |
| Marsh | 2 | X | | |
| Uncultivated Land | 1-2 | | | |
| Hilly Ground | 1-2[3] | X | | |
| Rocky Ground | 1-2[4] | X | | |
| Basaltic Ground | 2-4[4] | X | | |
| Kurkar Ridge | 3 | X | | |
| Hills of Red Sand | 2 | X | | |
| Sand Dunes | 2 | X | | |
| Badlands and Severely Eroded | 2 | X | | |
| Uncultivated Ground | 3[5] | X | | |
| Barren Soil | 3[5] | X | | |
| Natural Pasture | 4 | X | | |
| Nature Reserve | 5 | | | X |

[1] Identification of water bodies is directly related to their size.

[2] Seasonal sensing required

[3] Requires stereoscopy and shadowing

[4] Regions of rocky ground should be discriminable; however, there may be much confusion between categories both rocky and hilly, and others both rocky and basaltic.

[5] The meaning of these categories is not clear.

TABLE B-XIII

AREA MAPPED: CHINA

SCALE: 1:7,500,000

Agricultural Areas, 1947, Department of State
Map Division (CIA) 10749

| MAP CATEGORIES | Capability to Map From Space | Constraining Factors | | |
|---|---|---|---|---|
| | | | Nature of Categories | |
| | | Inadequate Resolution | Abstract (Including Statistical) | Synthetic or Residual |
| Over 40% of Area in Cultivation | 1[1] | X | X | |
| 20-40% of Area in Cultivation | 1 | X | X | |

[1]The size of the unit over which the decision is made will produce different levels of generalization.

IA-NASA-171

# APPENDIX 2

## ON THE USE OF SPACE PHOTOGRAPHY FOR IDENTIFYING TRANSPORTATION ROUTES: A SUMMARY OF PROBLEMS (PRELIMINARY)

# ON THE USE OF SPACE PHOTOGRAPHY FOR IDENTIFYING TRANSPORTATION ROUTES: A SUMMARY OF PROBLEMS (PRELIMINARY)

by

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TABLE OF CONTENTS

## INTRODUCTION

The problem of using outdated road and transportation maps or finding accurate new ones has confronted almost everyone from time to time. This is true not only for super highways in the U.S. but also in identifying trails and dirt roads in remote areas that are incorrectly listed or omitted entirely due to outdated or inadequate information. Present methods rely on costly field studies and random if any air photo reconnaissance.

It has been widely suggested that space photographs may be used for up-dating maps of transportation networks. The proponents of such a view argue that the extremely high altitude of space photography would permit coverage of large areas with single photos, thus eliminating many inaccuracies in present procedures, while consistently providing current information on the area. New and existing roads could be identified and transportation maps accurately and easily up-dated. The necessary construction of new and expansion of old transportation networks into areas of recent and future urban development could be rationally planned. Existing natural and future man-made obstacles to proposed road construction could be readily foreseen and compensated for, thus eliminating much costly right-of-way purchase at a later date. Presumably, this same identification ability in up-dating maps would be even more valuable in road analysis of remote areas.

In order to use space photography for such purposes it is necessary not only to detect the presence of linear elements (i.e. roads, railroads, pipelines, etc) but also consistently to identify and discriminate between them. It has been suggested that color space photographs of the resolution obtained with the 80 mm lens employed in the Apollo VI space photography, which lie in the range of 180 to 450 feet (on axis and 20° off-axis) with a contrast ratio of 1.6:1, contain enough useful information to update transportation maps showing at least the major highways in the U.S.

The present study, the first of a series, systematically documents for the Dallas-Fort Worth area the potentials and problems of Apollo VI color space photography in the detection and identification of existing road networks. This area was selected for examination because of the apparent number of visible roads and the variety of landscapes, soils and land uses available. Figure 1 is a 3X reproduction of the space photograph showing the area covered, while Figure 2 gives both the Interstate and US Highways, with major towns and cities. We have found in this study that to be consistently detected a road normally should have a width (road or road plus shoulder width) roughly between one-third to equal that of the photographic resolution, depending on the background against which the road is viewed. For the Dallas area this means that only roads (actually roads + shoulder + right-of-way) no less than 100 and perhaps as much as 300 feet wide would be fully, and unambiguously, detected.

As the road width decreases other elements enter into a resolution cell resulting either in misidentification of roads with other linear elements, or a failure to detect roads. Consequently, for certain detection we estimate at this time that the resolution of a film should be of the order of the narrowest road which one desires to identify. With resolutions of 50 to 100 feet one should be able to detect paved, two lane highways, and a fifteen foot resolution should enable detection even of narrow dirt roads in most cases, provided sufficient background contrast is maintained. Further studies are planned for the fall of 1969 using photographs with resolutions of 10 feet to 100 feet to document the validity of this hypothesis.

## CAMERA AND FILM DATA[1]

The Apollo VI space photograph shown in Figure 1, is one of a stereo triplet obtained April 13, 1968, at 8:43 a.m. local sun time, from an altitude of 128 statute miles. The camera employed was a 70 mm. J. A. Maurer Model 200-G sequence camera. Each frame (41° field-of-view) was taken 8.64 seconds apart with 65% overlap at 1/500 second

[1] In the preparation of this section we have drawn heavily from an undated, unsigned manuscript "Camera System and Calibration", Apollo AS-502 (Apollo 6) by the Instrumentation and Electronic Systems Division, Manned Spacecraft Center, Houston Texas. Quotations labelled 'camera system' are from this document.

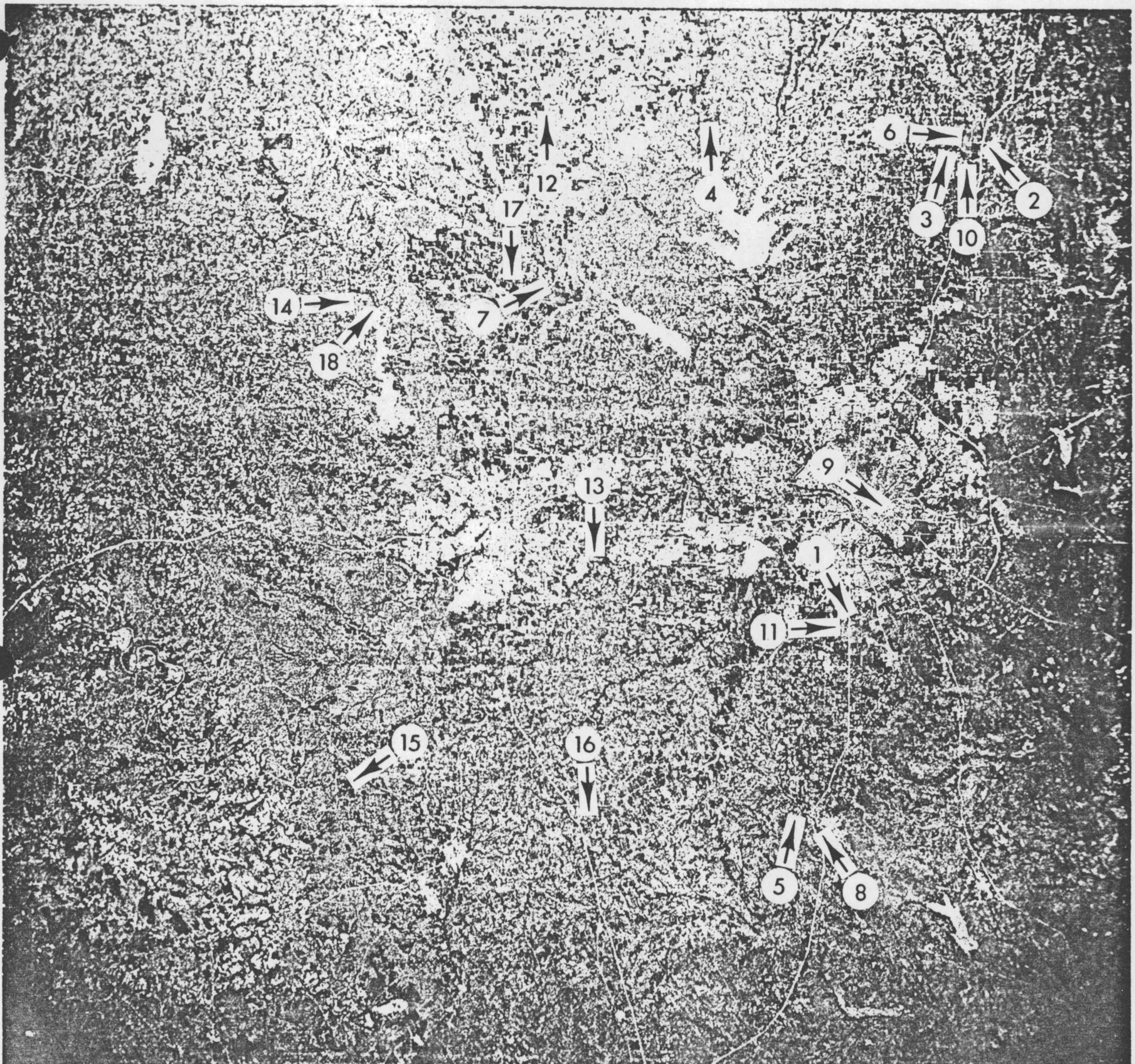



Figure 1. A 3X black-and-white enlargement made from Apollo VI Ektachrome photo, April 13, 1968. The aerial oblique photos and ground photos in the paper were taken during the first week in April, 1969 and are keyed to this area. The oblique photos provide some measures of the road network interpretations made from the space photograph. The numbers on the photograph correspond to the illustrations in Figures 6, 7, and 8.

# DALLAS-FORT WORTH AREA COVERED BY APOLLO VI SPACE PHOTOGRAPH, APRIL 13, 1968

## Base: Sectional Aeronautical Chart

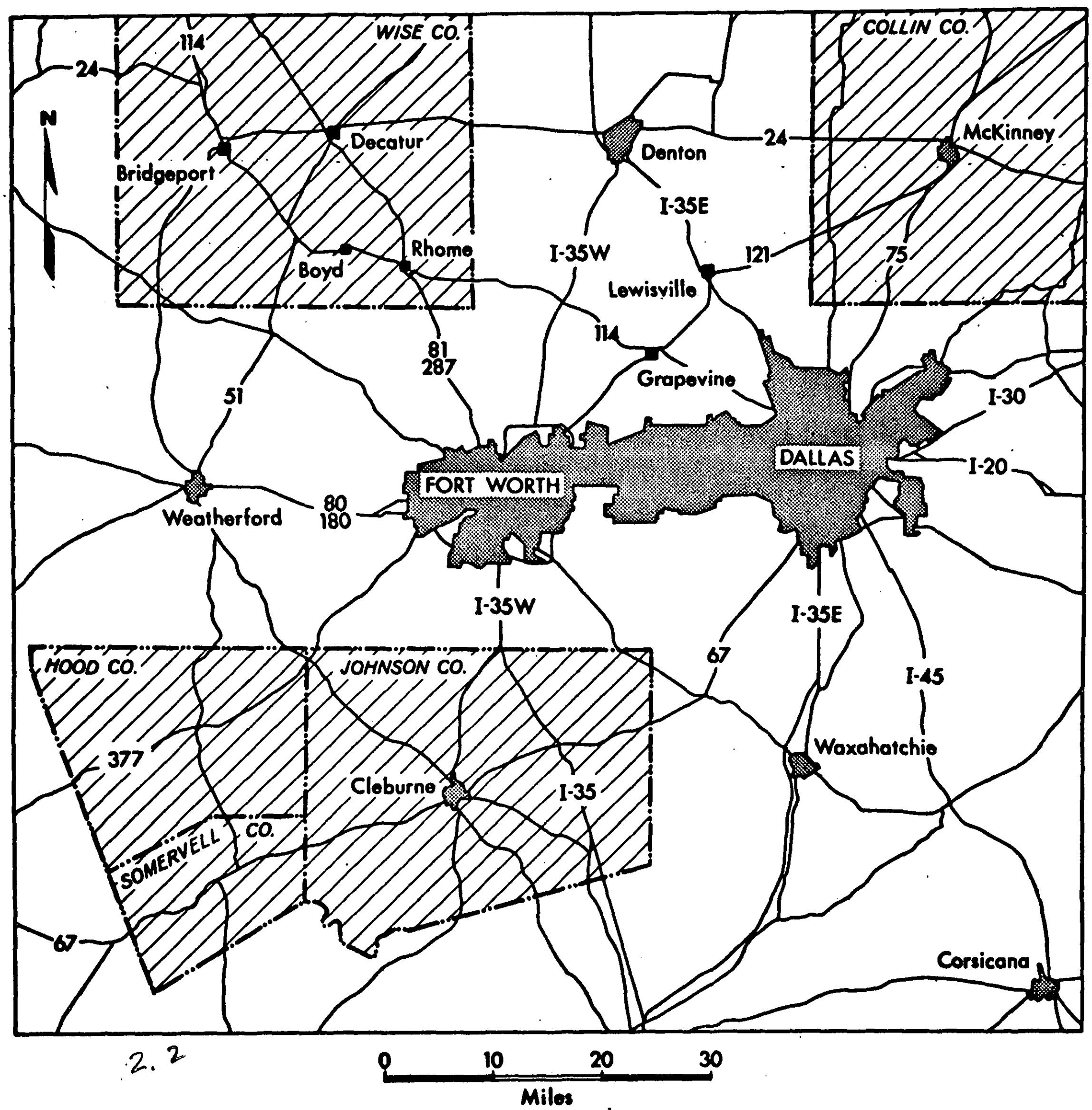



Figure 2. This map depicts the area covered by the space photograph. The Dallas-Fort Worth Metropolitan area, excluded from the study, as well as a four county sample areas are shown by shading. By comparing the map with the photo it can be seen that each sample county is in a different land use area, and that even some of the major roads are not visible.

2.2 / 5.85 = 0.375

and f 5.6. Spacecraft stabilization was such that the photograph has less than one-half degree tip in the direction of flight and one-third degree tilt across track. The lens used was a f 2.8 Kodak Ektar of 76 mm. focal length without a filter. In order to reduce the high atmospheric luminance from short wavelength Rayleigh scattering a sharp cutting Wratten 2E haze filter was used which cut with 6.5% transmission at 420 nanometers, 59% at 430 nm, 80% at 440 nm and 90% at 480 nm. Beyond 500 nm it is virtually flat in its response at 91% transmission to 720 nm. The film used was Kodak type SO-121, a high resolution, high contrast, aerial color positive.

Since sufficient quantities of flight emulsion were not available prior to shipment of the camera to the launch site no resolution testing was done using the flight film and flight lens. However the manufacturer's lens test at f 2.8, 1/1000 sec with Plus-X (type 3401) film gave the following average of radial and tangential resolutions with a high contrast target: 0°, 71 line pairs/mm; 5°, 70; 10°, 65.5; 15°, 46; 20°, 35.5; and 25°, 13. Areal weighted average resolution was 45 line pairs/mm. It has not proved possible for us to test this lens with SO-121 film but, from performance tests with other lenses and films we believe this lens-film combination would be likely to have a performance at a contrast ratio of 1.6:1 (a common ratio between roads and background in this area, as well as being a standard value) of the order of 50 line pairs at 0° (nadir) and 5°; 45 at 10°; 30 at 15°, 20 at 20° and 10 or less at 25°. These resolutions give equivalent ground resolutions on the 70 mm film, with a mean scale of 1:2,800,000 of 180 feet at 0° and 5°, 200 at 10°, 300 at 15°, 450 at 20° and 900 at 25°. A rough areal weighted average resolution would be 30 line pairs per mm, equivalent to 300 feet with a 1.6:1 contrast ratio.

The photographs were taken through a hatch window inclined at such an angle to the camera that the light rays reaching the camera ranged from "near normal at the corners in the direction of flight to approximately 10° at the center of the leading edge. The angles of incidence increase toward the trailing edge when they become greater than 50 degrees" (Camera

Systems). The significance of this is that using a refractive index of 1.5442 for quartz, the maximum polarization of light in the plane of the surface occurs at 57° 4'. In addition the Apollo window consists of a series of plates, thus multiplying polarization effects as the rays pass from surface to surface, first through an optical grade quartz heat shield, then multilayer blue-red reflection coatings, and then through 2 panes of Corning #1723 aluminosillicate glass, themselves coated with reflection reducing layers. Thus the light rays reaching the film range from slightly polarized at the edges in the direction of flight to completely polarized, or nearly so, at the trailing edge and corners.

The combined effect of differences in resolution across the lens, some lens vignetting, (the side hatch window frame does not cause vignetting) and (in some cases) the difference in the degree of polarization of the light reaching the film from the leading to the trailing edge will be considerable in influencing the detection of narrow linear elements such as roads. In addition since the solar angle was about 39° with the sun relatively at azimuth 106°, tall trees and buildings cast shadows of twice their height. There should therefore be some differences in detection in the fore-lit (azimuth 315°) and back-lit (azimuth 135°) direction depending in part on road direction and on the presence of trees or buildings lining the roads.

## STUDY PROCEDURES

Six X enlargements of the color photograph and the red, green and blue color separation plates were produced and all linear elements thought to be roads were traced onto transparencies for study.[2,3] Those roads

[2] A 6X magnification was used so that viewing with an additional 3X Richards Binocular viewer would be adequate for detection of roads, while the 6X magnification provided an adequate scale for plotting.

[3] The color separations were made using standard black and white masking techniques.

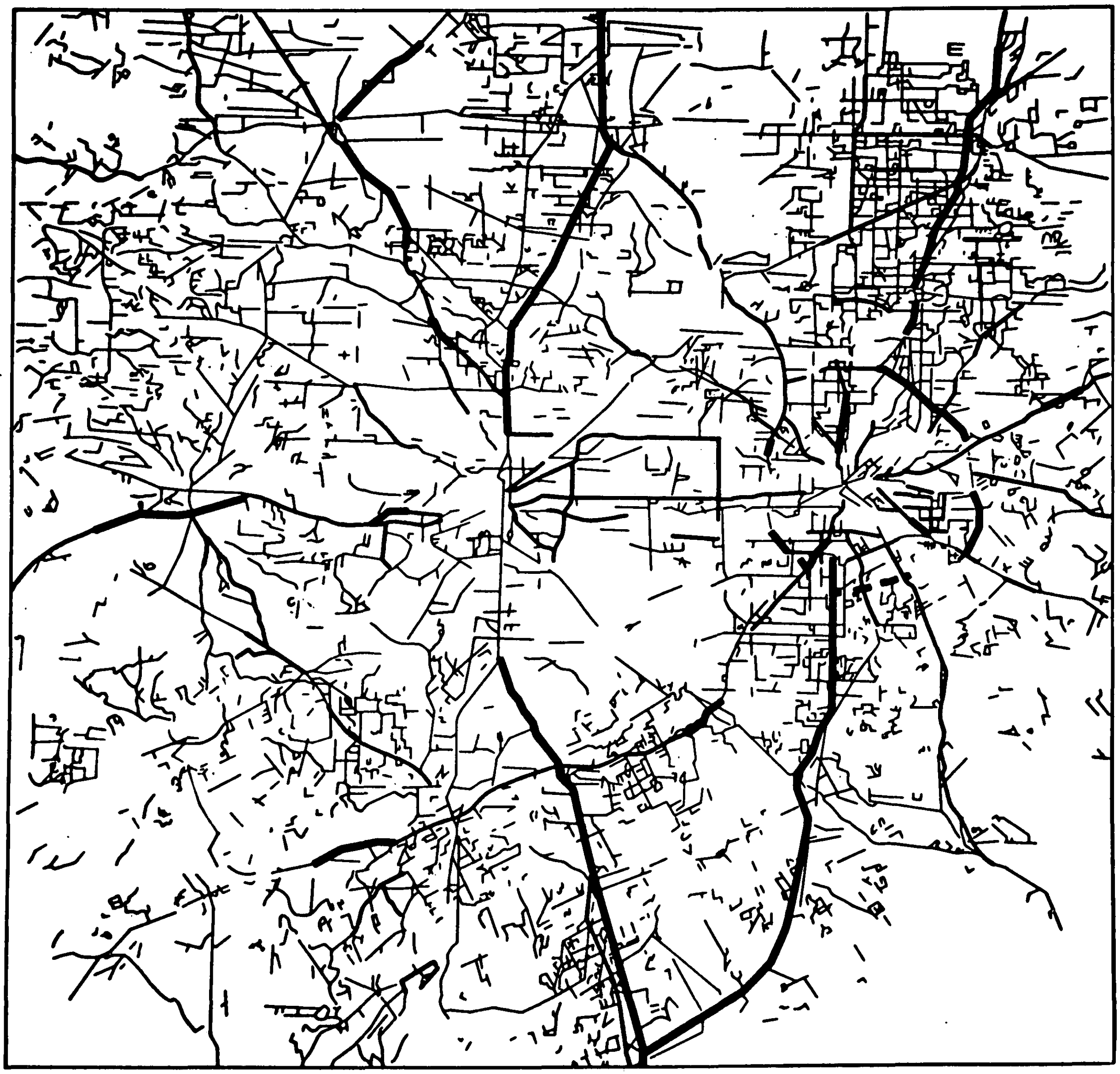
visible on each of the color separation plates and the color photograph were compiled separately and combined into the two accompanying maps. Figure 3 depicts those roads visible, by degree, on the color photograph alone and Figure 4 shows those roads detected when the separation plates and the color photo were combined. Figure 5 was created by placing an overlay of the visible roads on an orthochromatic print of the space photo.

In studying the roads, the enlargements were viewed with various magnification on a Richards light table with different intensities of back- and fore lighting. The original color print was also projected, viewed under a stereoscope (3X, 8X, 16X) with the adjacent photographs to obtain binocular reinforcement, and studied in a 25X microfiche viewer. Only that part relating to the paper positive enlargements is reported here as the other work is not yet complete.

To achieve meaningful results the investigator must always make a certain number of arbitrary decisions which serve as guidelines for the project. It is necessary for the reader to know of the decisions made here in order to view the conclusions from the proper perspective.

Linear elements, (roads),were separated into three categories of visibility. It was felt that three was the optimum number in order to obtain the most distinct and separate classification and thus the least confusion and overlap. In looking at a visible line on the photograph the decision to identify it as a road or another linear element was the investigator's also. A road often disappeared while going through an urban area and at single spots in rural areas. The decision to infer its route or delete it in such cases was also the choice of the observer. Analysis of a sample region of the Dallas-Fort Worth Metropolitan area proved that the number of visible roads was too minimal (22%) to be considered. Therefore an arbitrary line was drawn around the cities and they were excluded from the study. In smaller cities and towns, attempts were made to detect only highways; never city streets. Finally, sample areas had to be selected for more detailed investigation. Four counties, each in a different area of the photograph and with different terrain, land use and soil color, were chosen as representative of the photograph as a whole (Figure 2).

## ROADS* DETECTED ON A SPACE PHOTOGRAPH: Dallas-Fort Worth Area, Texas



**DETECTABILITY ON APOLLO VI PHOTOGRAPH, APRIL 13, 1968**

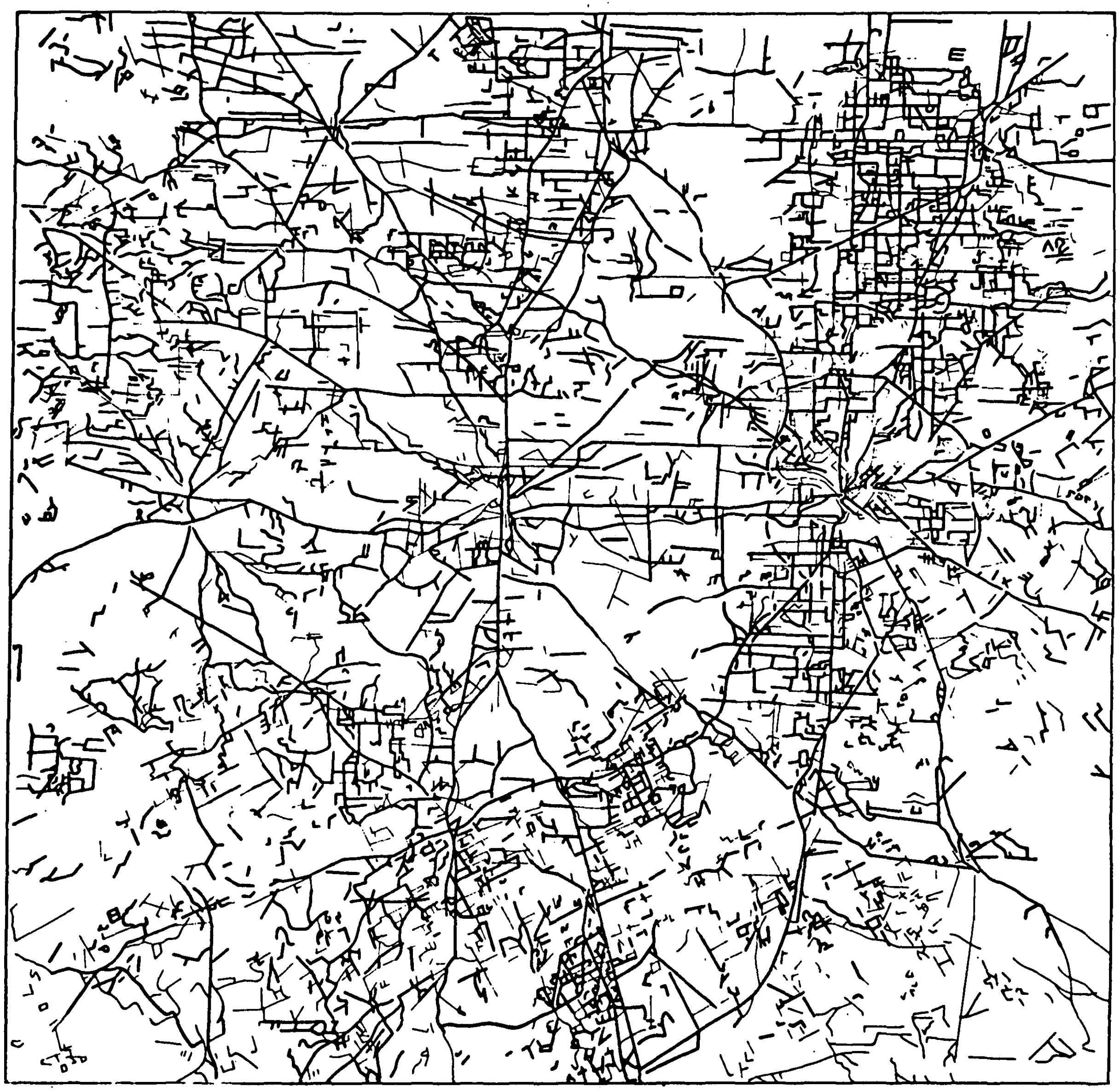
**High — Medium — Low**

***Roads include linear features mistaken for roads.**

Figure 3. Linear elements detected on Apollo 6 color space photo of the Dallas-Fort Worth area. Three categories of visibility are shown.

# ROADS* DETECTED ON A SPACE PHOTOGRAPH AND COLOR SEPARATION PLATES:

## Dallas-Fort Worth Area, Texas



—— COLOR APOLLO VI PHOTOGRAPH, MARCH 13, 1968

—— ADDITIONAL ELEMENTS ON SEPARATION PLATES

*Roads include linear features mistaken for roads.

Figure 4. Roads detected on a space photograph and color separation plates of the Dallas-Fort Worth area, Texas.

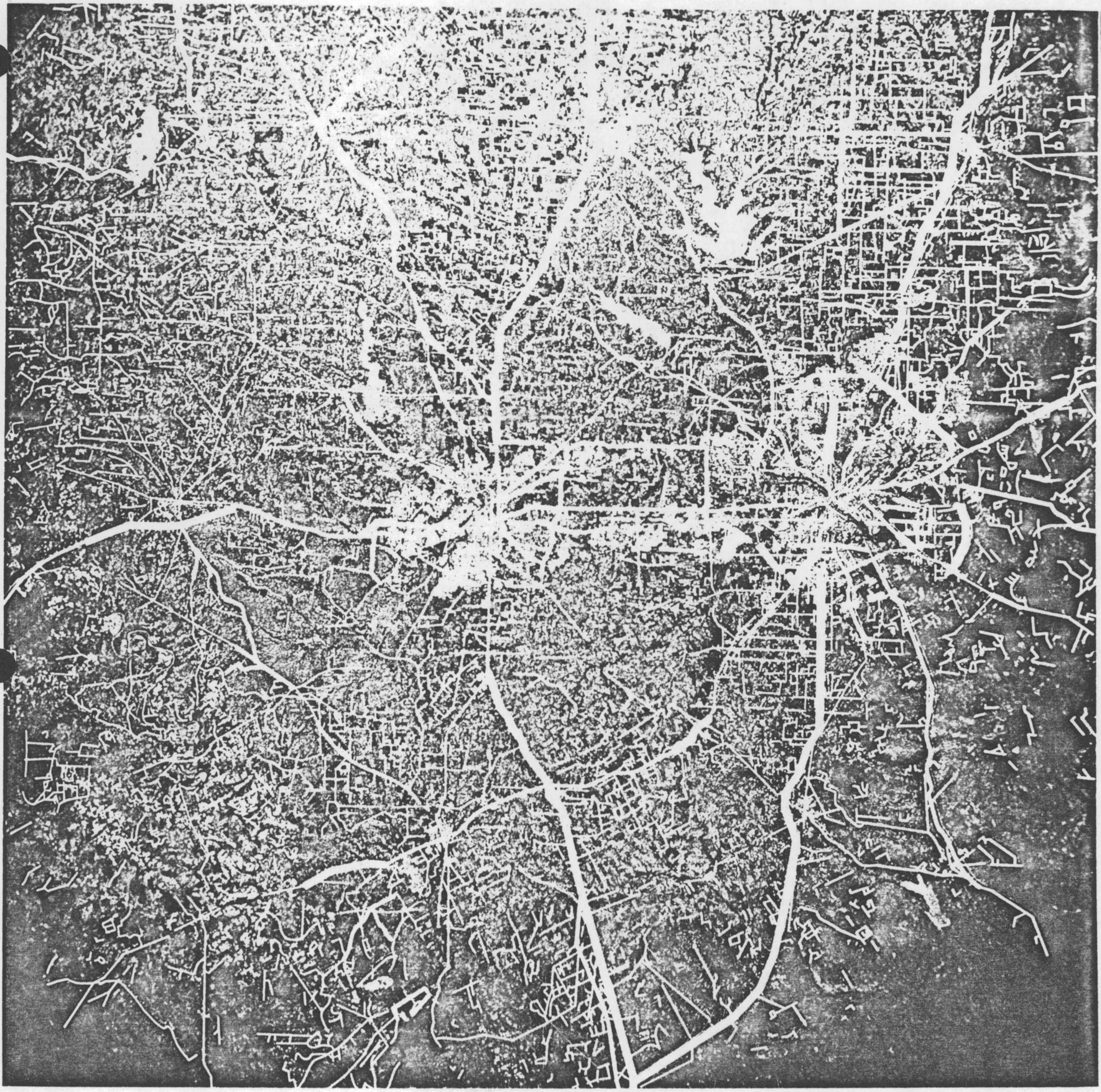


Figure 5. Visible roads overprinted on an orthochromatic print of the Dallas-Fort Worth space photo.

The roads detected in the four county sample area on the color photograph and separation plates were transferred to 1:250,000 scale county maps. These maps, obtained from the Texas Highway Department, proved invaluable in the study. All existing roads, except for minor private trails to oil wells, were represented as well as pipelines, cables, and railroads. The road network was updated as of January 1, 1967, within 16 months of the Apollo VI space photography. Detailed analysis discovered that many false alarms, lines incorrectly identified as roads, had been drawn on the transparencies of the color photograph and the separation plates; although they were linear in nature they were not roads but were later discovered to be other natural and cultural features. Topographic maps and air photo mosaics of the area were used to identify these false alarms. The percentage of actual roads visible on the color photograph and/or color separation plates varied with each of the counties, from 66% for Collin County to 37% for Hood-Somervell Counties. With this result in mind we have analyzed a number of factors which affect road identification. Before proceeding to this analysis, it is necessary first to discuss the types of roads present in the area, for the general character of the roads is the most important single factor influencing their detection.

## TEXAS HIGHWAY DEPARTMENT ROAD CLASSIFICATION

The Texas Highway Department distinguishes six major classes of roads in the study area as follows:

1. Divided Roadways: These are concrete super-highways at least two lanes abreast or more on each side of a divider. Commonly, they also have service roads paralleling them, especially near major cities such as the Dallas-Fort Worth complex. The road width is no less than 48 feet, shoulder width an additional 28 feet and right-of-way a further 274 feet. Such a road is illustrated in Figure 6-1.

2. <u>Paved Roadways:</u> These are two lane concrete highways with either gravel or asphalt shoulders. The road width averages 24 feet, the shoulders are from 8 to 10 feet wide on each side and the right-of-way occupies an additional 56 feet. The portion of the right-of-way that is not road surface usually consists of well-kept green grass with occasional small trees and shrubs. At times the right-of-way is cluttered by trees, brush, or commercial advertising but this is almost always along older roads. Naturally in urban areas the right-of-way is much narrower, consisting only of the road and occasionally the shoulder (Figure 6-2).

3. <u>Bituminous Surfaced Roadways:</u> These two lane roads are usually 20 feet wide but occasionally, for some state highways, widen to 26 feet. The shoulders consist of gravel or asphalt and are usually 3-4 feet wide on a side, yet many of the minor roads of this type have no shoulders. The amount of right-of-way depends on its role as a major traffic artery. Minor farm-to-market roads may have only 60 feet (including road and shoulder widths), while state highways usually have 120 feet. Naturally the upkeep of the right-of-way is relative to its use (Figure 6-3).

4. <u>Metal Surfaced Roadways:</u> These two lane roads are of two types, those using yellow gravel and those using white gravel, depending on the area. The roads themselves are only 18 feet wide and have no shoulders. The right-of-way width varies from 40 to 69 feet (including road surface) but is usually the former. The right-of-way itself is brushy and weedy unless the farmer has used it to extend his fields up to the road (Figure 6-4).

5. <u>Graded and Drained Roadways:</u> These roads consist of bare earth with very slight chert or gravel cover in spots to aid trafficability in wet weather. The roads are 16 feet wide with no shoulders. In addition their slopes have been graded to promote drainage and water run-off. Right-of-way consists of 50 feet including road surface but is weedy and brushy. The farmer usually utilizes it to expand his acreage, and crop capacity, thus narrowing this theoretical width (Figure 6-5).

Figure 6-1. Interstate 35, a divided highway, going south out of Dallas to Waxahatchie, is an eight lane road with two lane access roads on either side. With such a wide concrete surface it is easy to see why it has high reflectivity and can easily be seen in rural areas from the space photograph. In urban areas, such as this however, the visibility is reduced due to other paved surfaces and a lack of contrast with its adjacent land. Divided highways, with this shoulder are no less than 70 feet wide and frequently, as here, are much wider.

Figure 6-2. U. S. 75, just west of McKinney, is a paved concrete highway. Recently constructed, the concrete has not been darkened by tire wear, exhaust fumes or weathering. As a result it appears almost white against a dark, cultivated background. Paved roadways are 25 feet wide and with their shoulders are 37 feet wide.

Figure 6-3. Farm-to-Market Road 2478 west of McKinney is an asphalt road with little or no shoulder. Being black by nature anyway, constant use has only served to dull the asphalt and blend it into the adjacent land. Although such roads are visible in many areas the consistency of detection with space photography of this resolution depends on the adjacent land use. Obviously fields of ripened, golden grain will provide greater contrast than green wheat or dark, plowed ground. Bituminous surfaced roads are 20 feet wide and normally have an additional 8 feet of shoulder width.

Figure 6-4. Metal surfaced roads (gravel) such as this one near Denton seldom have shoulders and are usually only 19 feet wide. As a result their visibility from space is highly variable. If white caliche gravel is used against plowed ground it is naturally more visible than yellow ironstone gravel next to brown pasture or the reds and yellows of plowed red-yellow podzolic soils. In Collin County white caliche gravel is commonly used. Despite its pronounced contrast with green wheat, and bare soil such roads as a group were too narrow to be consistently detected.

Figure 6-5. Graded and drained roads such as this one west of Waxahatchie consist of dirt native to the immediate area, built-up and sloped by a road maintainer. Being narrower than gravel roads (16 feet wide) and lacking even metal on their surface, visibility from space is happenstance. Here, there is plowed ground on one side but pasture and stubble on the other. As a result the road may appear as only a field border from space.

Figure 6-6. Bladed earth roads such as this one near McKinney were seldom detected. Besides being very narrow (fifteen feet or less and lacking shoulders), the right-of-way is obviously almost nil and is not clear or mown. Trees, shadows, and weeds hinder detection.

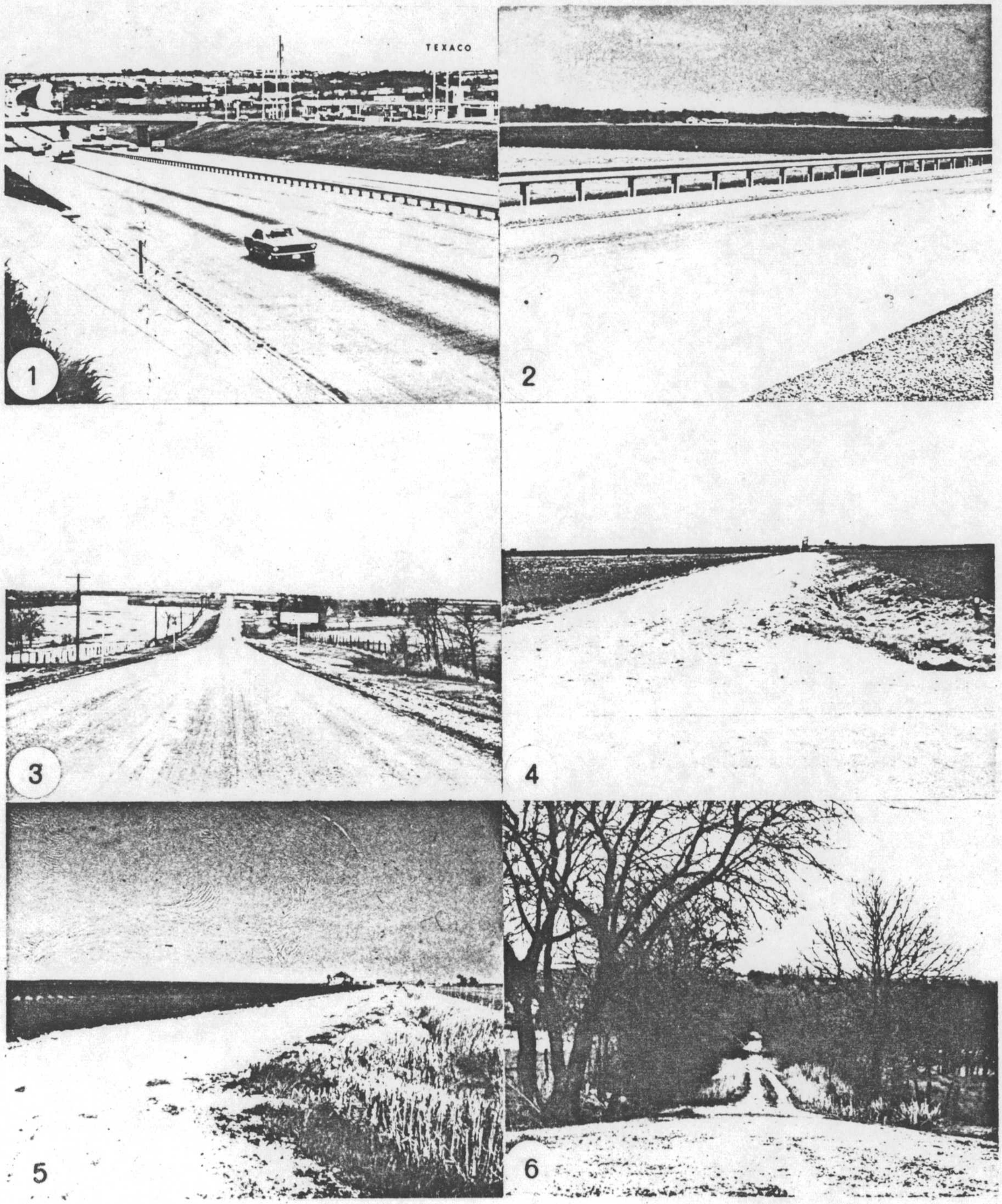



Figure 6, 1 thru 6

6. Dirt Roads: Dirt roads are supposed to be 16 feet wide and even have some gravel on them. In practice they are often one lane or narrow two lane paths with ruts and their surface consists of dirt native to the area. There are no shoulders and the 40 foot right-of-way seldom fully exists. More often the road is surrounded by weeds, overhanging trees and brush, or abuts fields and fences (Figure 6-6).

## FACTORS INFLUENCING ROAD DETECTION AND IDENTIFICATION

In addition to camera window, lens and film limitations, which will be explored in detail in a subsequent report, there are certain environmental factors that cannot easily be altered. However, they must be understood and taken into consideration when analyzing road networks from space. Road width, right-of-way, road type, topography and water bodies, linearity, land use, and sun angle are the environmental elements found to have the greatest effect on road detectability.

### Road Width and Right-of-Way

As Table 1 indicates, the widest roads (road surface plus shoulder) were most easily seen and most often detected. One hundred per cent of the divided highways were detected (Figure 7-7) but the percent visible drops rapidly as the road width declines until an average of only 15 per cent of the narrowest roads were visible. Field work led to the conclusion that shoulder width and material play a vital role in visibility. Those roads having a wide shoulder made of a material, e.g. caliche gravel, that contrasted vividly with the adjacent land were more easily seen from the air than those without shoulders (Figure 7-8). Problems of false alarms and loss of visibility were pronounced in all classes of roads except broad, divided highways; but even they were less visible in urban areas (Figure 7-9). The width of the right-of-way and its use also influenced road visibility. Areas where the right-of-way

Figure 7-7. Interstate 35, a four-lane divided highway near Justin, is much more visible here than State Highway 114 (E-W) which intersects it in the right center of the photo. The four-lane road has a much wider right-of-way in addition to access roads which accent the total road surface. Road width and right-of-way obviously play an important part in detectability from space since the elements being detected are near the system resolution limits.

Figure 7-8 The white gravel shoulders of this concrete highway U.S. 287 west of Waxahatchie add to the road surface and aid in visibility. The well-kept right-of-way with either bare ground or green grass also add contrast for the road. Thus the effective width of the road is almost comparable to that of a four-lane road.

Figure 7-9 This low altitude oblique of Dallas shows the effect of the urban maze on roads entering and within the city itself. Notice how the road at the left top of the photo disappears as it enters the suburban areas. From altitudes of 110 miles it was impossible to detect the Interstate I-20 shown here, let alone the many side streets.

Figure 7-10 This extreme example near McKinney illustrates the importance of right-of-way in road detection. What right-of-way the dirt road does have is ill-kept and contains over-hanging trees, water and brush; from high altitudes the road appears as only a field border. Were the brush and weeds cleared to the fence line and grass planted, the right-of-way would probably aid and not hinder detection of the road.

Figure 7-11 Notice how much more visible is Interstate 635, under construction, than Interstate 35 which runs from left to right across the lower portion of the photo. The broad, graded dirt surface of I-635 provides a much wider and more sharply contrasted surface to the adjacent fields than does the completed paved and grassed I-35. It is understandable why roads under construction were always the most visible on the space photograph.

Figure 7-12 The linear, grid system, roads in this photograph near Krum are readily visible, but the others are not. From the lower left corner of the photo a road follows the line of trees to the right, crosses the stream and extends to the right side. Unless the road is known to be there it is almost entirely invisible. The road that extends from the upper left center to the lower right corner of the photo is equally difficult to detect. This terrain could hardly be classified as rugged. The difficulties of detecting roads in a dissected landscape can be imagined.


Figure 7, 7 thru 12

TABLE 1

DETECTABILITY OF ROADS BY WIDTH ON APOLLO SPACE PHOTOGRAPH

| ROAD TYPE | ROAD WIDTH | ROAD PLUS SHOULDER WIDTH | % VISIBILITY |
|---|---|---|---|
| Divided Roadway | 46 | 70 | 100 |
| Paved Roadway | 25 | 37 | 80 |
| Bituminous Surface | 20 | 28 | 65 |
| Metal Surface | 19 | 19 | 38 |
| Graded and Drained | 16 | 16 | 18 |
| Bladed Earth | 16 | 16 | 15 |

TABLE 2

PERCENT OF VISIBLE ROADS ON APOLLO SPACE PHOTOGRAPH TEXAS COUNTIES

| ROAD TYPE | WISE | COLLIN | JOHNSON | HOOD-SOMERVELL |
|---|---|---|---|---|
| Divided Roadway | 100 | 100 | 100 | NONE |
| Paved Roadway | 80 | 84 | 86 | 69 |
| Bituminous Surface | 77 | 70 | 65 | 48 |
| Metal Surface | 30 | 54 | 49 | 20 |
| Graded and Drained | 17 | 32 | 14 | 11 |
| Bladed Earth | 17 | 0 | 0 | 43 |

was wide, the grass mown, or where there were few trees or brush were most visible (Figure 7-10).

Road Type

The road type or paving surface of each road was obtained from the legend of each county map and the percent of each type visible was computed. Table 2 illustrates the importance of road surface type in road detection. Eighty per cent of the paved roads and sixty-five per cent of the bituminous surfaced roads were detected, but only thirty-eight per cent of the metal surface (gravel), eighteen per cent of the graded and drained roads, and fifteen per cent of the earth roads were visible. In two counties, Collin and Johnson, no bladed earth roads could be detected.

The figure for Hood and Somervell Counties, 43%, may be somewhat misleading since there are only 34 miles of bladed earth road in the county and thus a small mileage detected is a very large percentage. However, since the lower three types of roads did not have road shoulders their poor visibility is probably due to road width in addition to surface type. This notion was supported by field observations which indicated that roads under construction were always more visible than an old road of the same class (Figure 7-11). In other words, the broader the surface in use, whether in construction or by type (i.e., divided highways), the easier it was to detect.

Topography and Water Bodies

Confusion of roads with topographical and hydrographical features was one of the major problems and causes of confusion in this study. Comparison of the space photograph with 1:250,000 scale topographic maps of the area, air-photo mosaics, and aerial oblique photographs showed that the rougher the terrain the weaker the visibility and the greater the error. As a road passed through hill cuts, into valleys or around hills its visibility almost always lessened and at times the road disappeared (Figure 7-12).

In Hood and Somervell Counties, which are the most dissected, 62% of the roads were not visible and 7% of those lines detected were in error. By contrast in Collin County, having a gentler landscape, only 44% of the roads were not detected and only 4% of the lines were incorrectly identified. Yet, since topography accounts for 48% of the incorrectly identified roads, it is obviously still a problem in the best areas of the photograph.

Lakes, streams and rivers compounded the topographic problems and were sometimes mistaken for barely visible roads in the study of each of the sample counties as Table 3 indicates.

Fifty-eight miles of rivers and streams, 7.2 miles of waterways, and 4 miles of lakeshore were incorrectly identified as low visibility roads. This represented 35% of the total error in the sample area. The four miles of lakeshore were east of Dallas in the dark blue portion of the color space photo. Since many linear elements ran adjacent and up to the lakes on all parts of the photo it was assumed they were roads to lake cottages and beaches and indicated as such. In this instance, however, the high return was due to the lakeshore itself and a newly constructed dam. Figure 8-13 illustrates the high reflective quality of a lakeshore when compared to the roads in the area. Actual roads crossing, running parallel to, or up to water bodies were found from observation and field work to be more difficult to detect, this being especially true of roads in the barely visible class.

Linearity

Barely visible roads on the photograph which followed a grid or rectangular pattern were always found to be more easily seen than a sinuous road of the same type, as is shown by Figure 8-14. Linearity did not affect those roads in the upper two categories (very visible, visible) as much, but even they lost some of their reflective quality if they began to weave. From observation and ground studies it was concluded that metal, dirt, graded, and bituminous roads (i.e. roads other than those paved or divided) were always more difficult to detect

TABLE 3

ERROR ANALYSIS OF LINES INCORRECTLY INTERPRETED
AS ROADS ON APOLLO 6 COLOR SPACE PHOTOGRAPH
DALLAS-FORT WORTH AREA

| CATEGORY | MILES IN COUNTY | | | | Total | % |
|---|---|---|---|---|---|---|
| | Collin | Wise | Johnson | Hood-Somervell | | |
| Streams, Rivers | 11.8 | 25.1 | 8.2 | 12.7 | 57.8 | 29.3 |
| Field Borders | 12.5 | 11.4 | 6.9 | 8.1 | 38.9 | 19.7 |
| Pipelines | | 11.1 | 11.1 | 6.2 | 28.4 | 14.4 |
| Telephone Cables | | | 3.7 | 6.2 | 9.9 | 5.0 |
| Boonville Oil Field Border | | 4.7 | | | 4.7 | 2.4 |
| Railroad | 7.4 | | 5.6 | | 13.0 | 6.6 |
| Lakeshore | 3.7 | | | | 3.7 | 1.9 |
| Erosion Control Waterways | 7.2 | | | | 7.2 | 3.7 |
| Roads-Trails to Oil Rigs | | 15.1 | .8 | | 15.9 | 8.1 |
| Unknown | 2.5 | 2.4 | 5.1 | 7.6 | 17.6 | 8.9 |
| TOTAL MILES | 45.1 | 69.8 | 41.4 | 40.8 | 197.1 | 100 |

| | |
|---|---|
| Figure 8-13 | The shore of Lake Arlington near Fort Worth could easily be mistaken for a road from a high altitude. It is difficult to define where roads to lakeside cottages and beaches end and the shore itself begins. Close observation is needed even at this altitude to determine if a road crosses the dam or if it turns left to follow the lakeshore. |
| Figure 8-14 | The road which meanders up the middle of the photo near Boyd from bottom to top and the one which runs from left to right across the center are much less visible than the rectangular road system on the right side of the photo. Yet, even linearity poses its problems in road detection: the straight line across the bottom of the photograph is a railroad. |
| Figure 8-15 | The railroad track and train in this photo near Cresson are easily visible but could still be mistaken for a road. The roads which run from the lower left to center and from left center to center top of the photo are far less visible. Again we are presented with the problem: Is this linear element a road? |
| Figure 8-16 | It is possible by close observation of this aerial oblique area to determine which of these lines are field borders and which are roads, but it requires a trained eye. From space platform altitudes such borders could be and were mistaken for roads; whether a better resolution could solve this problem or not has yet to be determined. |
| Figure 8-17 and 18 | Figure 8-17 shows the rectangular field and road pattern of a portion of Denton County while Figure 8-18 illustrates the dissected, cross-hatch field and road systems of Wise County. In the photo of Denton County the roads are easily visible and detected with the aid of field borders; Wise County roads are more difficult to differentiate from other linear elements (such as the pipeline running across the lower right corner of the photo). The land use in Figure 8-17 is mostly wheat and other crops contained in regular field patterns and roads can more readily be defined. The pasture and extensive areas of fallow ground in Wise County tend to blend in with the roads and thus hinder road detection. |

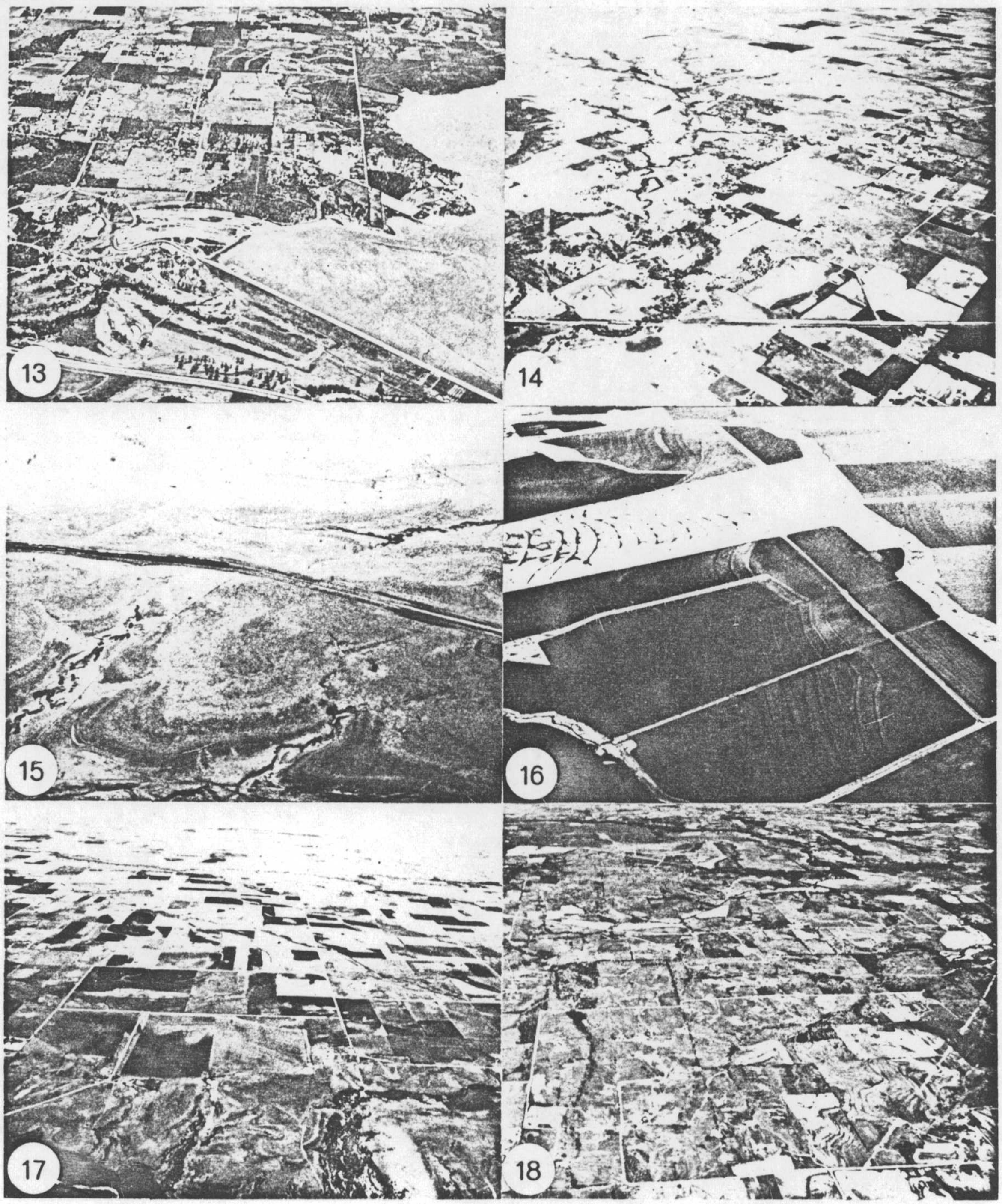



Figure 8, 13 thru 18.

if they were sinuous and much had to be inferred in tracing their routes. This fact also led to confusion with streams, as stated above, since both had similar meandering characteristics. For example, Hood and Somervell Counties consist of rough terrain with meandering streams. Consequently, 412 miles were incorrectly identified due either to being not visible or they were linear elements other than roads; this amounted to 69% error! By contrast Collin County, having a rectangular grid system, had 22% less error (See Table 4).

However, sinuous elements were not the sole cause of error. In many cases linearity itself was a major contributor to false alarms. These elements, classified as barely visible roads, consisted of 39 miles of field borders, 28 miles of pipeline, 10 miles of telephone cable and 13 miles of railroad. Together these linear elements composed almost 46% of the total false alarm error (Table 3). The ease of confusion of these elements with roads is illustrated by Figures 8-14, 8-15, 8-16, and 8-18.

Land Use

Study and observation of the photographs and the sample area in particular indicated that land use also presented problems in road detectability. Urban areas and clusters of dwellings always decreased the visibility of the road in question. Those roads classed as visible or barely visible in rural areas often disappeared upon entering even a small village and their route had to be inferred or discontinued until it reached the other side of the town. In general the larger the urban area the more difficult it became to detect a road. As previously stated, the visibility of the Dallas-Fort Worth Metropolitan area was so minimal that it was excluded from the study completely. Given the same color photograph, those roads in blue areas, which as a result of field work was usually found to be wheat or bare plowed ground, were always more visible than roads in the rust or brown colored areas - stubble, pasture, or bare gound (Figure 8-17 and 8-18). Rural areas, depending on land use, enhanced or decreased road visibility. Observation in the field and oblique photographs found those roads in areas such as Collin County,

TABLE 4

ROADS NOT DETECTED AND FALSE ALARM* MILES IDENTIFIED ON APOLLO SPACE PHOTOGRAPH (TEXAS COUNTIES)

| COUNTY | ACTUAL MILES | NOT VISIBLE MILES | % | FALSE ALARM MILES | % | MILES TOTAL ERROR | % |
|---|---|---|---|---|---|---|---|
| Collin | 1080 | 478 | 44 | 45 | 4 | 523 | 48 |
| Wise | 984 | 552 | 56 | 70 | 7 | 622 | 63 |
| Johnson | 1122 | 540 | 48 | 41 | 4 | 581 | 52 |
| Hood-Somervell | 597 | 371 | 62 | 41 | 7 | 412 | 69 |
| Total | 3783 | 1941 | 51 | 197 | 5 | 2138 | 57 |

*False alarms are lines incorrectly interpreted as roads

TABLE 5

COMPARISON OF ROAD DETECTION USING MULTIPLE SPACE PHOTOGRAPHS : COLLIN COUNTY, TEXAS

| Position On Photo | Total Miles | Miles Visible | % Visible |
|---|---|---|---|
| I(Upper left) | 1184 | 773 | 65 |
| II (Upper center) | 1188 | 807 | 68 |
| III (Upper right) | 1157 | 726 | 63 |
| Combined Photos | 1186 | 955 | 80 |
| Original Study | 1080 | 602 | 56 |

where fields were more rectangular, cultivated, and had crop growth, contrasted very readily with the surrounding land, but in Wise and Hood-Somervell Counties the many oil rigs, pasture, grassland, and the dissected landscape hindered road detection.

Sun Angle

The creation of fore and back lighting due to the position of the sun in relation to the camera contributed to the already numerous variables and problems in road detectability. In the series of color space photographs covering the Dallas-Fort Worth area the sun lay at 39° above the horizon at an azimuth 106°. From three over-lapping color space photographs of Collin County, Texas, (Table 5) it was documented that road detectability depended on the county's position on the photograph in relation to the sun. In each of the three photographs approximately the same percentage, 65%, of the roads were visible, but they were different roads. Consequently, one is confronted with the problem or difficulty of studying over-lapping photographs of the area taken from various angles. However, when this was done the percentage of visible roads jumped to 80%. It should be noted that, for this study, the county road map showing actual roads was used when locating visible roads on the photograph to eliminate false alarms. This *a priori* knowledge accounts for the higher visible percentage than the figures given in Table 4.

Detectability: Contrast Ratio of Roads and Background

Some 500 measurements of contrast ratios between roads of various types and different backgrounds were made in the field during March-April, 1969, following the Apollo IX flights. These data are being prepared for computer analysis. A sample of the data is tabulated below to indicate some of values encountered.

| Road Surface | Contrast Ratio for 12" Green Wheat Background | Contrast Ratio for Bare Earth Background | Contrast Ratio for Dry Pasture Background |
|---|---|---|---|
| Under Construction | 1.12 - 1 | not avail. | .98 - 1 |
| Concrete | 2.3 - 1 | 2.12 - 1 | 1.61 - 1 |
| Asphalt | 2.15 - 1 | 2.44 - 1 | 1.60 - 1 |
| Gravel | 2.76 - 1 | 3.64 - 1 | 2.14 - 1 |
| Dirt | 1.62 - 1 | 2.81 - 1 | 2.00 - 1 |

For each road type the road itself is naturally more visible when it is more sharply contrasted to its adjacent surfaces. Pasture, for example, tends to blend into the road surface and consequently reduces visibility.

Color Separation Plates

Color positive separation plates were documented in this study to be of significant value for further studies of this type. Of the 11,278 miles of existing roads in the area covered by the color space photograph use of the color separation plates enabled us to detect 1,640 miles (14.6% of all existing roads) not visible on the color photograph. When this is compared with only those roads detected the percentage jumps to 23.3%. Each separation plate (red, green, blue) detected some roads not visible on any other separation plate or the color photo. Those roads visible on a separation plate but not on the photograph were always detected as barely visible and seemingly did not have any definite characteristics, but rather were scattered randomly across the photograph with a very slight concentration in the darkest portions. The concentration in the edges and darker areas may be accounted for by slight over-exposure in the separation plate negatives. Of the three separation plates the blue and green were most useful in detecting roads.

Mr. Don Ross and associates of Philco-Ford also produced color separation plates and density slices of the Dallas area for the U.S.G.S. Geography Branch. Through the courtesy of Mr. Jack Wilson we have

## COMPARISON OF TWO SEPARATION TECHNIQUES FOR ROAD DETECTION IN SPACE PHOTOGRAPHY

| METHOD USED* | MILES VISIBLE | % VISIBLE |
|---|---|---|
| Color Photo (UK) | 326.8 | 73.3 |
| Red Separations: | | |
| Red Separation (UK) | 309.2 | 69.4 |
| Red Separation (PF) | 113.6 | 29.2 |
| Red Separation - 28 slices in false color (PF) | 206.4 | 49.7 |
| Red Density Slices - B & W, 14 slices (PF) | 248.4 | 55.7 |
| Cyan Separations: | | |
| Cyan (blue-green) Separation (UK) | 311.2 | 69.8 |
| Cyan Separation (PF) | 263.2 | 67.8 |
| Cyan Separation - 18 slices, in false color (PF) | 242.8 | 58.4 |
| Cyan Separations - 3 different exposures (PF) | 280.0 | 63.0 |
| Cyan Density Slices - B & W, 13 slices (PF) | 248.0 | 55.7 |
| Combined Philco-Ford Methods | 322.8 | 72.4 |
| Combined University of Kansas Methods | 343.2 | 77.0 |
| Combined All Methods | 355.2 | 79.7 |

UK - University of Kansas Separation Techniques, i.e. regular color separation prints, 6x magnification

PF - Philco-Ford Separation Techniques, i.e. transparencies and fine density slices, 10x magnification

* Areas measured vary slightly for different methods due to inconsistency in photographing identical areas.

had the opportunity to study these plates. Although the fine slicing may prove to be very useful in other types of land use studies it has been tentatively documented for the Dallas area that the basic three color separation plates used in the original portions of this study yield more data (Table 6) for transportation network studies than the fine slicing of the Philco-Ford technique. In addition the density slicing appears to compound the problems previously stated and require more time. We also tended to become more confused and unsure in road identification when using the Philco-Ford method. We will give a thorough account of the Philco-Ford density-slicing technique and tallying at a later time.

## CONCLUSIONS

Although the color space photograph appears to have good resolution and return at first appearance, closer observation and analysis proved that it contains many different but inter-connected problems and is insufficient for study of a complete transportation network. The paved highways and "super expressways" of America are easily visible due to their wide surface width and superior paving surface, but as the class of road lessons, so does its visibility until the point is reached that only a minute portion of gravel and dirt roads are detected. . .and they are barely visible. Topography, water bodies, linearity, land use, and sun angle all present additional problems in the possibility of road identification. As a result color space photography of this resolution is useful only in detecing major roadways in rural areas. If further detail or analysis is attempted other linear elements or false alarms become incorporated into the supposed network.

Color space photography possesses great potential in the study of transportation networks, but many of the problems must first be eliminated. Future research will have to include photographs of a higher resolution so minor roads and complete road networks can be consistently detected and identified. Also a series of photographs of the study area should be taken from several angles due to the previously mentioned effect of the sun.

Further studies are now under way to document the consistency of color space photography in road detection. Nine separate photographs of the Dallas-Fort Worth area taken from Apollo IX will be used to analyze the road detection consistency of photographs with 300 foot resolution. In addition, studies of photographs with resolutions varying from 10 feet to 100 feet are to be conducted later this summer to determine the capabilities and limitations of such systems in detecting transportation networks from space.

# APPENDIX 3

## ENVIRONMENT MAPPING WITH SPACECRAFT PHOTOGRAPHY: A CENTRAL AUSTRALIAN EXAMPLE

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# ENVIRONMENT MAPPING WITH SPACECRAFT PHOTOGRAPHY: A CENTRAL AUSTRALIAN EXAMPLE

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TABLE OF CONTENTS

## INTRODUCTION

In two companion papers (Simonett and Henderson, 1969; Schwarz et. al., 1969) we have discussed the problems of thematic mapping from space by focusing attention on line and point phenomena, namely, detection of roads on a space photograph of the Dallas-Fort Worth area, and categorization of land use in Eastern Kansas on the basis of 40-acre decision cells. In this paper we are concerned primarily with a third problem, namely that of boundary delineation as a precursor to area typing.

The example now to be discussed concerns resource mapping of a natural environment near Alice Springs, Central Australia, where both boundary detection and categorization are complicated by the inherent complexity of landscape elements. In this environment we are not dealing with the same degree of patterned regularity found in cultural landscapes; nor are we dealing with more or less discrete entities such as crop types and roads, or cultural vs. natural phenomena. Instead nature has provided in this region a continuous variation in space of the several elements: terrain, soil surface, and vegetation. We know from principles of geography and ecology that such variation is not random, and were we to study it on (or near) the ground, we could eventually decipher all the intricacies of the patterns. When viewed from space, however, the very meaning and composition of boundaries, to say nothing of the "things" they separate, become increasingly ambiguous.

Two themes will be pursued in the Central Australian study to illustrate some advantages and disadvantages of using space photography in world resource inventories. The first concerns itself with the detection and meaning of boundaries, the second with sources of confusion during categorization.

In the discussion to follow we will demonstrate that space detected boundaries, regardless of their apparent obscurity, derive substantially from ground information. Direct comparison of boundaries in the field with those on the space photograph, as well as indirect line by line comparisons using low altitude obliques and photo mosaics, have


Figure 1. Location Map for the region northwest of Alice Springs, Central Australia. The numbers give the locations of air photo mosaics in Figures 13 and 14.

shown without question that even the smallest pin pricks of space data relate to qualitative changes in the landscape. Moreover, space boundaries are often easier to detect than are identical boundaries on photo mosaics.

Detecting a boundary and knowing that the landscape is somehow different either side of it is not the same as knowing either the nature or magnitude of that difference, nor is it to be presumed that the boundaries lie all at the same hierarchical level in a classification. Since generalizing is unavoidable in space photography due to current resolution limitations, boundaries may result from changes in one or several features of the environment, none or all of which may be significant in a particular resource inventory. While the boundary has meaning, therefore, it may not be one we wish to map.

Categorization is also related to this problem of generalization. Image discrimination functions such as texture, height etc. have restricted values in space photo interpretation. Tone is the most versatile of the image qualities but its limitation should be appreciated. Disjunct shades of similar color on the space photo sometimes relate to dissimilar combinations of elements in the landscape. Equally serious, dissimilar colors sometimes contain a similar combination of elements but in different proportions or under different illumination. In both cases substantial errors of interpretation arise, even among experienced interpreters.

The Alice Springs area was photographed with Ektachrome MS Aerographic 70 MM film in August 1965 by the crew of Gemini V. Figure 1 is a photo enlargement on which the main geographic features have been identified. This photo was selected for study because it is representative of the mapping problems to be encountered in very large regions of the semi-arid and arid tropics. In addition, the original photograph is of acceptable to good quality despite a substantial haze scattering in the blue and to a lesser degree even the green sensitive layers (Figure 7). Three of the investigators (Simonett, Cochrane, Morain) have been to the Alice Springs area on separate occasions and between us we have spent seven weeks in the field studying the soils, vegetation and topography.[1] This is immensely important from the point of view of categorizing areas delineated on the photo. In addition, one of us (Simonett) has conducted aerial and ground reconnaissance of the region with space-photo-in-hand for purposes of comparing boundaries, and obtaining low altitude aerial oblique and ground photos for laboratory comparisons. Finally, although the area is remote, the natural environment is fairly well known thanks to the efforts of R. A. Perry and his colleagues at CSIRO Division of Land Research. Perry's (1961) pasture map of the area is particularly valuable as a source of information and comparison.

## NATURAL FEATURES OF THE ALICE SPRINGS AREA

The Alice Springs study area (Figure 1) covers almost 21,000 square miles of country in semi-arid central Australia. It stretches from the James and Krichauff ranges in the south, and includes most of Missionary Plain, a large part of the Macdonnell and Chewings Ranges, all of Napperby Lake and Stuart Bluff Range and terminates at Mt. Denison in the north. Alice Springs itself is located on the lower right margin of the photo. The following brief discussion of landscape types draws heavily from the works of Perry (1960) and Perry et. al. (1962).

Physiographically four major landscape divisions are delimited on the Perry Pasture Map. These are:

1. Folded Ranges: represented on the photo by the James, Waterhouse, Macdonnell, Hann and Stuart Bluff Ranges.
2. Crystalline Uplands: Reynolds ranges, Crown Hill, Pine Hill.
3. Crystalline Ranges: Strangways Range, Mt. Chapple, Mt. Hay, Mt. Zeil, Mt. Heughlin, Redbank Hill.

[1] At the time of writing of this report G. R. Cochrane is engaged in an additional 5 weeks of field work and low altitude aerial photographic studies in the area.

# LANDSCAPES NORTHWEST OF ALICE SPRINGS, CENTRAL AUSTRALIA

## Base: C.S.I.R.O. Pasture Land Map, 1961

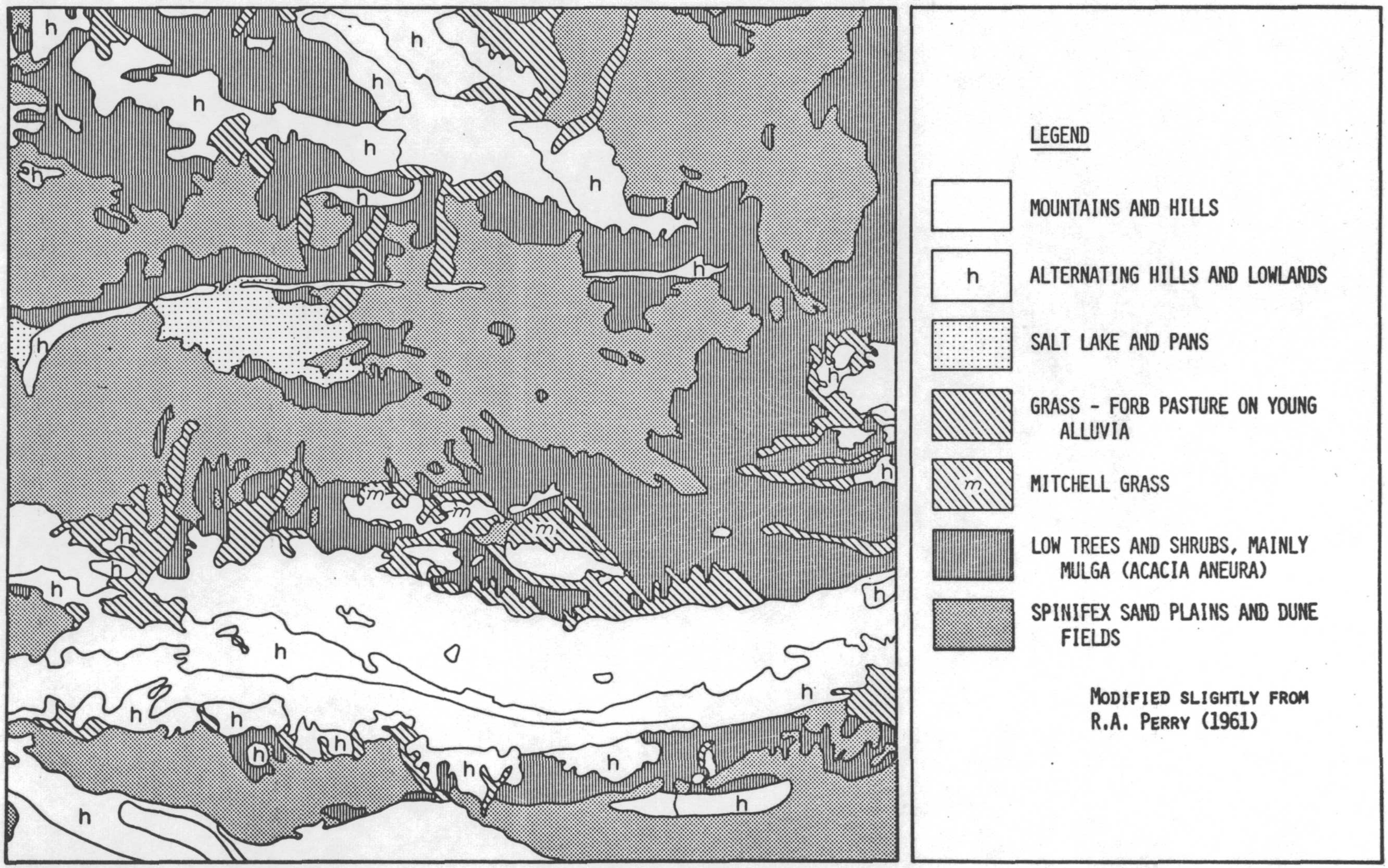


Figure 2. Landscapes northwest of Alice Springs, Central Australia. Modified slightly from R. A. Perry (1961), Pasture Land Map.

4. Northern Plains: Burt Plain, Everard Scrub, Missionary Plain (the last is not included by Perry as part of this category).

All of the ranges and uplands have large bare-rock outcrops and skeletal or shallow, stony soils. In the plains areas, soils are generally characterized as red sands, red clayey sands and red earths. Saline soils and unconsolidated sands are usually found along drainage lines and at Napperby Lake.

When vegetation types are superimposed on the physiographic and soil patterns, seven broad landscape types may be recognized. Figure 2 illustrates the distribution of these environments as mapped by Perry et al. (1962). Where possible the broad categories are defined in terms of vegetation even though in most circumstances the plant cover is open or very sparse. What is actually recorded on the space photograph is the spectral reflectance not only of vegetation but of rock and soil surface as well.

The seven landscape types delineated on Figure 2 are:

1. Mountains and Hills
2. Alternating Hills and Lowlands
3. Salt Lake and Pans
4. Grass-Forb Pasture on Young Alluvia
5. Mitchell Grass
6. Low Trees and Shrubs, Mainly Mulga (Acacia Anuera)
7. Spinifex Sand Plains and Dune Fields

Of these landscape units the Mountains and Hills and Alternating Hills and Lowlands categories have intricate mixtures of the other five categories recognized. The scale of these mixtures is far too small to detect or map on the space photo. Some discrimination of the larger entities may be feasible on say 10 X enlargements but uncertainties arising from shadowing and highlighting will prevent even modestly reliable categorization.

Salt Pans and Salt Lakes are largely bare of vegetation themselves (see photo 13 in Figure 10 and photo 19 in Figure 11) but are surrounded by a complex of spinifex, salt grasses, and other salt tolerant plants. Most species in this category are extremely sensitive to small changes

Figure 3 ( Following page)

1. Spinifex (Triodia basedowii) with scattered wichetty bush (Acacia kempeana), blue mallee (Eucalyptus gamophylla), Hakea divaricata, and Petalostylis cassinoides, near Connors Well 60 miles north of Alice Springs; 2. Typical mulga (Acacia aneura) community with a ground cover of kerosene grass ( Aristida browniana), at seventeen mile experiment site north of Alice Springs; 3. Forb-field plains with a variety of both perennial and annual chenopods, particularly Bassia spp., and composites including Brachyscome spp., and grasses mostly Aristida spp., Panicum decompositum, and Chloris scariosa, near Harry's Creek north of Alice Springs; 4. Short grass-forb pastures on Hamilton Downs station. Mount Hay is in background. Forbs increase in response to heavy grazing; 5. Kerosene grass (Aristida browniana) forb-field on young alluvium flanking the Macdonnell ranges west of Alice Springs; 6. Kerosene grass (Aristida browniana) on Napperby Creek alluvials. Low trees are of Eucalyptus suberia, Hakea divericata and iron wood (A. estrophiolata) and Atalayea hemiglauca.

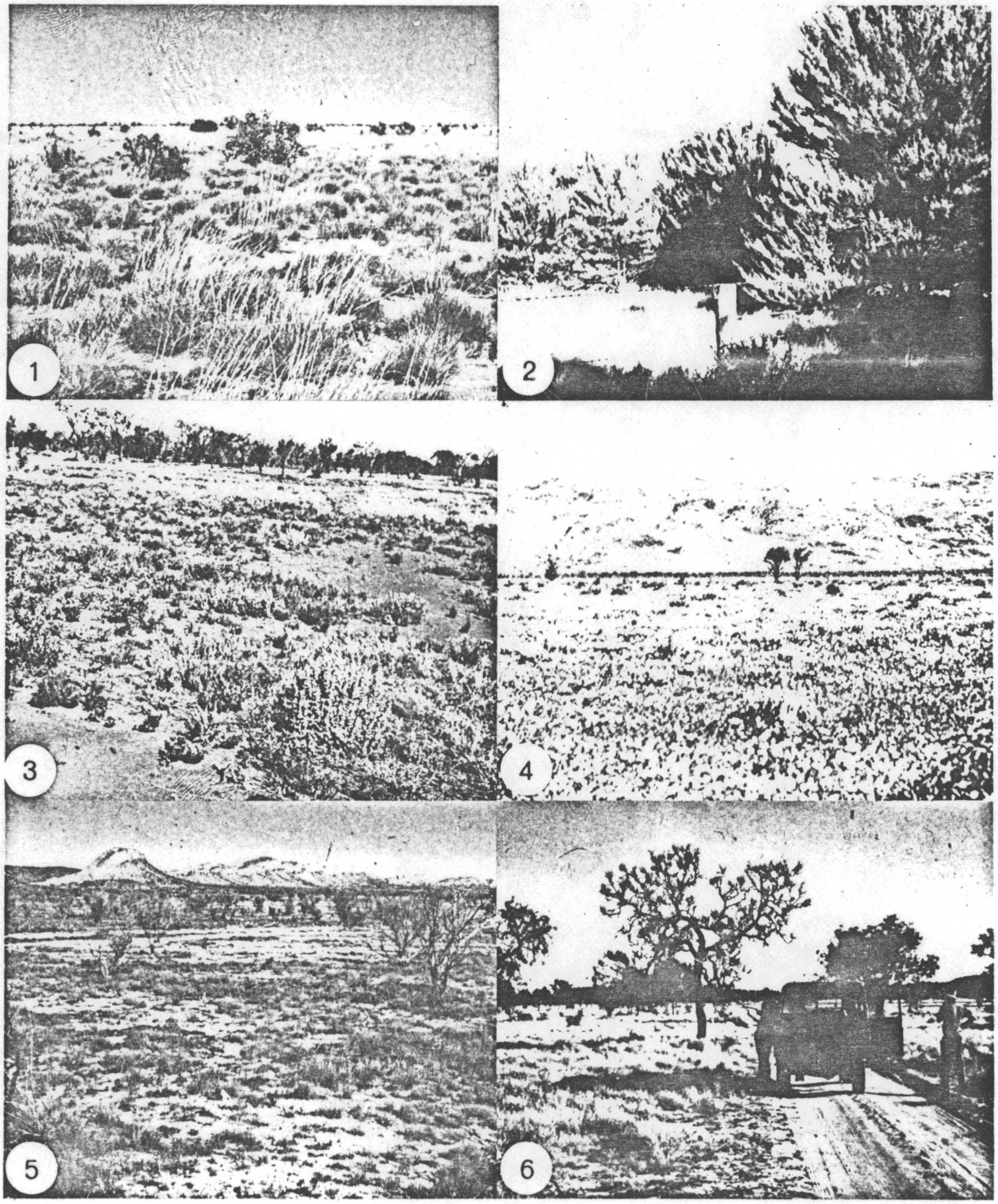


Figure 3

in salt content, soil texture and drainage and for this reason distinct belts of vegetation develop around the individual pans. As with the Mountain and Hill category most of these changes occur at scales too small to map and too small to be detected on the space photograph.

Mitchell Grass country is the most restricted spatially of the grass categories recognized. The type carries mainly Mitchell grass (Astrebla pectinata) as well as the other drought-evading perennial grasses, blue bush (Chenopodium auricomum) and salt bush (Atriplex vesicarium) (see photo 4 in Figure 3). It is generally restricted to flat or gently sloping treeless plains with heavy calcareous clay soils on Tertiary or recent alluvia.

On his original map Perry recognized two types of Short Grass-Forb pasture, one type occurring on young alluvia and the other on flat or undulating country. In this report the young alluvia type is retained as a predominantly grass category, but the more extensive variety on flat or undulating country is reclassified as Low Tree and Shrub.

In alluvial areas ephemeral short grasses and forbs form the predominant ground cover with scattered low trees overhead (see photos 5 and 6 in Figure 3). Kerosene grass (Aristida browniana) is the species most commonly encountered in the footslope zone of the ranges between Hamilton Downs and Dashwood Creek. Along Gidyea, Napperby and Day Creeks northeast of Napperby Lake sparse low trees occur together with kerosene grass. The main species involved are mulga (Acacia aneura), witchetty bush (A. Kempeana), gidgee (A. georginae), coolibah (E. microtheca), and ghost gum (E. papuana).

The Low Tree and Shrub category is overwhelmingly dominated by mulga (Acacia aneura) and is found on flat to undulating topography (see photo 2 in Figure 3) and on the flanks of mountain ranges (see photo 11 in Figure 4) on all rock types and on a wide range of soils. Associated with the mulga are: gidgee (Acacia geoginae), southern ironwood (A. estrophiolata), myall (A. calicola) and witchetty bush (A. kempeana). In all of these, height, density and vigor are highly variable due mainly

Figure 4 (Following page)

Ground Photographs of representative vegetation types and landscapes near Alice Springs: 7 River red gum (Eucalyptus camaldulensis) along Napperby Creek. 8 Soft spinipex (Triodia pugens) with Coolibah (E. microtheca) near Rembrandt Rock southeast of Napperby Salt Lake. 9 Interbedded sedimentaries (limestone, sandstones and congomerates) in the Macdonnell ranges. 10 Melalenca spp., swamp scrub or the Yuendumu road 7 miles southeast of Napperby Salt Lake. 11 Mulga-spinnifex slopes of the Heavitree Range near Ellery Gorge in the Macdonnell Ranges. 12 Bare areas and mulga on Missionary Plain, located as site 12 in Figure 12.

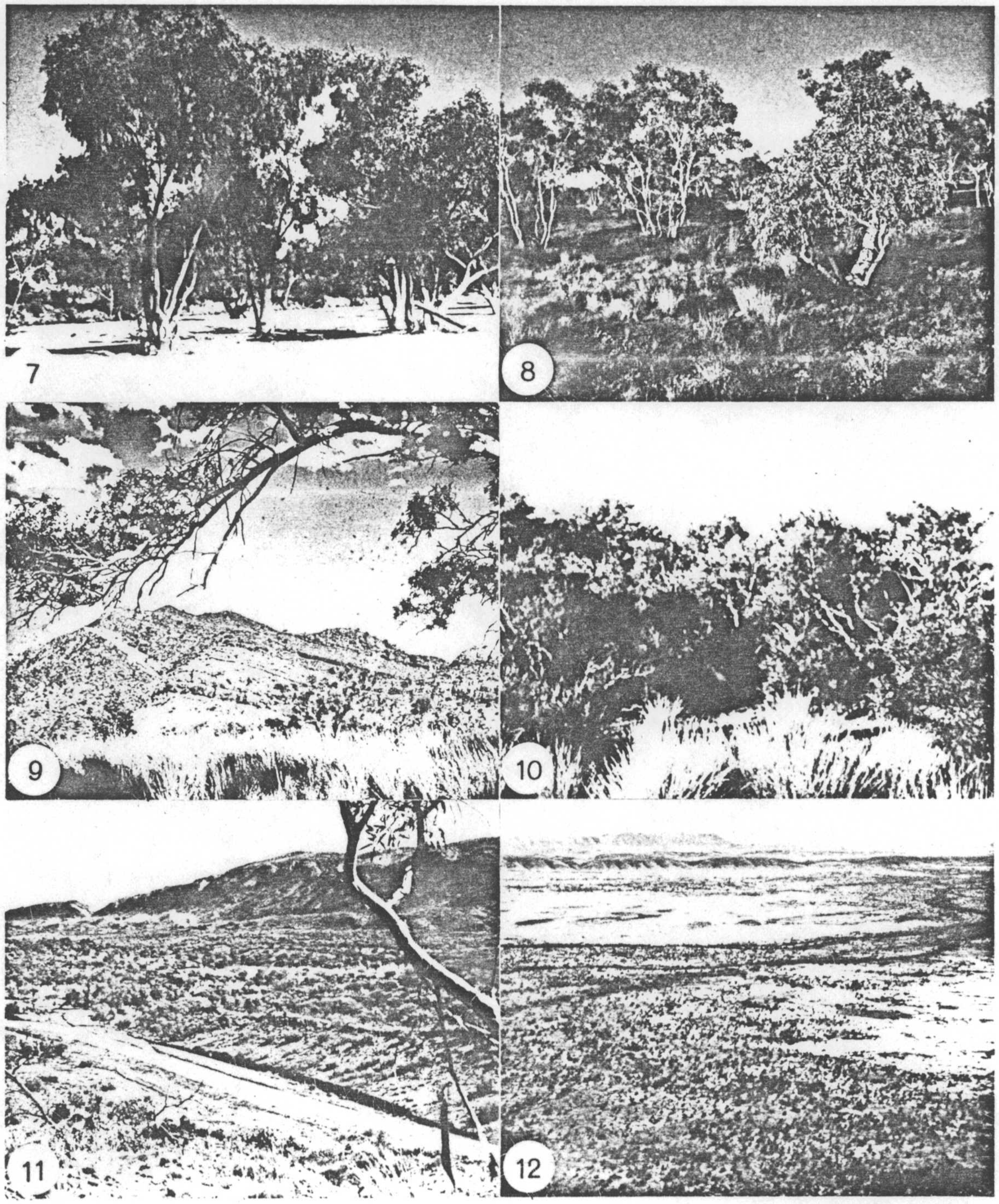


Figure 4

to the effects of drought. As a consequence an endless variety of structural subtypes exists, most of which have ill-defined boundaries.

Spinifex Sand Plains and Dune Fields occupy most of the central portion of the photo. Hard spinifex (Triodia basedowii) (see photo 1 in Figure 3) is the dominant species on flat sandy plains with smaller areas of soft spinifex (T. pungens) (see photo 8 in Figure 4) and feathertop (Plectrachne schinzii). Trees and shrubs are widely scattered except in local low spots where mulga and coolibah (E. microtheca) congregate. In dune fields hard spinifex occupies the flanks with mulga in the swales. Dune relief frequently approaches 20 feet or more from swale to crest with troughs 400 yards wide and dune flanks 150-300 yards long depending on orientation. The parallelism and linearity of these dunes give rise to alternating zones of spinifex and mulga vegetation which are easily distinguishable even from orbital altitudes.

## IMAGE CHARACTER AND TRANSFORMATIONS

The basic requirement for photo interpretation is that the photo in question have differences in tone, texture, shape and size between entities. Ordinarily the photo-interpreter works with high resolutions such that texture, shape and size convey most of the information, and differences in tone are of relatively modest importance. Air photos commonly show quite different tones for objects or aggregates of objects which we know to be the same, depending on lighting conditions and other variables; conversely, similar tones may be noted for unlike objects.

With the resolution in the space photograph between relatively low contrast entities (300 to 450 feet, areal weighted average resolution) several features should be mentioned: 1) detailed texture, shape and size clues are completely missing, though textures, shapes and sizes at a much grosser level of generalization may appear for the first time; 2) tone is retained as the major clue, but because of the modest resolution many entities are mixed in resolution cells thus seriously diluting discrimination power; 3) as many as 8 discrete categories of landscape in the Alice Springs area have much the same light tone on the space photograph, yet all are worthy of separate categorization: neither man nor machine (IDECS) can make such separation rationally on this color photo, partly because the phenomena may be truly unseparable and partly because of the haze noise in the blue and green-sensitive layers in the film; 4) as Schwarz et. al. (1969) have shown, at the 400 foot resolution level there are few environments which do not have a majority of cells containing two or more categories; 5) when unknown proportions of well-, moderately-, poorly-, and totally-unknown entities are mixed in a cell, who can understand the "information" such mixtures convey; and 6) the grosser the resolution the more one obtains an average of the landscape.

## Image Transformations

The more important image transformations performed on the Alice Springs photo are described in the following pages in order to give insights into the general complexity of photo content.

Most color film, including Ektachrome MS film, consists of three separate recording dyes (layers of the emulsion) each sensitive to a different region of the visible spectrum. The sensitivity (S) of each layer to light of a given wavelength ($\lambda$) is defined as:

$$S(\lambda) = E(\lambda)^{-1}$$

where

E is the energy of monchromatic radiation of wavelength ($\lambda$) required to produce a given dye density in the individual layers when the film is developed. Figure 5 shows spectral sensitivity as a function of wavelength for each dye-type of Ektachrome MS film. As seen in this illustration each dye has a peak sensitivity at a different wavelength; thus, even though there is considerable overlap in their combined sensitivity, it is feasible to distinguish them in terms of general spectral

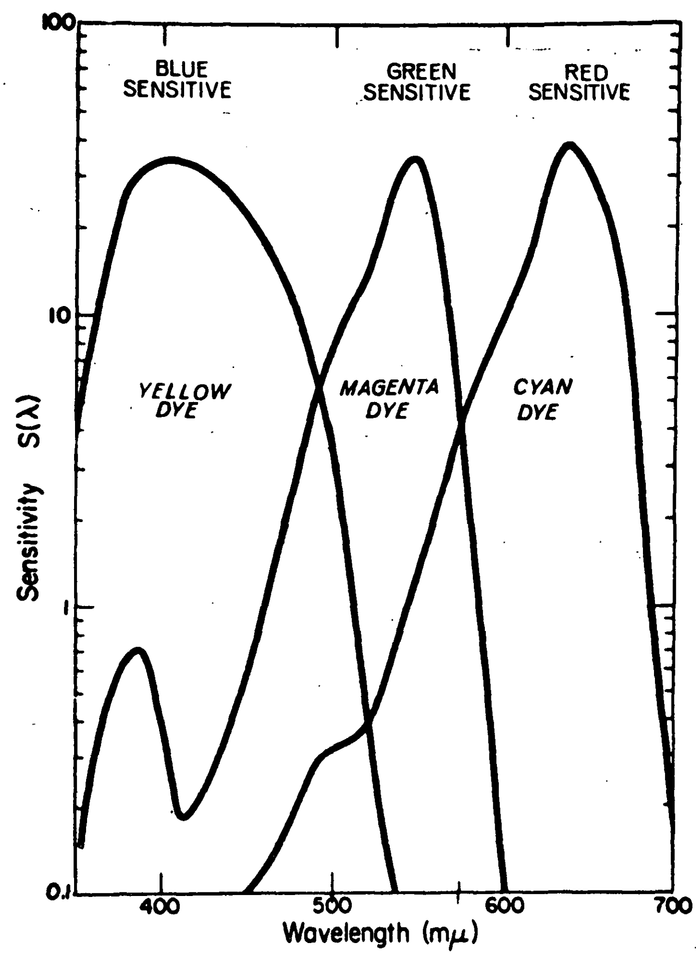


Figure 5. Spectral sensitivity of Kodak Ektachrome MS Aerographic Film (Estar Base), Type SO-151.

response regions. This approximation permits us to think in terms of three colors (blue, green, red) each corresponding to a particular wavelength band.

The limits of the respective wavelength bands occur at points where the sensitivity of each given dye decreases to about 10% of its peak sensitivity. This is an arbitary choice that results in blue being defined as wavelengths from 350 nanometers to 490 nm; green 490 nm to 590 nm; and red 590 nm to 690 nm. Figure 5 is a conceptual model in which the energy received by the film is lumped into three wavelength bands each corresponding to one of the primary colors. The actual error introduced by such lumping is small, because color photographs by their nature record only color, not the actual spectral reflectance of the original scene. The lumped model provides the necessary generalizing concept for analyzing the amount of information contained on a color photograph in each of the three bands.

One manipulation the lumped model permits us to carry out is that of separating the color photograph into three images each containing the information present in one of the wavelength bands. This procedure is a standard one involving: 1) masking to correct for overlapping skirts of the three dye density curves (Figure 6); and 2) preparation of black and white negatives from the color photo using blue, green and red filters. The particular filters used on the Alice Springs photograph, Wratten numbers 47B, 58, and 29, are illustrated in Figure 7, photos 1, 3, and 5. Masking is essential to insure that the content of each separation plate is crudely spectrally limited. Each of the separation plates is a rough record of the amount of energy received by the camera in the corresponding wavelength band (Figure 6); thus, variations in density on any of the separation plates represent approximate relative increase or decrease in reflectance in that wavelength region and in a general way simulate the way three true multiband photographs would appear. It is important to emphasize, however, that these separation plates are not quantitative, nor are they multiband; they are approximations.

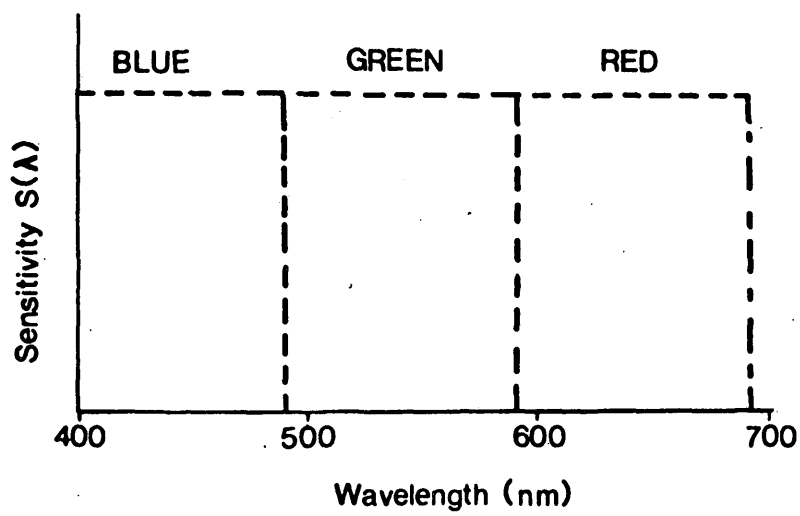


Figure 6. Crude lumped model for the blue, green and red sensitive layers of Ektachrome MS Aerographic Film after color separation and masking.

The separation plates give a visual account of the amount of information recorded in a given wavelength band and are therefore a valuable asset in deciphering some of the tonal ambiguity present in the original color photograph. This approach to the study of image content as a function of wavelength is useful in evaluating spacecraft photography, since atmospheric attenuation is a function of wavelength. Figure 8 -constructed from data in Elterman (1964) - shows the theoretical trend of atmospheric attenuation versus wavelength for Rayleigh, aerosol, and ozone attenuation factors in a "clear standard atmosphere". Actual atmospheric attenuation however, is a function of local weather conditions and dust content and the "clear standard atmosphere" never occurs in nature. Consequently, Figure 8 illustrates the best possible conditions ever available for spacecraft photography.

Comparison of Figures 7, photos 2, 4, and 6, with Figures 8 and 9 reveals, as expected, that attenuation is most severe in the shorter wavelengths. The blue band has very little terrain detail and is practically useless for mapping purposes. The green-sensitive layer contains considerably more terrain detail in the form of boundaries and discrimination of areas visible on the color photograph. In effect this means that the blue band merely adds noise to the color photograph, and the same is true to some degree of the green band. The red-sensitive layer is, as expected, most contrasty with clear vegetation and soil boundaries. ? Figure 9 is particularly interesting in this respect. It shows the blue, green and red separation plates of aerial obliques located as marked on Figure 1. The blue separation plate shows the effect, even with short passage through the atmosphere, both of inherent low contrast (few blues occur in arid regions; only whites have high reflectance in the blue region), and contrast reduction from scattering, and consequent weak boundary discrimination. The improved level of boundary delineation possible with the green and red plates is consistent with the amount of detail recorded on the space photograph, indicating that this procedure does give a reliable guide to where information lies in the latter.

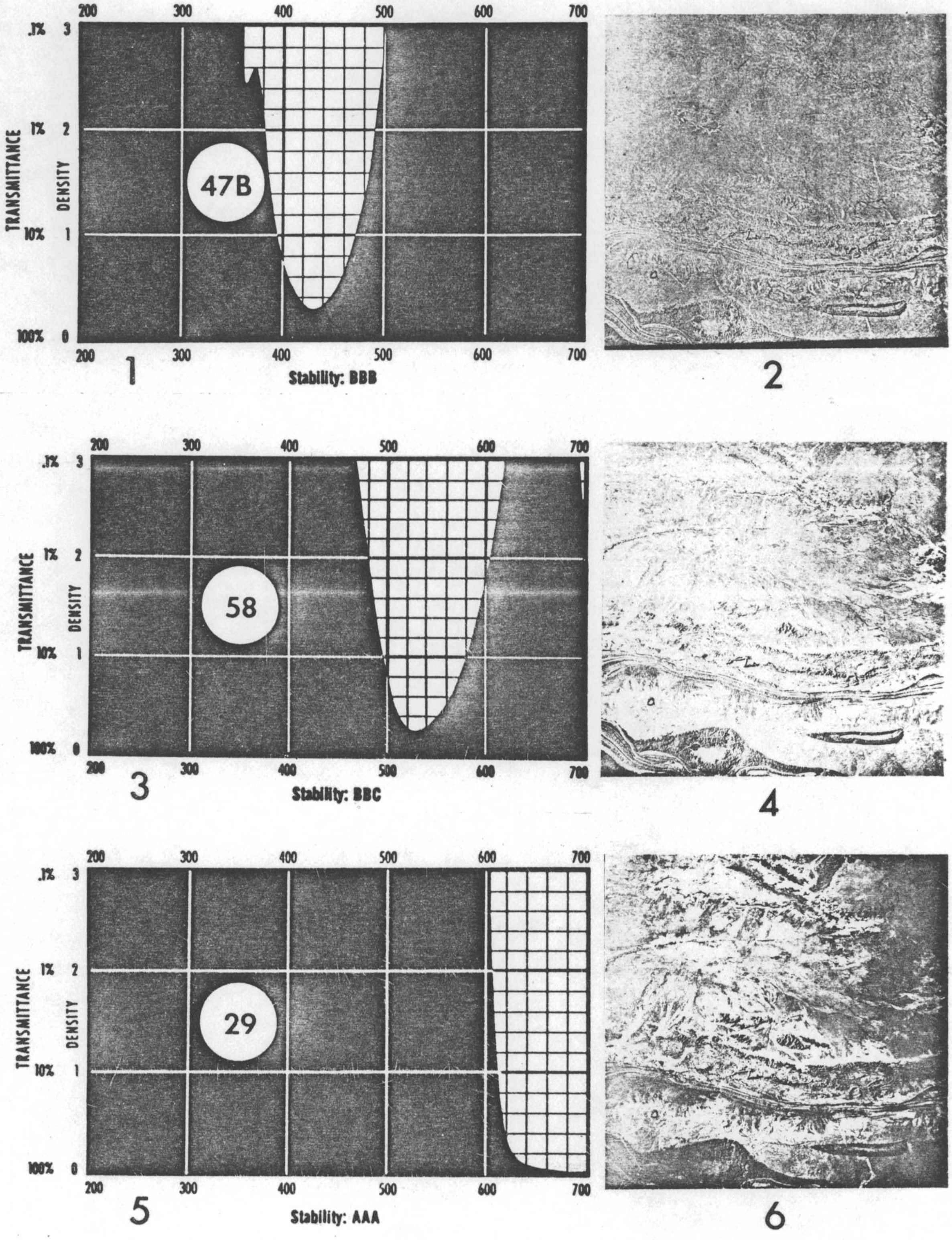


Figure 7. Reproduction of the blue, green and red separation plates of the Alice Springs space photo with the filters used for the separations.

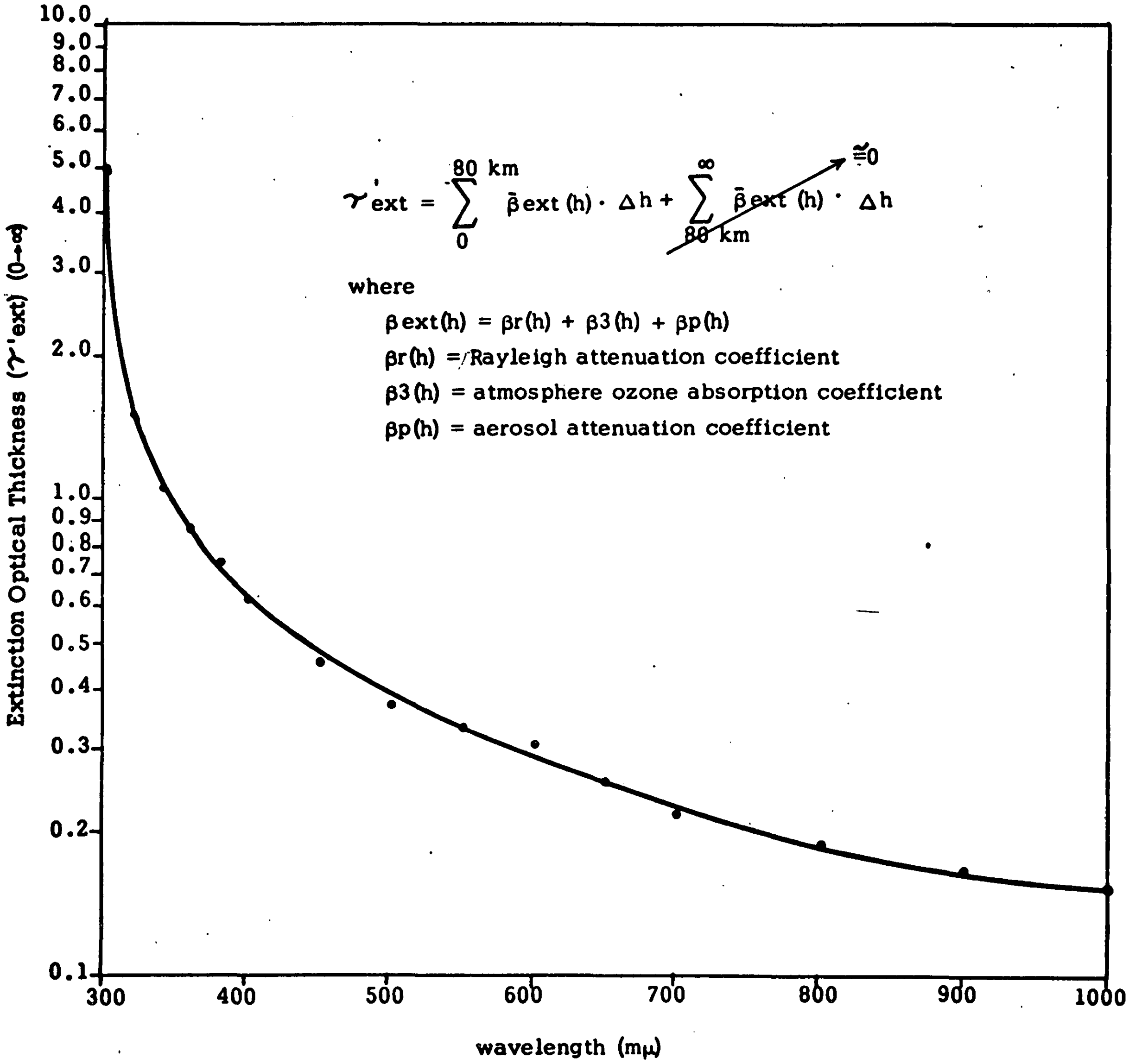


Figure 8. Theoretical trend of extinction optical thickness for a clear standard atmosphere (after Elterman 1964).

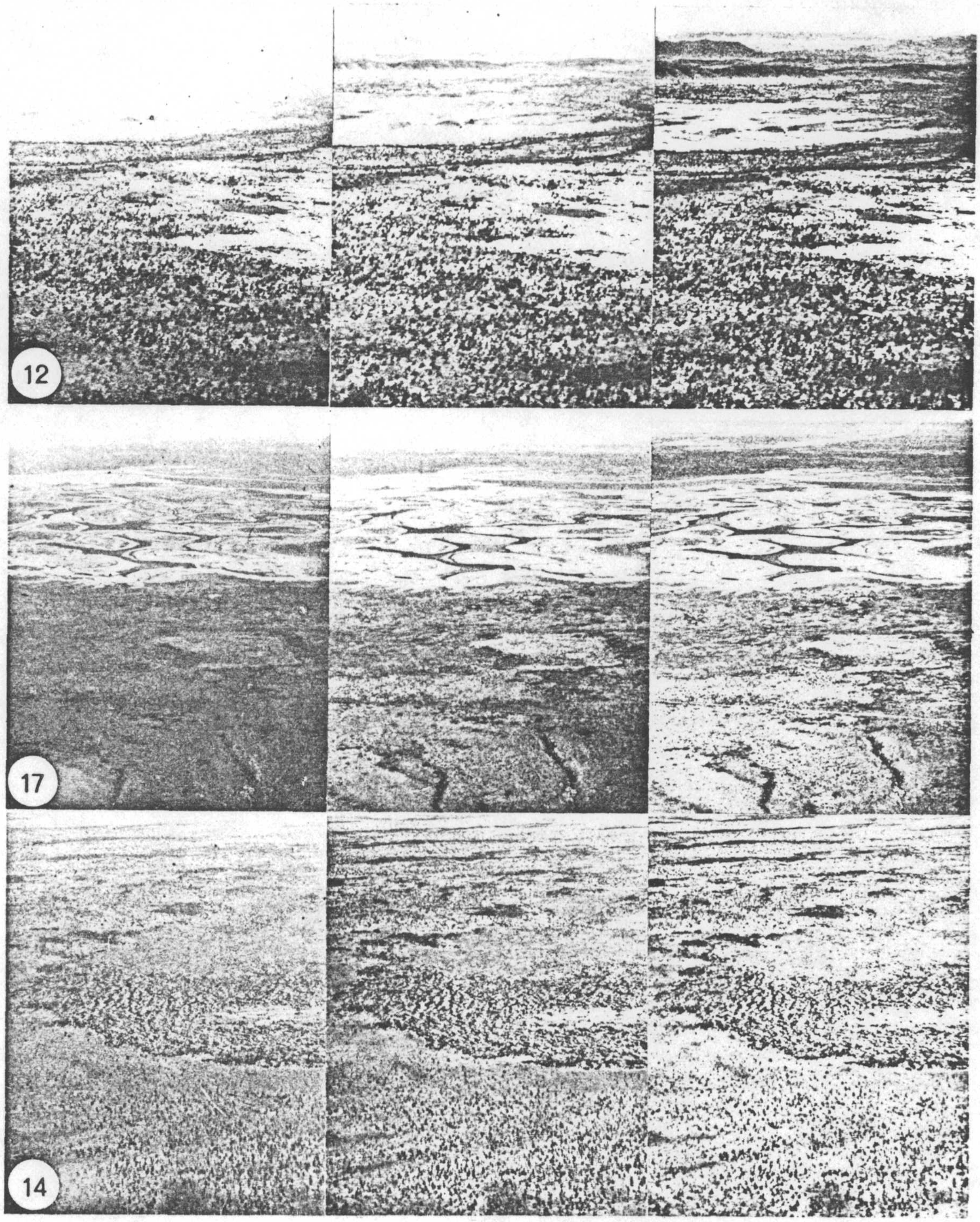


Figure 9. Blue, green and red separation plates of three aerial color oblique photographs obtained August 1968. The location of these areas is shown on Figure 12, sites 14, 17 and 12, respectively located west and north of Napperby Salt Lake, and southwest of Alice Springs on Missionary Plain.

## Edge Enhancement and Differentiation

Another possible transformation of space photographs consists of edge enhancement and differentiation. Edge enhanced images may be produced photographically by the Kodak tone line process. This process consists of stacking a positive and negative transparency in an exact registry sandwich which appears as an almost uniform grey surface at normal incidence, but at all other viewing angles lines can be seen wherever abrupt density gradients occur. Now, in order to obtain a photographic record of all the lines from all viewing angles the sandwich is placed over a sheet of unexposed film on a rotating vacuum board. The film is then exposed by a point light source offset from the axis of rotation, and at all points where a sharp density gradient exists a line will appear on the enhanced image. The resulting image in effect clips out a band of similar gradients along boundaries; i.e. it is a range of certain slopes in the first derivative of the original.

Edge enhanced images of the Alice Springs photo have been made on an experimental basis but a further rather massive investment of time would be required to optimize them and conduct an interpretation. One of the major difficulties is that all density changes on the original image— whether representing true large scale boundaries or merely scratches, image texture, or a fine mosaic of terrain types — appear as edge-enhanced features. It is therefore not possible for all edge enhanced boundaries to separate meaningful landscape changes. On the other hand very subtle but meaningful differences not detectable by eye will also be enhanced, and for this reason the technique is potentially valuable (Wingert, 1967).

## Other Manipulations

Other manipulations one can perform on the photographs include all those with the IDECS system. Since these are fully reported and illustrated in Peterson et al. (1969) we will not add to the bulk of this report by detailing them here. Furthermore, since the IDECS combinations of the Alice Springs area are currently being evaluated in the field (May-

June,1969 by Professor G. R. Cochrane) we cannot report on them at this time. They will be included in the later published version of the report.

## BOUNDARY DELINEATION AND VERIFICATION

### Boundary Delineation

The delineation of boundaries and categorization of areas presented here are based on interpretation of 6 X enlargements of both the original color photograph of the Alice Springs area and its red and green separation plates. The initial interpretation consisted of tracing all boundaries observable on the unaltered color enlargement. Three types of boundaries were mapped; those representing obvious, sharp, color differences separating grossly dissimilar entities; those representing less obvious but nevertheless distinct differences in color and density; and those differences in tone and density regarded as dubious ro conjectural. The same procedure was applied to the red and green separation plates.

Following boundary delineation, the three resulting maps (original color photo, red separation, and green separation) were compared qualitatively by superposition. They were found to display remarkable similarity in their total boundary content although some differences were observed.

1. An approximately equal number of first category boundaries were drawn on both color photograph and red and green separation plates and these were strongly coincident as to location.
2. The second category of boundaries, those defined by moderate contrast ratios across adjacent entities, demonstrated less agreement of the color photo and red and green separations. Grassland boundaries seem to be easier to detect on the color photo and green separation, whereas the darker tone of wooded areas are better defined on the red separation.

3. Numerous differences in both the number and placing of third category boundaries occured. Since these boundaries are defined by low contrast ratios between adjacent entities, a much higher degree of subjectivity is involved in their mapping. The exact placement of any particular boundary on a separation plate is bound to shift slightly from its placement on the original color photo, especially when dealing in minor changes in entity characteristics. A subtle qualitative change between landscape types is rendered ambiguous on a color photograph because of complex interactions of atmospheric attenuation factors and the gradual change in the spectral reflective properties of the two entities involved. These influences combine to produce a low contrast ratio between the entities. When a separation plate is produced some ambiguity due to attenuation and to different reflectances in each layer is filtered out. More importantly, because the cutoff values for the information contained in the particular spectral region are relatively sharp, minor shifts in boundary location take place.

It is not surprising, therefore, that even experienced interpreters confronted with two presentations of fundamentally identical data arrive at different conclusions regarding the discrimination of subtle landscape changes. In part this also will arise from different ways of lumping and splitting. Some observers are born lumpers; other are born splitters; yet others are fuzzy-minded academics with no consistency at all. The same problems of lumping and splitting apply to all qualitative judgments by men. It even applies to maps such as those prepared by Perry (1961), themselves substantially based on aerial photographs, which we have used as "Ground Truth" to compare with the space photograph.

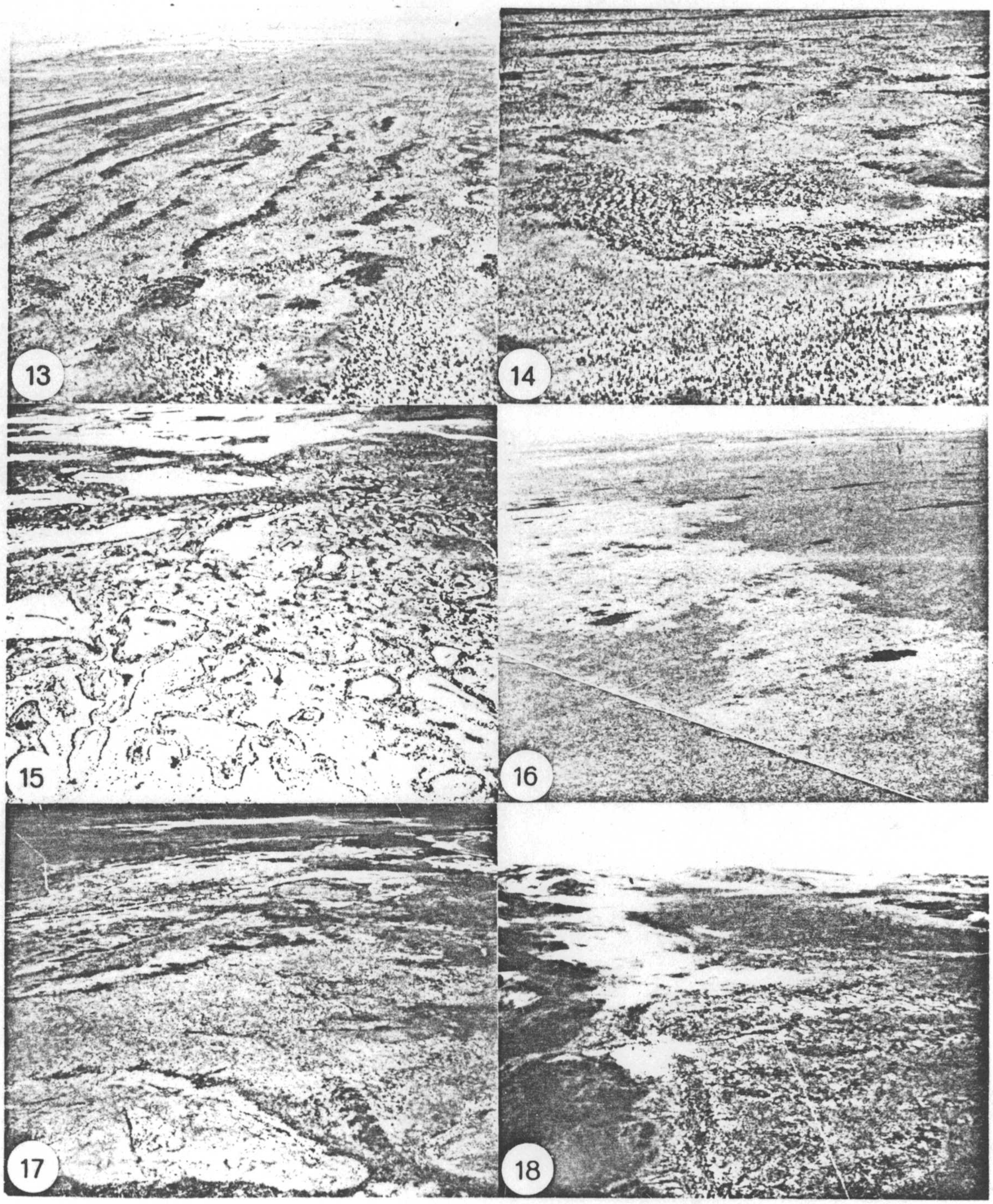


Figure 10. Aerial oblique photographs mostly near Napperby Salt Lake. The numbers are keyed for location to those given in Figure 12: 13 dunes west of Napperby Salt Lake. 14 Mulga and dunes west of Napperby Salt Lake. 15 Salt pans in troughs between irregular dunes west of Napperby Salt Lake. 16 Looking northeast from Aileron homestead. 17 Confluence of Napperby Creek and Napperby Salt Lake. 18 Looking E.S.E. from Mount Chapple to Redbank Hill.

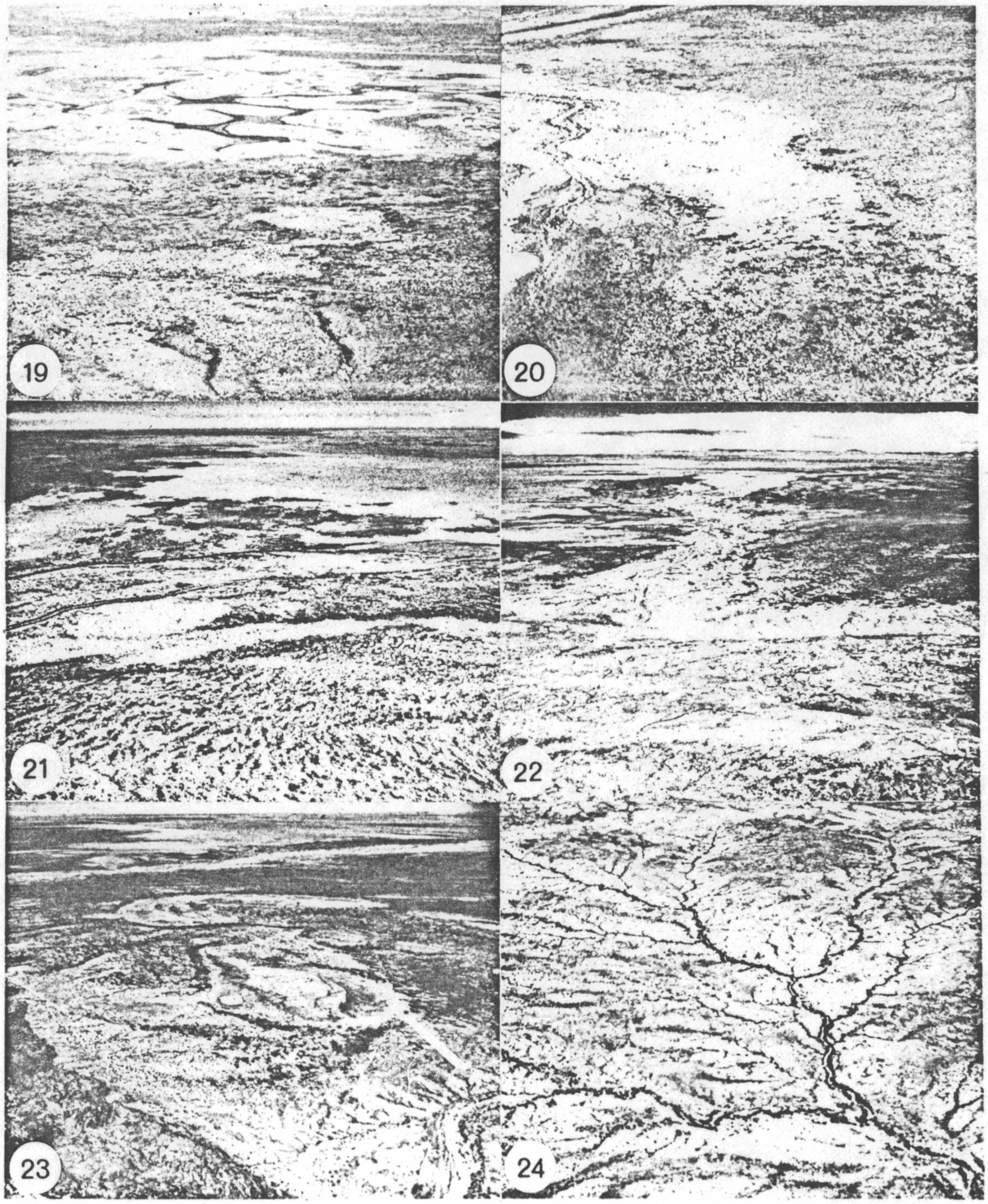


Figure 11. Aerial photographs mostly near Gidyea, Napperby and Day Creeks. The numbers are keyed for location to those given in Figure 12: 19 Looking south to Napperby Salt Lake. 20 Looking N.N.E. along Gidyea Creek. 21 Woodford River in mid distance looking east near Ti-Tree. 22 Looking south along Day Creek. 23 Napperby Station, airfield and Napperby creek in foreground, Day Creek in distance. 24 Headwaters of Day Creek in area of dissected lateritic residuals.

## Boundary Verification

One of the primary aims of this report is to demonstrate relationships between boundaries discernable on space photography and terrain features, and through this to gain insight into the meaning of such boundaries. The oblique photographs in Figures 10 and 11 are black and white reproductions of color photos and illustrate a range of terrain conditions through which we can begin to appreciate the nature of entities encountered and their spatial confines.

The location of each of the obliques is plotted on the Alice Springs photograph in Figure 12. By comparing the obliques with the corresponding area on the space photo it is possible to make point-by-point comparisons of the efficiency of the space photo in aiding boundary detection and delineation of "real entities". An even more detailed comparison is feasible in Figures 13 and 14 which show for four regions - the locations of which are noted on Figure 1 - reproductions of an air photo mosaic based on pan minus blue 1:48,000 scale photos and the 1965 Gemini photo brought to a common scale of 1:500,000.

In order to make such comparisons compact we have collected them into Table 1, which should be examined carefully in conjunction with Figures 10, 11, 12, 13 and 14. In Table 1 we give in turn the location of the obliques, the terrain types portrayed, the distinctness of the boundaries as seen on the color obliques and the detectability of the boundaries on the space photo. The content of Figure 13 and 14 enable those figures to stand alone.

A full comparison of each item would be wearisome. Summarizing all these checks and comparisons we conclude that:

1. Even minor juxtaposed point to point changes in tone on the Gemini photo are meaningful. The fact that we are unable to decipher the meaning without detailed field work is at this time immaterial. It is encouraging to realize the very modest changes in plant communities which may be detected. Thus, quite subtle differences between crests and swales of dunes mantled mainly with spinifex are detected because of their linearity.

TABLE 1

DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

| PHOTO OBLIQUE AND AREA | TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS | DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS | DETECTABILITY (SPACE PHOTO) |
|---|---|---|---|
| Figure 10; 13 and 14 Dunes West of Napperby Lake | a) dense mulga groves (dark grey) | very distinct | Excellent; depends on length-width of grove |
| | b) spinifex on dune flanks (med. grey) | ill-defined | Not discriminable except by deductive association |
| | c) mulga savannah (speckled) | moderate to ill-defined | Detail lost by generalization; interpreted as spinifex sand plain (Figure 11) |
| Figure 10; 3 Napperby Lake | a) salt pan (white) | very distinct | Excellent for large entities; ambiguous when next to spinifex |
| | b) spinifex dunes (mottled grey-light grey) | complex but distinct pattern | Detail lost by generalization; interpreted as spinifex sand plain (Figure 11) |
| | c) short tree & shrub (mulga) (dark grey) | distinct to ill-defined belts | Not detectable |
| Figure 10;4 Near Aileron Station | a) spinifex sand plain (medium grey) } b) short grass-forb (light grey) } | distinct to gradational | Not detectable |
| | c) Stuart highway (white line) | very distinct | Not detectable (< system resolution) |
| | d) dense mulga groves (shadows) (dark grey) | very distinct | Very poor (most groves too small) |
| Figure 10; 5 Confluence Napperby Creek and Napperby Salt Lake | a) dense mulga (dark grey) | very distinct | Poor/ambiguous; entities mere specks |
| | b) salt pan (some white/some with water) | distinct/very distinct | Detectable as gross features; detail lost |
| | c) short grass & forb w/scattered trees (light grey) | very distinct/gradational | Good/excellent |
| | d) redgum stringer | very distinct | Moderate; seen as pale line |
| | e) spinifex sand plain | very distinct/gradational | Good/excellent when adjacent to short grass |

(Continued on Following Page)

TABLE 1 (Cont.)

DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

| PHOTO OBLIQUE AND AREA | TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS | DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS | DETECTABILITY (SPACE PHOTO) |
|---|---|---|---|
| Figure 10;6 Mt. Chapple - Red bank Hill | a) hills and mountains (dark grey-in shadow) | very distinct | Excellent |
| | b) mulga clumps & savannah | distinct to ill-defined | Not detectable individually; interpreted as spinifex-mulga transition in Figure 17 |
| Figure 11;7 Napperby Lake | a) spinifex islands (white/med grey) | very distinct when water present, less so when not | Fair/good for largest islands; detail apparent but not coherent |
| | b) irregular spinifex dunes (?) (med-dark grey) | distinct | Boundary with lake distinct, others not detectable |
| | c) spinifex w/scattered low tree (med. grey) | distinct/gradational | Not detectable except as continuation of (b) |
| | d) mulga clump? redgum stringer? (dark grey) | distinct | Not detectable } <system resolution |
| | e) Yuendumu road (med. grey line) | fairly distinct | Not detectable |
| Figure 11;8 Gidyea Creek | a) spinifex sand plain (med.-light grey) | very distinct | Excellent; high contrast with (b) |
| | b) short grass-forb w/scattered low trees (light grey) | very distinct | Excellent; high contrast with (c) |
| | c) mulga scrub (dark-very dark grey) | distinct/gradational | Good/excellent; boundary with (a) somewhat diffuse |
| | d) red gum stringer | very distinct | Poor/not detectable; < system resolution |
| Figure 11;9 Woodford River | a) mulga scrub (cont. dark grey) | very distinct | Good/excellent diffuse boundaries in some locations |
| | b) dune field (as in Figure 10, photo 12) | very distinct | Excellent detection of field boundary; dune detail lost; interpreted as mulga scrub in Figure 17 |

Continued on Following Page

TABLE 1 (Cont.)

DETECTABILITY OF LANDSCAPE BOUNDARIES FROM SPACE

| PHOTO OBLIQUE AND AREA | TERRAIN TYPES PORTRAYED ON B & W OBLIQUE PHOTOS | DISTINCTNESS OF BOUNDARIES AS SEEN ON OBLIQUE PHOTOS | DETECTABILITY (SPACE PHOTO) |
|---|---|---|---|
| Figure 11;9 (cont.) Woodford River | c) spinifex sand plain (med. light grey) | very distinct | Excellent adjacent to (a); merges imperceptably to mulga savannah |
| | d) short grass/scattered tree (light grey) | very distinct | Excellent; gradational to mulga savannah |
| Figure 11;10 Day Creek | a) mulga scrub (cont. dark grey) | very distinct/distinct | Excellent; high contrast with (b) |
| | b) short grass w/scattered trees (med. grey) | distinct-diffuse | Excellent; diffuse boundary with spinifex |
| | c) kerosens grass w/scattered trees (med. grey) | diffuse | Excellent; entity ambiguous with mulga scrub |
| Figure 11;11 Napperby Station | a) mulga scrub (dark grey) | very distinct/distinct | Excellent; intricate detail |
| | b) mulga savannah/short grass (speckled-med-light grey) | very distinct | Excellent |
| | c) red gum stringer | distinct | Fair; ambiguous pale grey line |
| | d) hills | distinct | Fair/poor; ambiguous |
| Figure 11;12 Headwaters Day Creek | a) low tree/shrub-spinifex (light to medium grey) | gradational | Not detectable; detail lost by generalization |
| | b) red gum stringers (very dark grey) | very distinct | Very poor; present but incoherent |

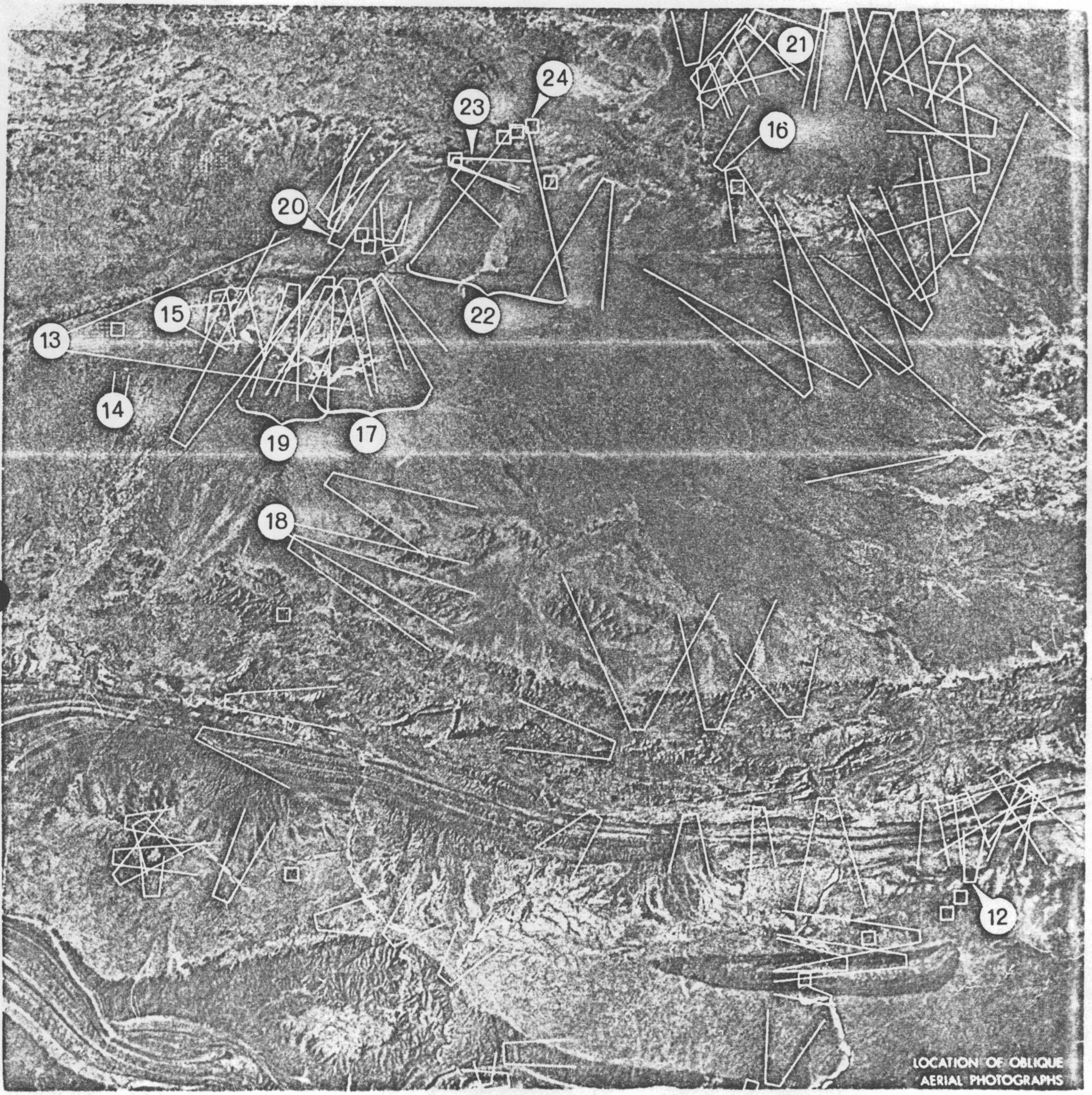


Figure 12. Locations of low altitude aerial oblique photographs. Numbers correspond to photographs illustrated in Figures 10 and 11.


Figure 13. Comparison of air photo mosaics with red separation plate enlargements. Top, Woodford Creek area; bottom, Napperby and Day Creeks. Scale of reproduction 1:500,000. The center of each area is indicated on Figure 1 with the number 13 and the letter T or B for Top or Bottom.

2. High contrast juxtaposed point to point changes signal that different entities are being sampled. If each entity is regarded as having its own three-dimensional probability density function for each resolution cell (the three dimensions arise from the color bands in the lumped model of Figure 6) then changes above a certain degree unambiguously indicate the presence of these entities. In short, marked changes in tone are never noise even at the resolution cell level. This is very well evidenced in the comparison between dark, light and mid grey tones on the red separation plate near Napperby Salt Lake. Dark points are always mulga, light are always salt pans, and mid tones are spinifex sand plains; see for example Figure 14 where this is readily confirmed.
3. The space photo enables many quite transitional or fuzzy boundaries to be integrated and detected readily in comparison to using air photos of different acquisition dates, times and hence sun angles. Figure 13 shows this well in the Napperby and Day Creek area comparison.
4. In order reasonably to capture the environmental variability of this region a resolution with a 1.6:1 contrast ratio of 50 feet would be essential, though 100 feet would be acceptable. To obtain such resolution would require a system with an average of 30 line pair/mm resolution on a low contrast target and a focal length of no less than 12 inches and preferably 24 inches (Doyle, 1967). The scale of significant variation in this environment cannot be captured with a 400 to 500 foot resolution as in this Gemini photo (calculations confirming these estimated resolutions on the Gemini photo will be made when further data, requested from NASA/MSC is on hand).

Variations Between Photo-Interpreters

From the nature and degree of boundary differences we encountered in delineating boundaries, a number of questions arose concerning, first,

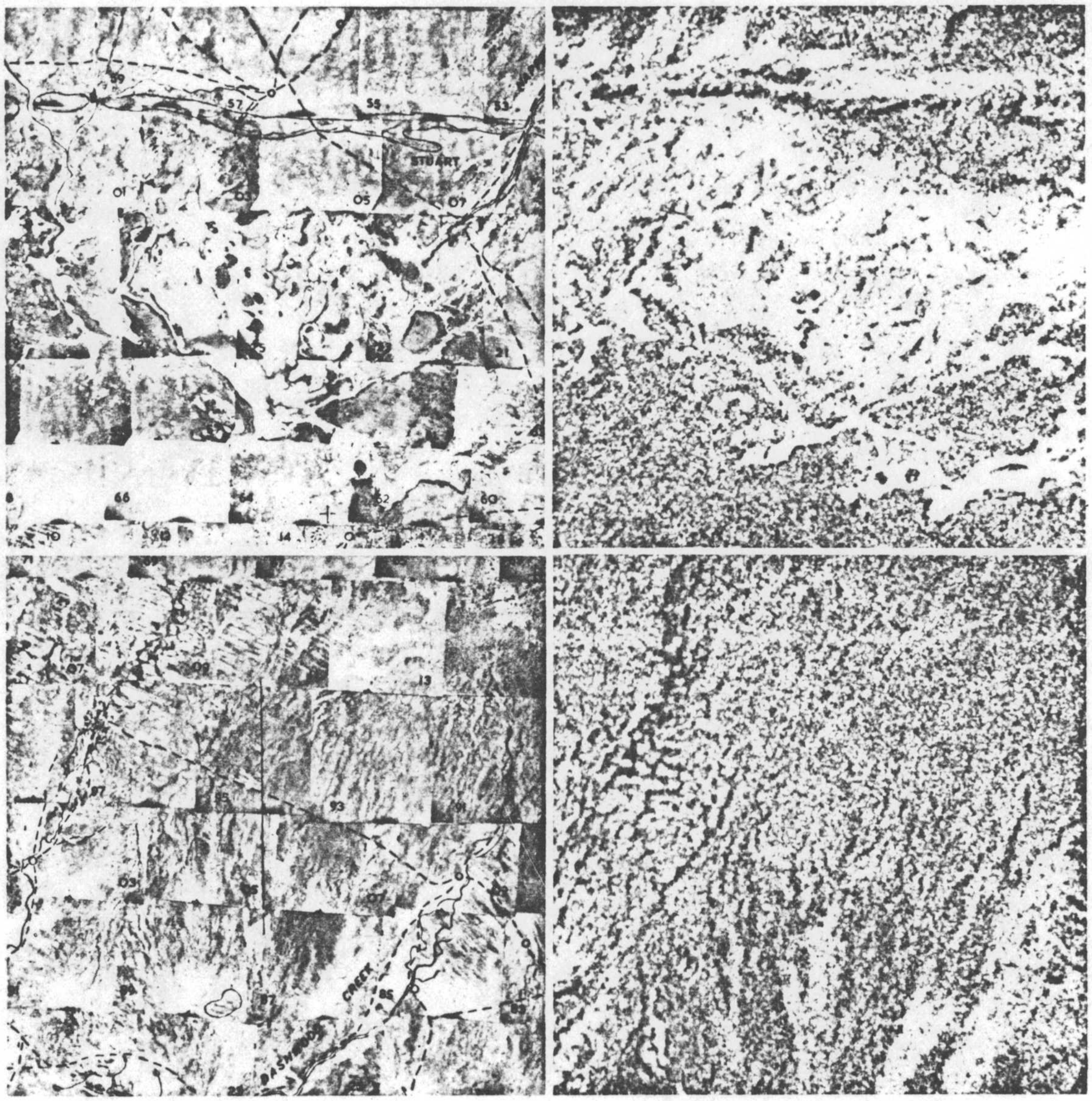


Figure 14. Comparison of air photo mosaics with red separation plate enlargements. Top, Napperby Lake; bottom, Dashwood Creek southwest of Napperby Lake. Scale of reproduction 1:500,000. The center of each area is indicated on Figure 1 with the number 14 and the letter T or B for Top or Bottom.

the ability of experienced interpreters to accurately map unfamiliar environments and, second, the comparability of their efforts. To gain insight into this problem a test area containing many of the vegetation types and boundary conditions was selected on the red separation plate. Twelve interpreters with no first-hand knowledge of this area were asked to perform a three category boundary delineation similar to that carried out by G. R. Cochrane who prepared the master boundary delineations.[3] No constraints were placed upon the interpreters as to what they should be looking for; simply that they should map as consistently as possible any boundaries they detected.

The results of these efforts clearly showed the extent of variation between interpreters and helped focus attention on the general problems of line detection. Four of the twelve interpretations, representing a fair cross section of all, were selected for comparison with the original work of Cochrane. Based on these interpretations Figures 13 through 16 illustrate the degree of variation encountered in four fundamentally different boundary situations. The name of the interpreters are keyed to the illustrations as follows: 1) G. R. Cochrane, 2) S. A. Morain, 3) W. G. Brooner, 4) F. M. Henderson, 5) D. E. Egbert.

Each of the four sets of boundary conditions contains its own problems of line detection. In Figure 15 attention is directed toward a portion of Napperby Dry Lake in which a complex pattern of salt pans, spinifex islands, and salt grass rises occurs. Comparing the five interpretations, it is clear that no two observers saw things alike, although there is fairly high congruence of boundaries in the lower portion of the area. Toward the center of the lake, however, where low contrast ratios prevail, there is virtually no comparison between interpretations. Here is a situation, according to the film density trace, in which numerous, small, moderately contrasting elements are contained in larger, area-

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[3] Cochrane's map was revised by Morain and checked by Simonett. We felt this procedure of serially reconciling differences was the most appropriate.

# VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY

## Alice Springs, Australia

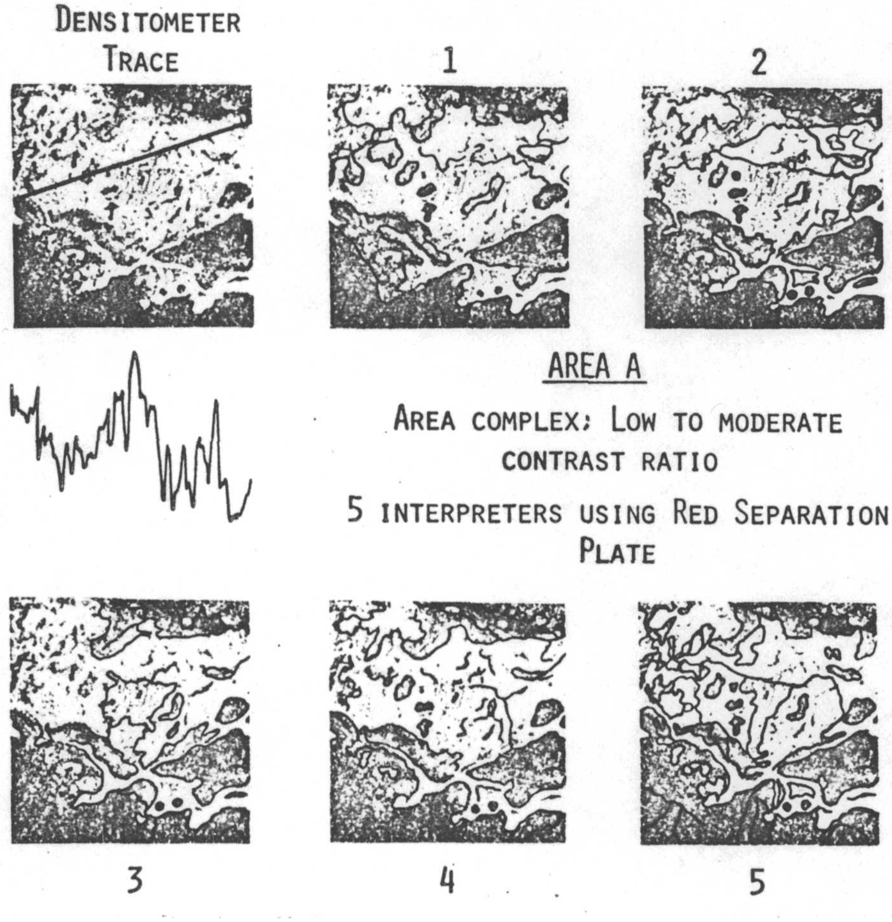



Figure 15. Interpretations of boundaries by five interpreters in an area where a complex of small entities containing low to moderate contrast ratios between entities occurs.

# VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY
## Alice Springs, Australia

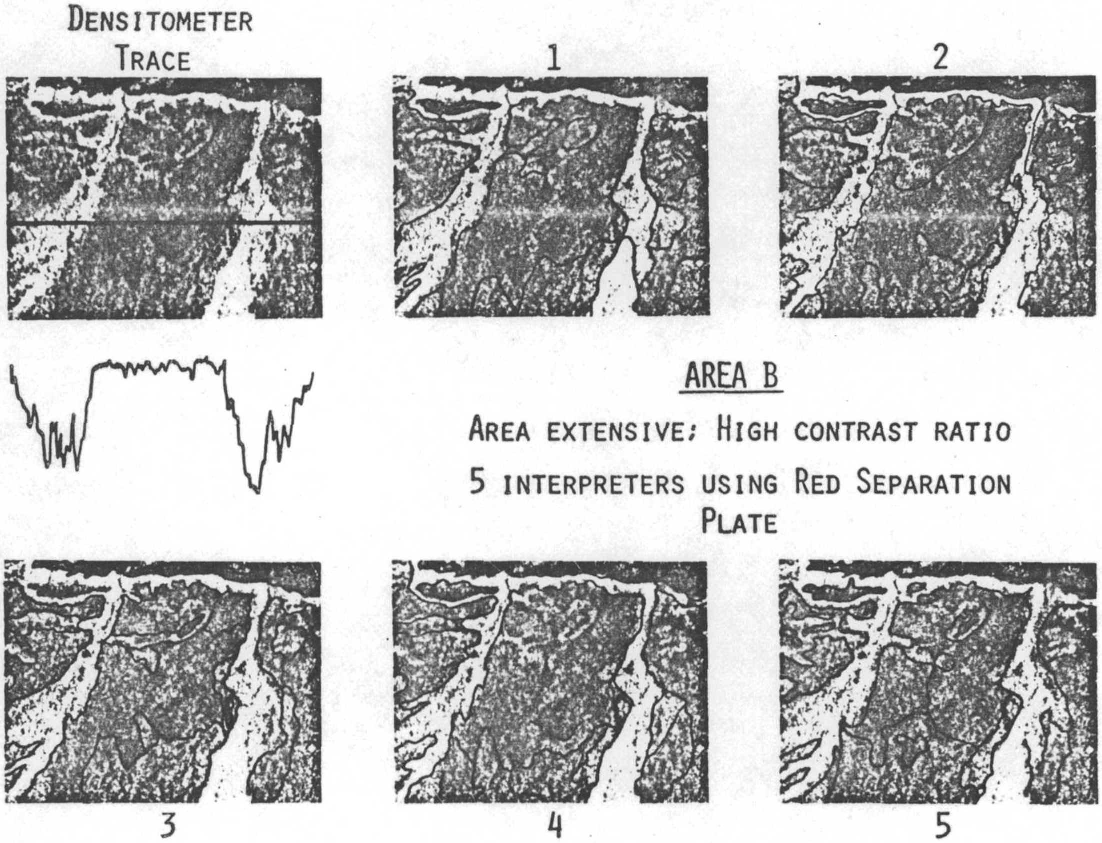



Figure 16. Interpretation of boundaries by five interpreters in an area where extensive entities are separated by high contrast boundaries.

extensive elements with lower contrast ratio. Such a condition is confusing to interpreters because the boundaries most readily detected lie at a scale too small to map; whereas those that perhaps should be mapped at a reconnaissance scale are difficult to discriminate.

The greatest comparability between interpreters is found wherever the phenomena being separated are extensive and contrast sharply with neighboring types. Figure 16 depicts this set of conditions in the area from Napperby to Day Creek and except for unavoidable differences in detail, all interpreters saw essentially the same pattern of boundaries; at least they all distinguished the creeks. In the areas between the creeks, however, everyone had a different view, and if each interpretation is considered by itself, the basis for each man's decisions can be appreciated. In fact, if judged solely by individual merits all of them are "believable" interpretations.

At the opposite extreme the least comparable results were obtained in situations characterized by extensive, low contrast areas. The region illustrated in Figure 17 is predominantly a mulga scrub and spinifex landscape with linear sand dune country in the upper half of the area. The film density trace shows clearly that almost no discrimination capability exists in this type of environment. About the only point of similarity between the interpretations is that all recognize the presence of Mt. Harris, the dark anvil-shaped area in the center of the frame. In terms of mapping, the area-extensive, low-contrast situations present essentially the same problem as do area-complex, moderate-contrast types. They all resolve to a question of how much detail is required to complete a given task.

The last example of boundary conditions, Figure 18 depicts a complex pattern of highly contrasting types. The topography in this locality is hilly to mountainous which means the interpreter may inadvertently delineate shadows with other dark toned entities, and sunlit spots with light toned types. This problem has been magnified in this example because a black and white separation plate was used for analysis. The original color photo would give a more accurate view of variable illumination.

# VARIOUS INTERPRETATIONS OF BOUNDARY CONDITIONS ON SPACE PHOTOGRAPHY

## Alice Springs, Australia

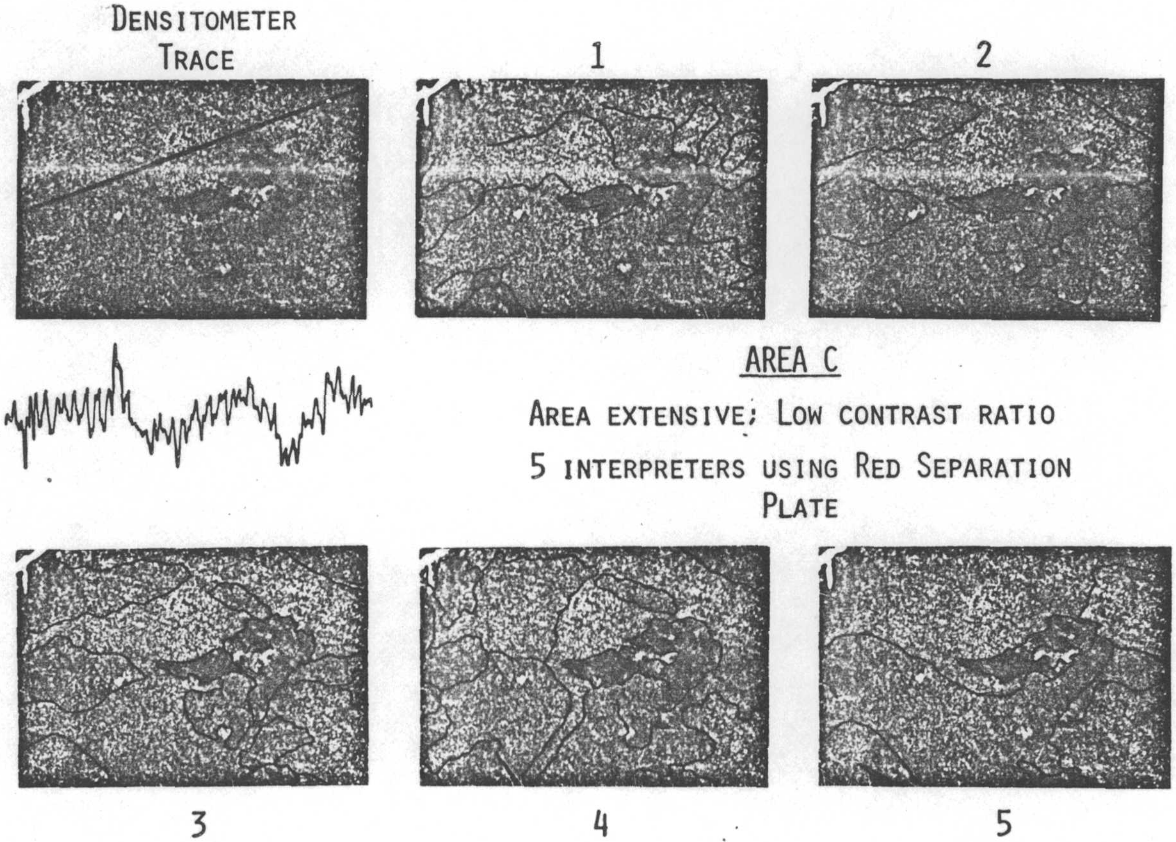



Figure 17. Interpretation of boundaries by five interpreters in an area where extensive entities are separated by low contrast ratios.

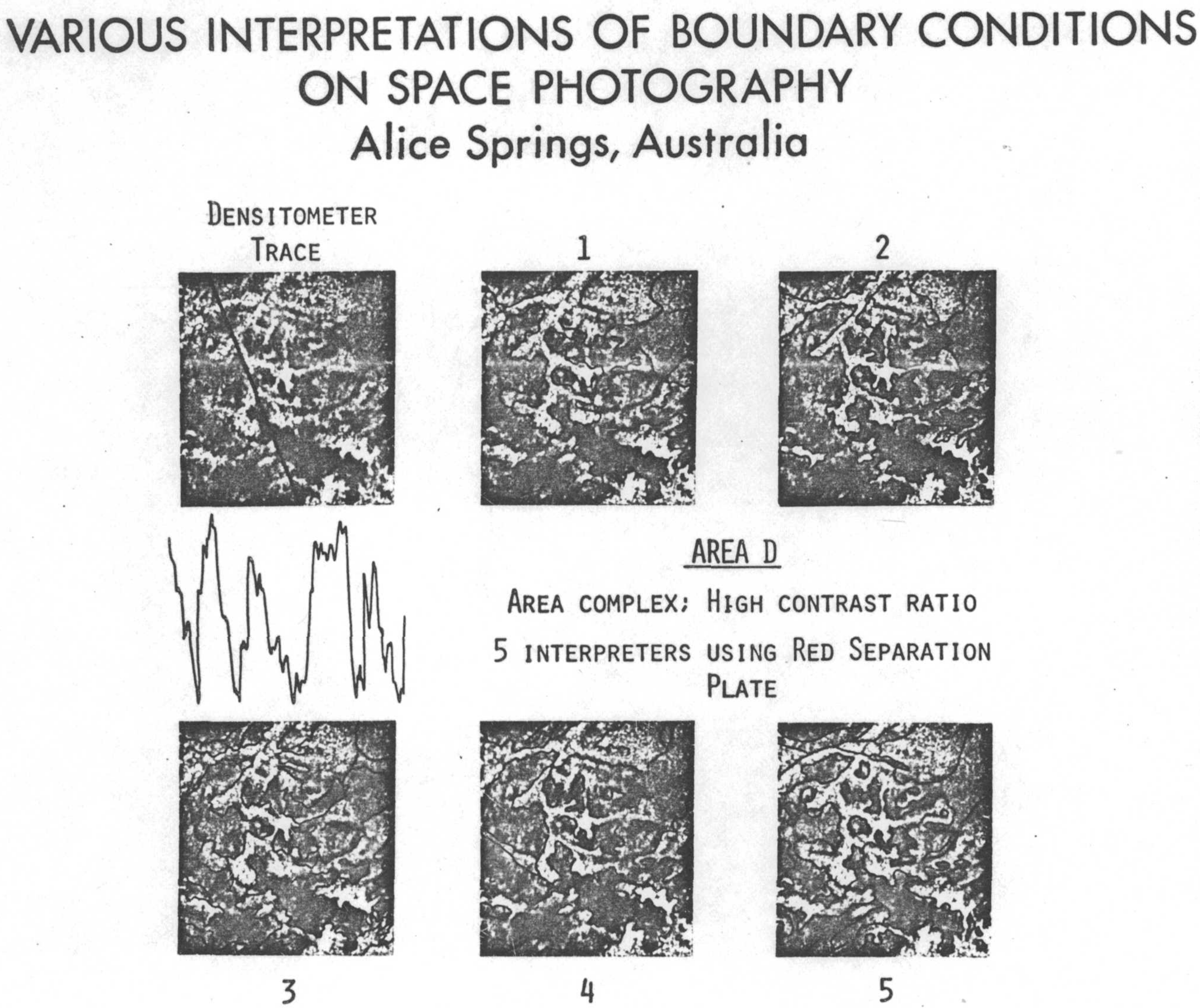



Figure 18. Interpretation of boundaries by five interpreters in an area where a complex of small sharply contrasting entities may be found.

## Classifying Entities

Our ultimate design in resource mapping from space is to interpret the meaning of those areas delineated. From the discussion of boundary detection, however, it is clear that at least in desert and semi-desert environments, good quality but modest resolution space photography contains many more meaningful boundaries than can possibly be mapped and categorized at survey scales. There is a two fold problem here; that of generalizing the boundary interpretation so that a map can be produced, and that of classifying the areas delineated. The first of these problems has not been studied and will not be considered further in this report. Except for a few loose rules regarding the minimal area that can be mapped at a given scale, generalizing by human interpretation is entirely subjective, whether done on air photos or on space photos.

In the final analysis categorization of areas must be qualitative because dissimilar entities are grouped together during the process of generalizing. In a sense this is precisely what we require in resource surveys - elimination of the "noise" contributed by detail. As long as we interpret space photographs with these considerations in mind we will not abuse the data.

Despite constant reference to data reduction, the Alice Springs photograph contains a vast amount of information from which a rather detailed (thirteen category) map of landscape types has been produced (Figure 19). Eight of the categories mapped are referred to as "primary types" and are considered by us to be acceptable groupings. An additional five categories constituting mosaics and transitions of these are based primarily on deductive and presumptive evidence.

Identification and distribution of the various categories was arrived at by combining the data from photo interpretation, field observation, and reference to the previous work of Perry (1961, 1962). All decisions for classifying areas were based on image qualities together with our field knowledge of the range of types present. After establishing the distribution of types, verbal descriptions of each (the legend items)

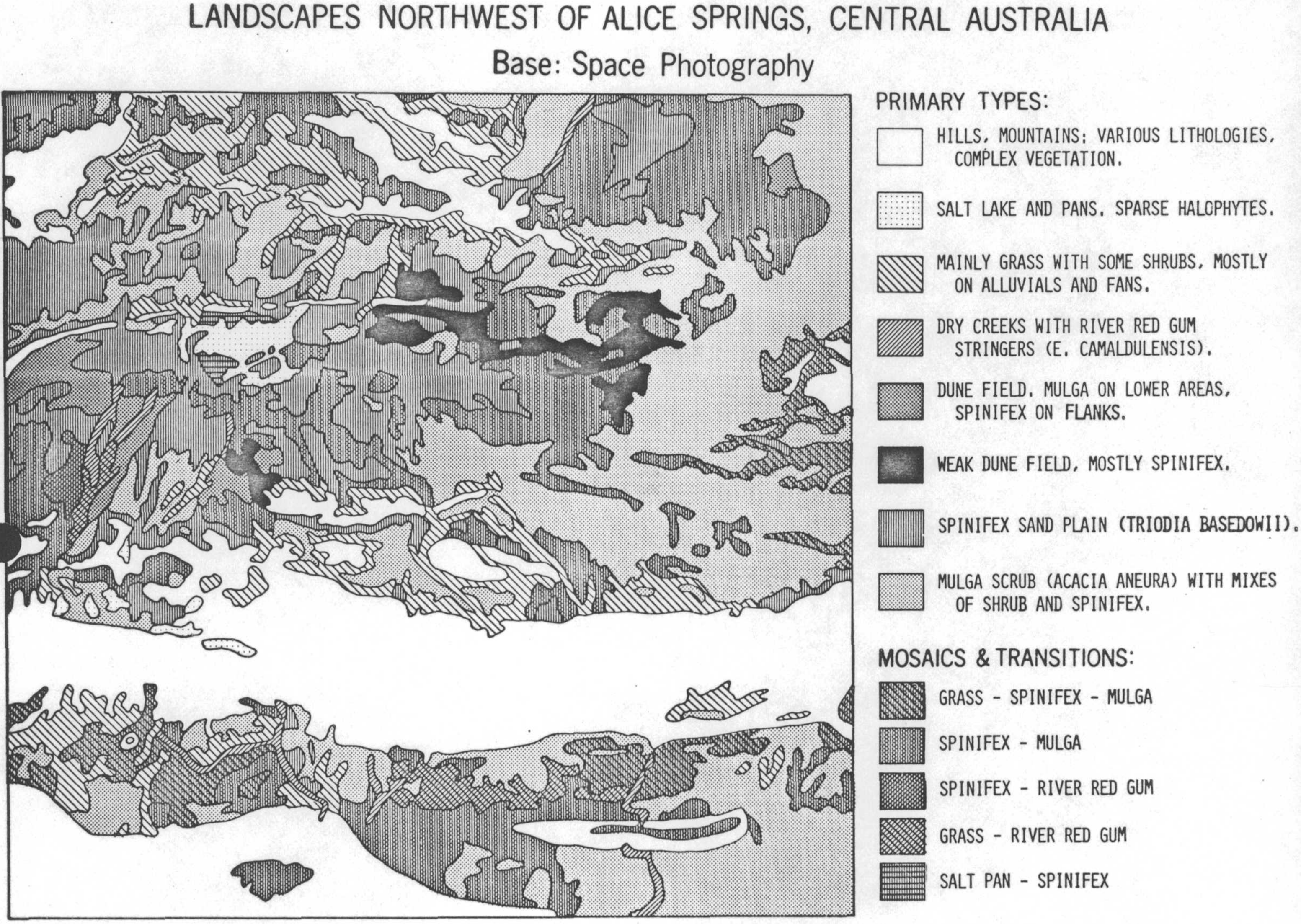



Figure 19. Landscapes northwest of Alice Springs, Central Australia. Boundaries and categories based upon space photography.

devised in accordance with field observations and the terminology already available from Perry.

Figure 19 is an unedited attempt by a single interpreter (Morain) to categorize areas on the basis of the above information. A number of inaccuracies (or at least questionable generalizations) are already known to exist, many of which could be improved by contributions from other interpreters familiar with the area. Two classification errors from the mosaic and transition categories will serve as examples of the sort of problems encountered.

The first of these is drawn from the grass-river red gum type. According to Perry, spinifex (T. clelandii) is the dominant grass with river red gum occuring along creeks. As used in this report the word "grass" refers to any genus of grass other than spinifex, even though the latter is in fact a grass genus. The interpreter failed to recognize the spinifex as such but was successful in distinguishing the larger entity, "grass". Inspection of the photograph reveals that grass was believed present because of the light tones present in the area. Spinifex was not suspected in this case because that entity normally has a darker tone than other grasses. Clearly we cannot map reliably at the generic level.

The second example concerns the Grass-Spinifex-Mulga mosaic. Here again Perry describes the identical map areas as combinations of either Mitchell or kerosene grass, mulga and river red gum. This time spinifex was suspected but failed to be present in reality. Inability to recognize river red gum is probably less serious a problem, since it characteristically occurred only along creeks and along some only sporadically.

Certain of the categories are intuitively obvious from their photo appearance, assuming the interpreter has a basic knowledge of the region. For example, hills and mountains, major drainage ways, and to lesser extent dune fields and foot slope alluvial areas, are easily identified.

Some drainage ways are particularly easy to discriminate if red-gum stringers line their courses. Whether this is due solely to very sharp

# COMPARISON OF BOUNDARIES: SPACE PHOTOGRAPHY vs. PASTURE MAP

## (Base: Map from Space Photo)

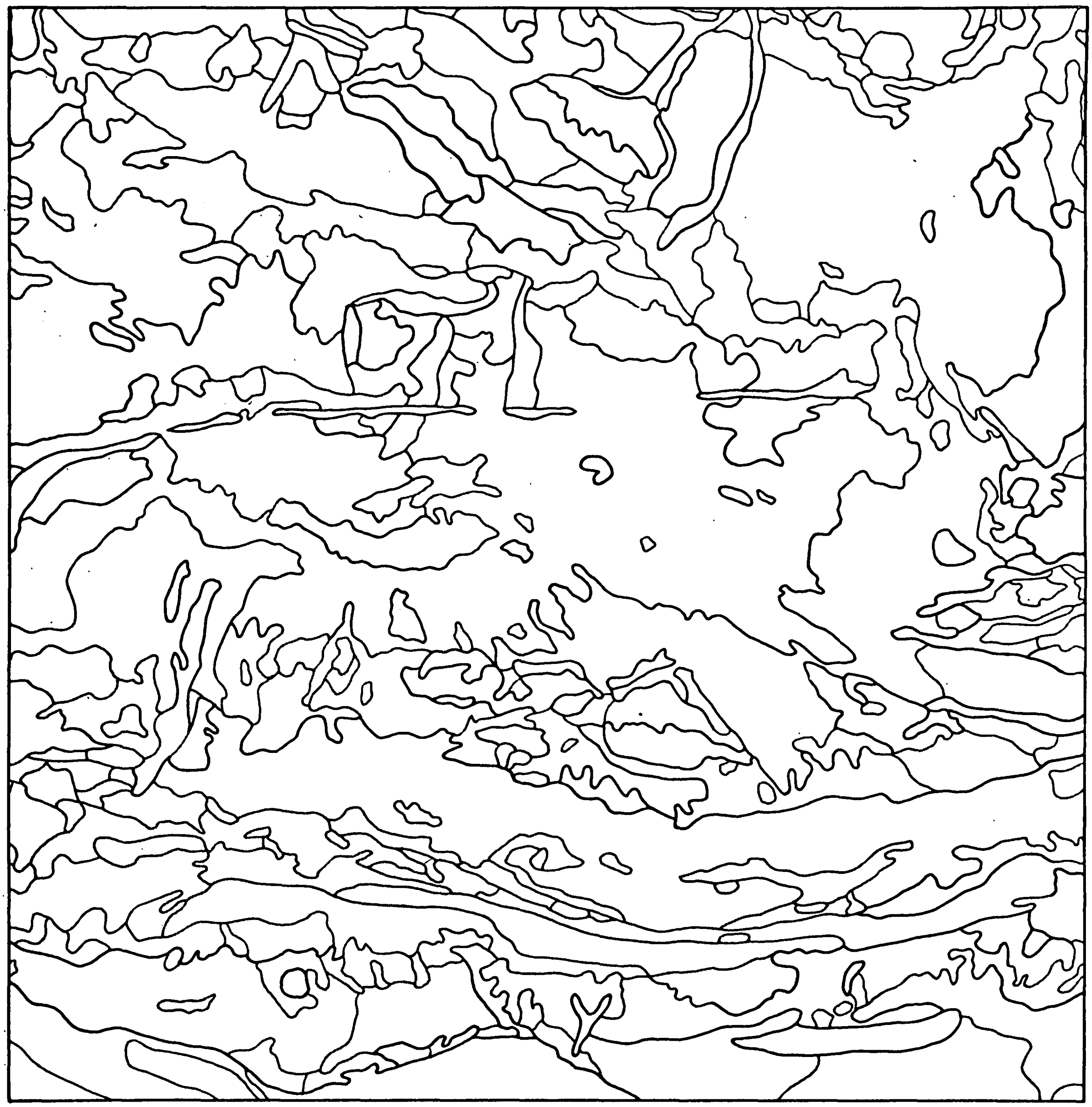
—— BOUNDARIES SHARED

—— SPACE PHOTO ONLY

Figure 20. Comparison of boundaries delineated on space photograph and Perry's (1961) map of the Pasture Lands of the Alice Springs Region. The boundaries shared and those noted only on the space photo are given.

# COMPARISON OF BOUNDARIES: SPACE PHOTOGRAPHY vs. PASTURE MAP*

## (Base: Pasture Map)



—— BOUNDARIES SHARED
—— PASTURE MAP ONLY

*AFTER R.A. PERRY, (1961), C.S.I.R.O. DIVISION OF LAND RESEARCH, CANBERRA, AUSTRALIA

Figure 21. Comparison of boundaries delineated on space photograph and Perry's (1961) map of the Pasture Lands of the Alice Springs Region. The boundaries shared and those noted only on Perry's map are given.

contrasts in spectral reflectance properties of the soil-vegetation interface or results from a combination of spectral reflectance and shadowing caused by tree height is not known. Many others with red gum are barely detectable after the fact but are otherwise ambiguous. The waterways themselves are reported to be only 150 feet wide, less than system resolution. The space photo was taken in late afternoon so shadows were present as may be seen in the mountains.

Some dune fields are equally easy to detect, but in this case the reason is likely attributable to vegetation contrast rather than shadowing. Wherever dunes are spaced more than about 120 yards apart (the approximate resolution of the camera system) with mulga developed in the swales, the field takes on a characteristic linear or "combed" appearance. Other dune fields are not easy to detect either because the dunes are too near each other to be resolved or because the spinifex-mulga relationship is nonexistent, or too fine to resolve, or has been weakened by drought. Due to their obscurity on the photograph (just a vague hint of the combed appearance) such dune fields are classified as "weakly developed". They are probably more wide spread than Figure 19 indicates.

The Mulga Scrub, Spinifex, and Scrub-Spinifex categories correspond fairly well spatially to the Low Tree and Shrub and Spinifex Sand Plain types mapped by Perry (Figure 2). Mulga scrub appears on the space photo in medium to medium dark tones and wherever it comes in contact with the lighter tones of alluvial grasslands, boundaries are distinct. Discrimination between Mulga Scrub and Spinifex Sand Plain is exceedingly difficult since the contact between these two is characterized by gradual shifts in their relative proportions in the landscape. Figure 19 recognizes a transitional type, Spinifex-Mulga, to draw attention to this ill-defined contact.

The final two figures (Figures 20 and 21) in this draft paper represent compilations, generalizations, and comparisons of all boundaries delineated on Perry's map and on the Gemini photo. These two illustrations were compared in the field during May and June 1969 by

Professor G. R. Cochrane. It is too early to report on these comparisons here, but he in effect has verified the basis on which each boundary appears to be erected such as differences in vegetation density, type, structure, and species; soil color, dissection, and exposure; lithology and other items. A detailed site-by-site comparison on the ground between Perry's map and the boundaries derived from the space photograph is essential to prove the meaningfulness of the boundaries in both cases.

## REFERENCES


Doyle, F. J. (1967), Mapping from satellite photography: Unpublished text of a lecture delivered under the auspices of the American Society of Photogrammetry, NSF Visiting Scientist Program.

Elterman, L. (1964), Atmospheric attenuation model, 1964, in the ultraviolet, visible, and infrared regions for altitude to 50 km: Environmental Research Papers No. 46, Optical Physics Laboratory Project 7670, Air Force Cambridge Research Laboratories, Hanscom Field, Mass.

Jackson, E. A. (1962), Soil studies in central Australia: Alice Springs-Hermannsburg-Rodinga areas: Soil publication No. 99, CSIRO, Melbourne, Australia.

Perry, R. A. (1961), Pasture lands of the Alice Springs area: Map (1:1,000,000), Division of Land Research and Regional Survey, CSIRO, Melbourne, Australia.

Perry, R. A., ed. (1962), General report on lands of the Alice Springs area, Northern Territory, 1956-57: Land Research series No. 6, CSIRO, Melbourne, Australia.

Peterson, R. M., G. R. Cochrane, S. A. Morain, and D. S. Simonett (1969), A Multi-sensor study of plant community densities and boundaries at Horsefly Mountain, Oregon: A Chapter in Remote Sensing in Biology, (ed. P.L. Johnson) University of Georgia Press.

Schwarz, D.E., D. S. Simonett, G. F. Jenks, and J. Ratzlaff (1969), The construction of thematic land use maps with spacecraft photography: Included in second annual report on U.S.G.S. Contract No. 14-08-001-10848, CRES, University of Kansas.

Simonett, D. S., and F. M. Henderson (1969), On the use of space photography for identifying transportation routes: A summary of problems: Included in second annual report on U.S.G.S. Contract No. 14-08-001-10848, CRES, University of Kansas.

Wingert, E. A. (1967), Tonal enhancement and isolation in aerial photographic interpretation: Unpublished M. A. thesis, University of Washington.

# APPENDIX 4

## THE COMPLEMENTARY ROLES OF AERIAL PHOTOGRAPHY AND RADAR IMAGING RELATED TO WEATHER CONDITIONS

IA-NASA-173

# THE COMPLEMENTARY ROLES OF AERIAL PHOTOGRAPHY AND RADAR IMAGING RELATED TO WEATHER CONDITIONS

by

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TABLE OF CONTENTS

# INTRODUCTION

In a discussion of the characteristics of side-looking radar systems, Pierson, Scheps and Simonett (1965) noted that these sensors have "an all-weather capability for obtaining imagery except for short wavelength systems, and these are restricted only by deep precipitating cloud masses." This report analyzes this near all-weather capability in more detail, and explores through a series of comparisons for different climatic environments, the comparative probabilities of successfully obtaining either radar imagery or aerial or spacecraft photography.

A most uncertain factor in aerial and spacecraft photography is the weather. Harman (1966) notes that "the ideal photographic day is one in which the air is free from clouds, smoke and haze; the sun is high enough to shorten objectionable shadows; and (for aircraft) the wind velocity and air turbulence at the flight altitude are at a minimum. All these conditions vary with the time of the year and the particular locality." Bird and Morrison (1964), in their study of space photography and its geographical applications, note that "the greatest problem in using satellite photographs is perhaps the extent of the cloud cover. Aerial photographs cover sufficiently small areas that it is possible -- though with long delays -- to choose a time for photography when the area is clear of cloud... On the other hand, when satellites in orbit are used, it is impossible to choose a period when the entire orbit is cloud-free. Indeed one feature revealed by the photographs is just how much of the earth's surface is usually covered by cloud. It is probable that the use of satellites for comprehensive space photography will be greatest in areas that are typically cloud-free...."

Given sufficient time in orbit, spacecraft missions at various seasons of the year should enable acceptable spacecraft photography to be obtained even for moderately cloudy regions of the world, on a one-time basis, and certainly repetitive photographs in desert regions will readily be obtained. However, for certain cloudy environments even one-time photography has relatively low probabilities of success as documented later in this study, and where information is urgently required within a short time the only sensor suitable for use will be X-band and longer wavelength synthetic-aperture imaging radars.

Thus, it is expected that radar will have a number of roles in space applications by ensuring that information is obtained irrespective of clouds, or night, or season as required for some of the more difficult environments and under severe time constraints. In regions of good weather and few clouds it will both complement and supplement the data obtained through photography.

Reference is made repeatedly in the following pages to the respective roles of radar and photography. The more important terms employed in this comparison are noted below in order to avoid possible confusion arising because of the sometimes subtle distinctions between them.

"Ancillary" is used only for the situation where radar is ancillary to photography. It implies a subordinate or subsidiary status of the one to the other in terms of imaging potential, although it should be recognized that each sensor obtains types of information unobtainable by the other. Thus radar may be ancillary to photography in desert regions in the sense that photography can be obtained much of the time. It implies neither that radar imagery is unobtainable or unimportant in these environments.

"Complementary" is employed to signify that a joint role is played by each sensor, the one "filling-out" or completing full coverage imagery for a particular project area not obtained by the other. As before, the term indicates only the ability to obtain ground imagery and does not refer to image content. Ideally it would be advantageous to have full coverage imagery from each sensor, but when this is not possible interpreters will have to augment deficiencies with imagery from the other system. The major premise of this paper, in fact, is to show that in many such cases photography will be deficient and will need to be complemented by radar imagery. The distinction between ancillary and complementary is therefore one of degree and not of kind. The former indicates the situation where photography is most frequently obtainable, the latter where photography is often unobtainable.

Other terms such as "supportive" and "alternative" should be clear from their context. Supportive always relates to the necessity for having both radar and photography to ensure complete coverage. Alternative, on the other hand, indicates the situation where only radar is expected to perform, thereby rendering it the primary, if not sole, imaging sensor.

## THE NATURE OF WEATHER LIMITATIONS ON PHOTOGRAPHY AND RADAR

### Photography

For most conventional airborne photographic missions broken and scattered cloud cover exceeding .1 (10%) of the area to be studied may lead to unacceptable results. For special missions of greater urgency in which imagery for only part of the area will yield information, up to .3 (30%) cloud cover may be tolerated though this normally constitutes the upper limit of acceptability. Figures 1 and 2 are photographs showing 10% and 33% cloud cover. It will be noted that with both of these, dense shadowing constitutes almost as serious a problem as observation by the clouds themselves. The degree to which thin high cirrus clouds are reported varies from one locality to another, and in some instances this could produce changes in the percent cloud cover to be expected in a given region. High cirrus clouds sometimes have a beneficial effect on the quality of aerial photographs taken beneath them by softening the indirect light and reducing the intensity of the shadows. However, photography obtained from very high altitude aircraft or from spacecraft when cirrus is present will suffer some degradation in tonal contrasts which will reduce the effectiveness of the photography.

A second condition frequently imposed is that the altitude of the sun (angular distance of the sun above the horizon) must be equal to or

Figure 1. The cloud cover in this photograph is almost exactly one-tenth (10.3%), and lies at the limits of acceptability for most mapping missions with aerial photography.

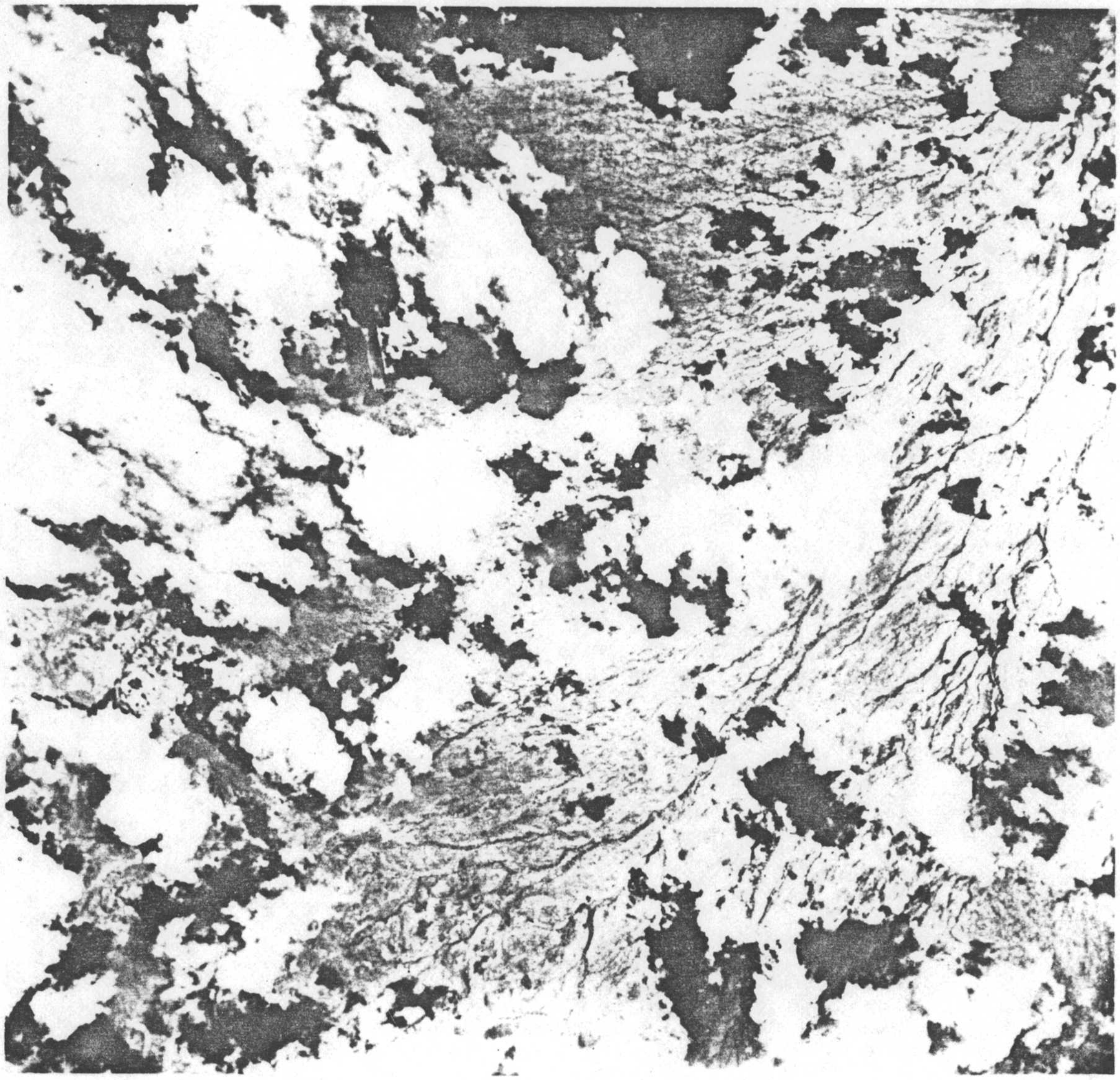

Figure 2. The cloud cover in this photograph is close to three-tenths (33.5%), and lies at the extreme upper limit for photographic mapping purposes.

greater than 30°.[1] This is desirable in order to reduce the length of the shadows cast by objects on the ground. When the elevation of the sun is 30° the length of the shadow of an object is equal to about one and three-fourths time the height of the object. The presence of many objects may be obscured by the shadows of others. In the interpretation of many aerial photographs, particularly color photographs, the 30° solar height rule may be too lenient. On the other hand, those parts of the world with latitudes greater than 83.5° never have the sun 30° or more above the horizon. In this study the 30° minimum solar elevation above the horizon was accepted as representing a reasonable compromise for the purpose of obtaining useful aerial photography.

For some purposes a cloud cover of 30% can be tolerated especially from satellite altitudes where an individual cloud subtends a much smaller angle at the camera than it would to a camera in an airplane. Figure 3 shows for the United States the average number of days in the month of July when the sun will have an angle above the horizon of 30° or more and the cloud cover will be 10% or less. A comparison of this map with Figure 18, which shows for the United States the average number of hours in July that the sun has an angle above the horizon of 30° or more and the cloud cover is 30% or less, reveals strikingly similar patterns. This suggests that whenever the cloud cover is equal to or less than 30% over large areas there is a good chance that there will be many sizeable areas with 10% or less cloud cover. For this reason, and since useful photography can be obtained with 30% cloud cover, a cloud cover of 30% was adopted as the upper limit for aerial photography. A further factor in this decision was our desire in comparing the time available to photographic and radar sensors, deliberately to bias the results in favor of photography by taking lenient decisions for photography and severe decisions for radar. In this way we believe all our figures to be conservative in that actual ratios are all more favorable for radar than these we present.

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[1] H. R. Cravet, "Planning and operation of a color aerial photographic mission," Manual of Color Aerial Photography (Wash., D.C.: American Society of Photogrammetry, 1968), p. 43.

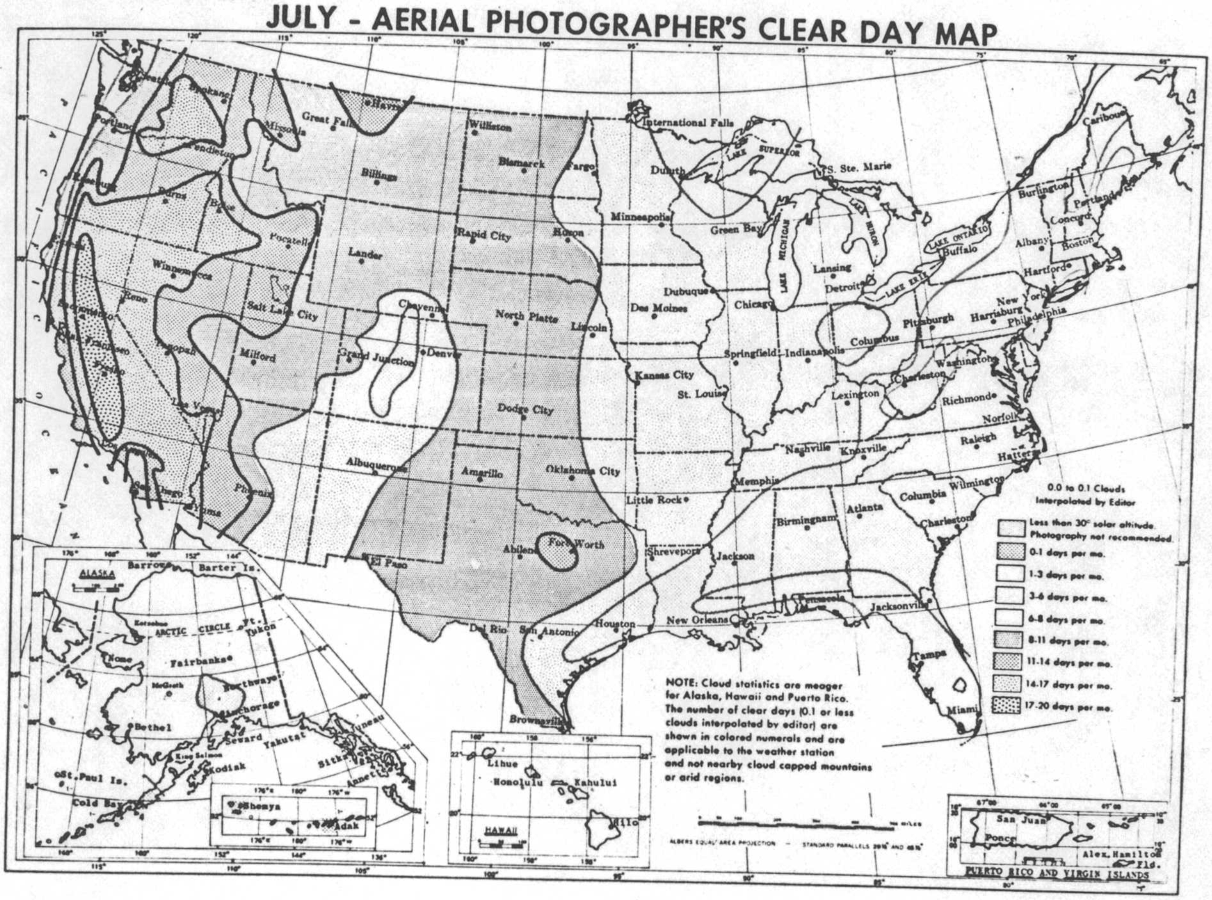


Figure 3. This Aerial Photographer's Clear Day Map for July indicates the number of clear days (i.e. 10% cloudiness or less) that can be expected from sunrise to sunset that meet the minimum 30 degree solar altitude requirement for aerial photography. After Manual of Color Aerial Photography (1968), p. 35.

The "Aerial Photographer's Clear Day Maps" contained in the Manual of Color Aerial Photography[2] are basically maps showing the average number of days per month that can be expected to have a cloud cover of 10% or less from sunrise to sunset. The latitude at which the sun will never have an altitude of 30° or more in January in the U.S.A. is indicated as a continuous break in Figure 4 between the first category (less than 30° solar altitude) and the other categories. It does not reflect the amount of time that the sun will occupy a favorable position in the sky. Note, for example, that on the January map Kansas City is indicated to have from 14 to 17 clear days. This tends to overestimate the amount of time actually available in terms of the two criteria because the sun has an altitude of 30° or more for less than one hour per day in January.

In addition to cloud cover and solar altitude, haze is another element of the weather known to limit the quality of photography. Harman (1966) notes that "the quality of the atmosphere known as haze often prevents a cloudless day from being suitable for aerial photography. Since the exact composition and occurrence of haze varies with locality, the probability of its occurrence must be considered purely from a knowledge of the area involved. There is, consequently, no data available on its probable presence."

Haze results from the hydrolization of nuclei in the air. For this to occur both water vapor and nuclei must be present. The most common nuclei which presently contribute to haze formation are those of salt and industrial chemicals. As a result the most serious haze conditions occur along coastal areas and over and near industrial complexes. True haze tends to diffuse only the blue end of the color spectrum and can be filtered with a yellow filter. Dust and smoke compose much larger nuclei and not only diffuse the entire color spectrum, but may absorb a large proportion of the sunlight. Satisfactory photography cannot be accomplished when such obstructions are in the air unless only the long wave near-infrared radiation is used for exposure on infrared-sensitive film.

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[2] H. R. Cravet (1968) pp. 30-40.

JANUARY - AERIAL PHOTOGRAPHER'S CLEAR DAY MAP

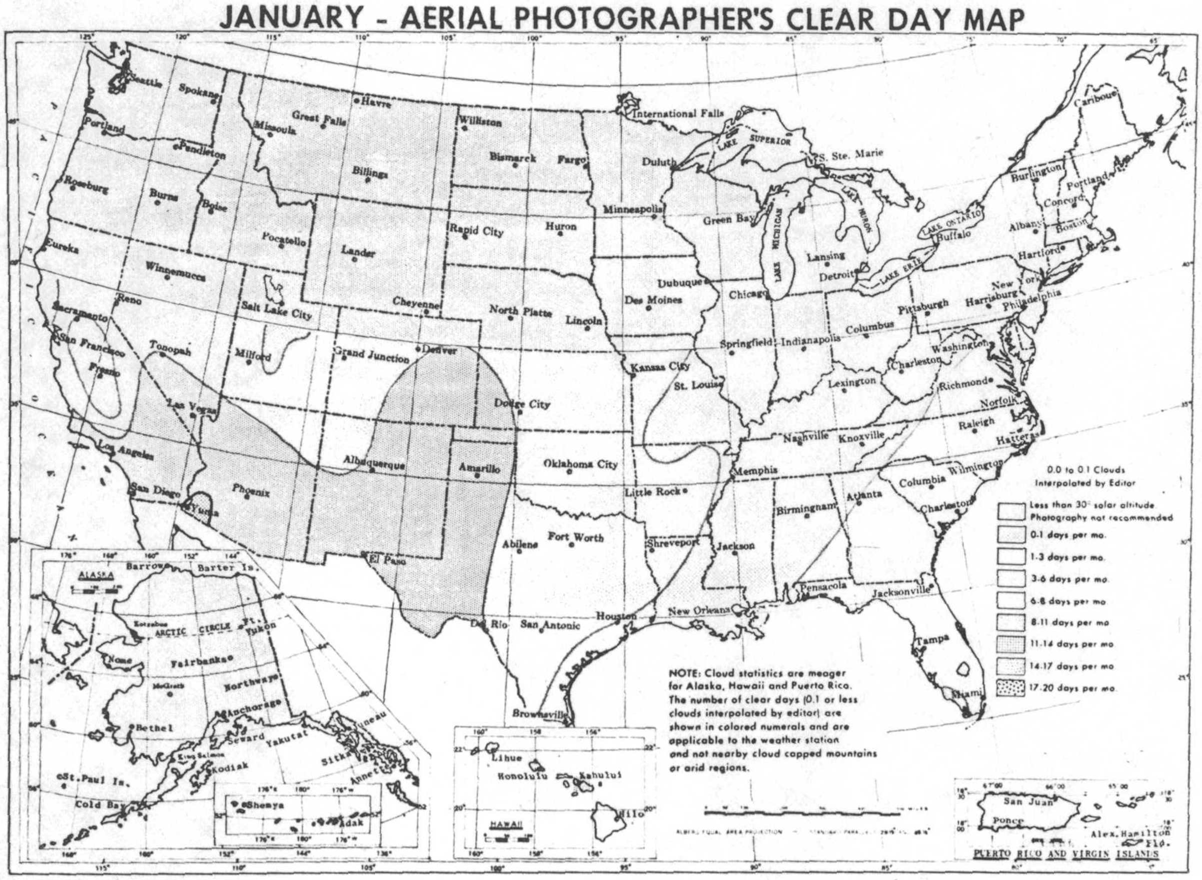


Figure 4. This Aerial Photographer's Clear Day Map for January indicates the number of clear days (i.e. 10% cloudiness or less) that can be expected from sunrise to sunset that meet the minimum 30 degree solar altitude requirement for aerial photography. After Manual of Color Aerial Photography (1968), p. 35.

The attenuation of contrast by haze in the atmosphere (Middleton, 1950; Bullock, 1956; Tupper, 1956; Bogachkov, 1962) gives a characteristic veiled or milky appearance and reduced contrast on uncorrected photographs; is highly variable; can produce some other very objectionable effects in photography; and, because of its variability, can never entirely be compensated for in processing techniques or in film-filter combinations. Bullock (1956) notes that "turbidity of the atmosphere is a variable thing. It varies with the weather, the time of day, the altitude, and with the nature of the suspended particles, but it is accepted that haze is present in the atmosphere to some extent all over the world."

Horvath, Braithwaite and Polcyn (1969) in a useful discussion of the effect of sensor altitude on the apparent radiance of an object (which fills the sensor's instantaneous field of view) note that the actual radiance is modulated by both (1) atmospheric attenuation through absorption or scattering of the radiation reflected or emitted from the object, and (2) atmospheric scattering and emission of unwanted radiation into the field of view. The latter effect is the most significant in the 400-900 n.m. region in increasing the total scene radiance and reducing target radiance contrast. They conclude that continued empirical studies are essential and that sample targets of known spectral character should be imaged at the time of overflight with low-flying aircraft in order to calibrate out the effects of various haze conditions over large areas.

In general haze may be attributed to two components. The lesser in importance of the two is the concentration of molecules of the various gases of the air; this accounts for some 1/5 of the over-all haze. These molecules vary in concentration with effects of temperature and pressure according to the molecular theory of gases. Consequently their concentration changes little from day to day. Haze may be practically invisible in a region where rainfall is sparse and the humidity is low (e.g. western plateau and desert country in the U. S.) whereas a heavy haze is visible practically all the time on the eastern seaboard.

By far the more important component of haze in photography is backscatter, according to Bullock 1956 (469-70). "...backscatter from haze also may be sufficient to destroy the survey value of photographs due to increased negative densities even when visibility in the forward looking view is judged to be acceptable or correctable within desired limits. In such a case yellow, red or infrared filters and panchromatic or infrared material are not generally accepted as being sufficiently corrective in nature. Stated simply this condition results when the solar rays are inclined to the vertical at angles less than the lens field semi-angle when appreciable haze is present."

Areas which are highly industrialized as in western Europe, England, and the northeast U. S., or regions of persistent stable subsidence inversions as in the smog zone around Los Angeles are usually partly obscured by smog and smoke, even on cloudless days. These smoke particles are larger than the particles in a typical moisture haze, which usually average $.3\mu$ to $.4\mu$. With ordinary moisture haze, there is a marked decrease in the extinction coefficient as one passes from the blue region in the visible to the near infrared such that by using the longer wavelengths a considerable improvement in photography can be affected. However, large particles of industrial smoke and smog produce severe extinction in the green and red regions of the visible as well.

In the discussion which follows no further mention of haze, smoke, cirrus trails or scattered ground fog is made, for detailed statistics on these matters are not readily available even for the U. S. let alone for the rest of the world. The remaining discussion of weather limitation on photography concerns cloud cover only and these other factors must be thought of as additional variables which will reduce the effectiveness of this sensor to varying degrees on different days in all localities but especially in seaboard locations, humid environments such as the wet tropics, and extensively industrialized regions.

Radar

Clouds and haze, no matter how thick, are without effect on radar and their presence cannot be detected on side-looking radar imagery (see Figure 5). This follows from a consideration of the particle size of droplets in clouds before they coalesce into rain (2-50μ) and the wavelength used in radar (.5cm - 1 meter).

Only rainfall produces serious attenuation of radar and this is both radar frequency, and rainfall-intensity dependent. A thorough study of these relations has recently been given by Medhurst (1965) under the title "Rainfall Attenuation of Centimeter Waves: Comparison of Theory and Measurement." In general the experimental measurements indicate more severe attenuation than the well-known Ryde theory would predict. Obscuring echoes can also affect the radar image. However, the echo is proportional to the 6th power of the drop diameter whereas attenuation is directly proportional to the liquid water content. This light rain which consists of small droplets will produce little obscuring echoes, but may produce substantial attenuation with long slant paths through rain. Both effects are inversely proportional to the wavelength raised to an exponent of 3 or 4 so their significance decreases rapidly with increasing wavelength (Moore and Simonett, 1967).

The maximum experimentally-determined two-way attenuation in the radar signal which would be produced by rainfall (as documented by Medhurst) is given in Table I and Figure 6 for 10cm., 3cm. and 1cm. radar systems. The attenuations given are the worst which would be experienced and present the most unfavorable situation for radar that could be obtained. Radar path lengths are quoted through rain of 2.5, 5, 7.5, 10, 15, 25 and 30 km. The shortest of these path lengths would be obtained by imaging at near grazing angles through isolated small thunder showers. A path length of 7.5km would be obtained by imaging in the near range at an angle of approximately 20° from the normal, through middle clouds of the altostratus or altocumulus type. It is assumed here that rain reaches from the top of the clouds to ground level. Since altostratus is a major source

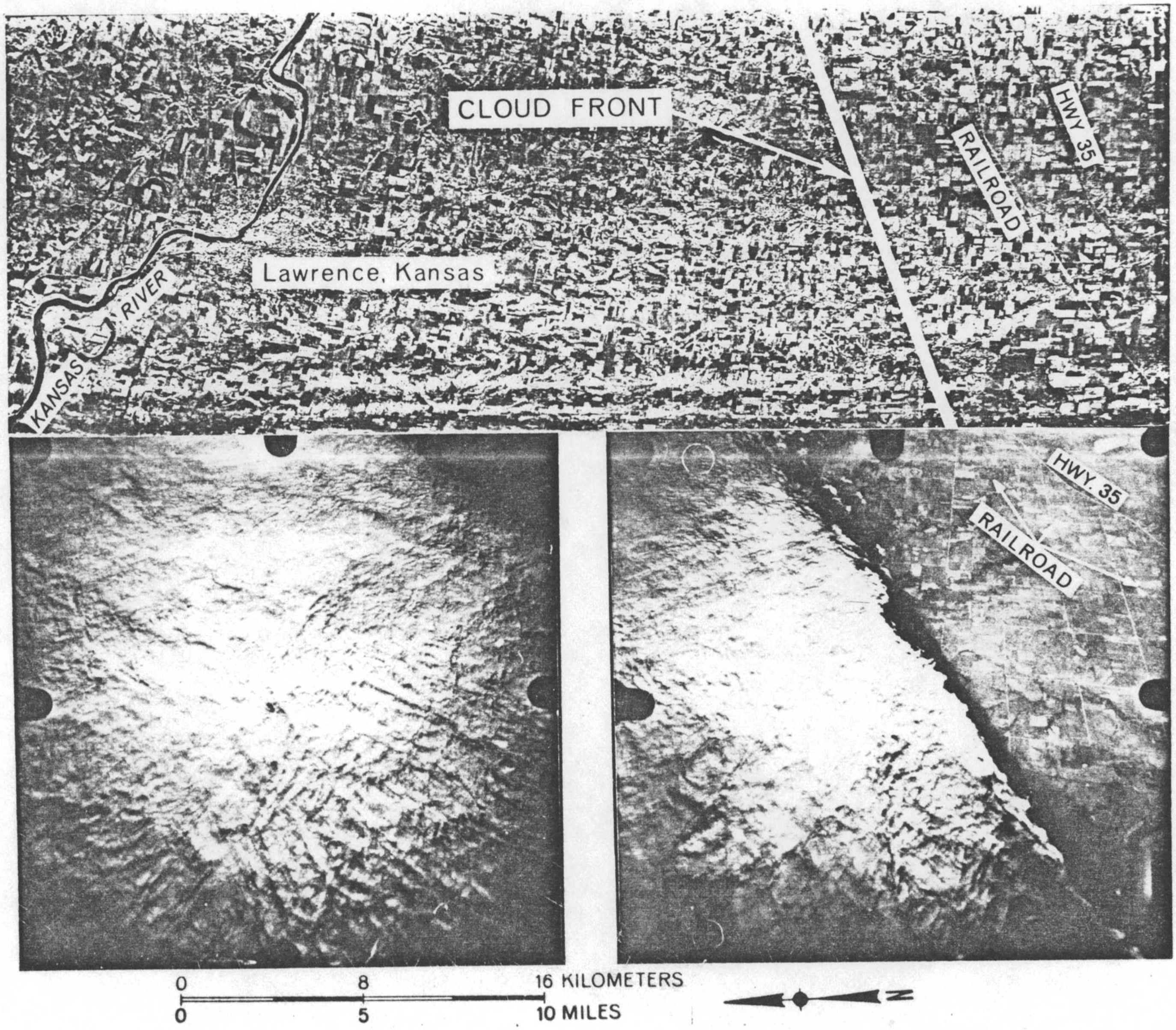


Figure 5. The penetration of clouds with a K-band radar is illustrated with simultaneous radar imagery and photography obtained near Lawrence, Kansas.

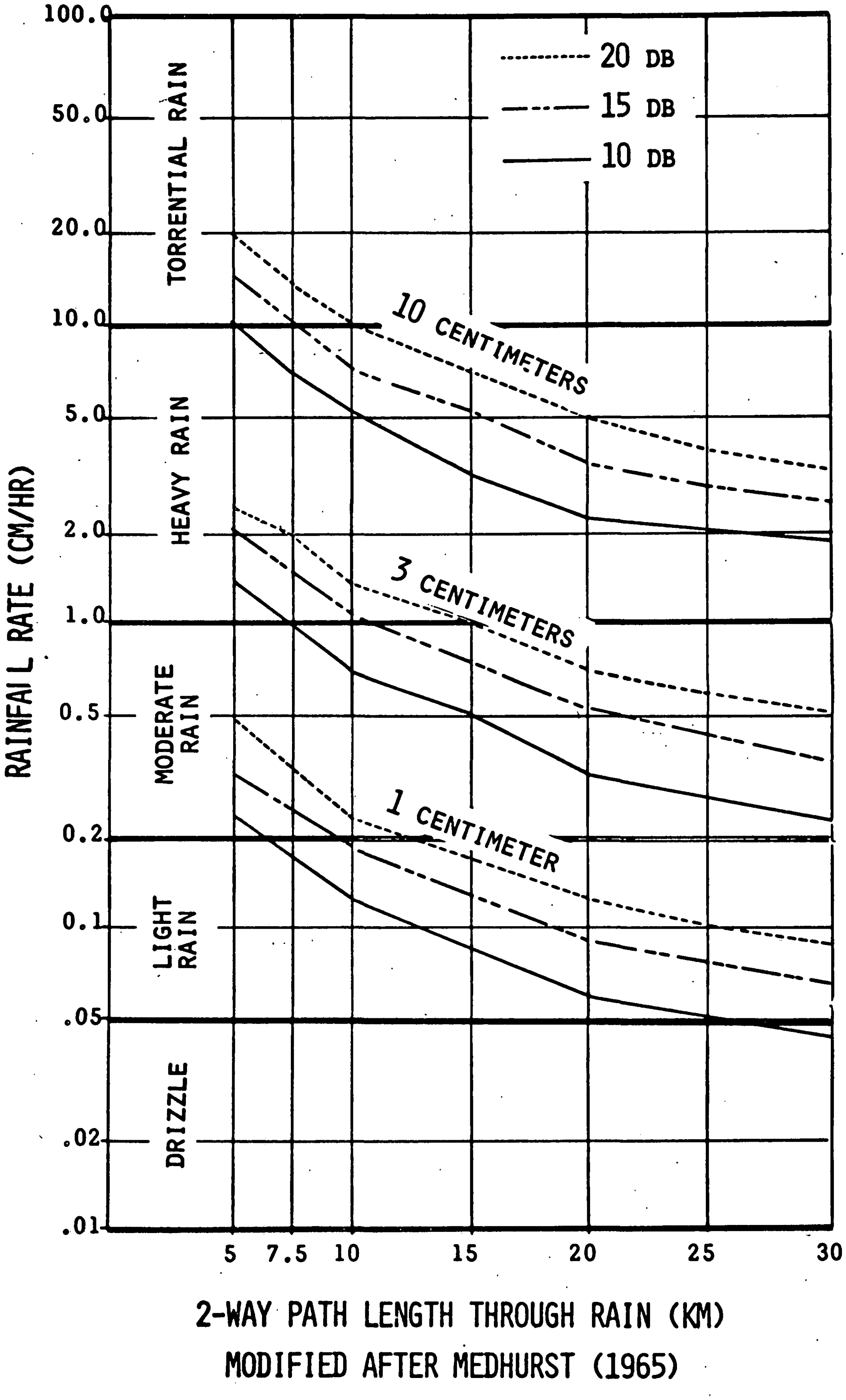


Figure 6. Relation between radar signal attenuation and passage through rainfall of various intensities and lengths.

of warm-frontal rainfall in the middle latitudes and cumulonimbus clouds represent precipitation from thunderstorms, it is appropriate to look at path lengths for these types in terms of selected radar pointing angles. In the figures which follow normal incidence is 0 degrees and grazing incidence 90 degrees. With a path length for alto stratus of 7.5km each way at 0 degrees and 10km at 20 degrees for cumulonimbus, other path lengths in the table below correspond to the given pointing angles:

| altostratus | cumulonimbus |
|---|---|
| 10km - 40° | 10km - 20° |
| 15km - 60° | 15km - 48° |
| 20km - 68° | 20km - 60° |
| 25km - 72° | 25km - 66° |
| 30km - 76° | 30km - 70° |

For spacecraft applications of imaging radar power considerations suggest that a look-angle of 32° may be employed. At the near range the angle will be about 22° and at the far range about 42°. As may be seen from the earlier tabulation for alto-stratus clouds the maximum path length at the far range (42°) would be 10km, while for cumulonimbus the maximum path length would be 13.5km. Those portions of the table involving path lengths of 15, 20, 25, and 30km therefore apply only to aircraft. Clearly as the angle of incidence from radar on aircraft approaches grazing the path length rapidly increases and even gentle rainfalls pose severe attenuation problems. Path lengths of these magnitudes, however, are only likely with warm frontal conditions or under relatively rare circumstances along the axis of a cold front.

The attenuations of 10, 15, and 20db in Table 1 represent severe, very severe, and extreme attenuations respectively (Austin, 1966) and would produce corresponding degradations in image quality. It should be emphasized that these values must be viewed with caution, for radars with excellent sensitivity may not suffer as severe degradation in image quality as that described here. Some of the imagery with which we are currently working can tolerate a 10db loss with moderate degradation. It is not possible, therefore, to formulate a simple rule for all cases, but in general:

1. 10db attenuation -- all signals from relatively smooth surfaces of low reflectivity become lost in the noise level, and many signals from rural landscapes are lost.
2. 15db attenuation -- all signals from rural landscapes would be lost, though cities and other normally highly reflective materials should still be clearly detected.
3. 20db attenuation -- about the only information left would be very high return point cultural targets.

The analogy to photography would be photos taken through a cirrus veil or smog of varying thickness. A less acceptable analogy would be to successively underexpose panchromatic film by say 2, 3, or 4 stops.

Since large differences in the rainfall rate required to produce a given attenuation are observed, it is necessary to assume a precipitation rate that would render attempts at radar imagery useless. A precipitation intensity equal to or greater than .25 inches per hour was selected.

Table 1 and Figure 6 relates the rainfall rate and the two-way path length to specified loses in signal strength for three selected wavelengths.[3] The solid lines show the path length and rainfall rate required to reduce the received signal to one-tenth the value it would have if no precipitating cloud mass were present. The unit relating the difference in intensity of two signals is called a decibel (db). It is defined as 10 log (I/Io) db. Thus, when I/Io is equal to 1/10, the signal is "down" 10db or -10db.

The above discussion should not be interpreted as meaning that a signal loss of 10 decibels is completely deleterious to radar imaging. A precipitation rate of .25 inches per hour (0.635 centimeters per hour)

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[3]R. K. Moore and D. S. Simonett, "Radar Remote Sensing in Biology," BioScience, XVII (June 1967), p. 386. The data used to construct Figure 6 were the most extreme values stated by R. G. Medhurst, "Rainfall Attenuation of Centimeter Waves: Comparison of Theory and Measurement," Trans. on Antennas and Propagation, IEEE (1965), pp. 550-564.

## TABLE I
## ATTENUATION OF RADAR SIGNALS BY RAINFALL

Precipitation rates in cm/hr required to produce 2-way attenuations of the received signal by 10, 15, and 20 db, based on the most severe attenuations obtained experimentally.

| | Rainfall in Centimeters per hour | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **10db Attenuation (severe)** | | | | | | | |
| Radar path lengths through rain (km) | 2.5 | 5.0 | 7.5 | 10 | 15 | 20 | 25 | 30 |
| Radar Wavelengths: | | | | | | | | |
| 10cms (3GHz) S-Band | 20 | 10 | 7.5 | 5 | 3.7 | 2.5 | 2.2 | 1.9 |
| 3cms (10GHz) X Band | 2.8 | 1.4 | 1.1 | .7 | .55 | .35 | .30 | .27 |
| 1cm (30GHz) Ka-Band | .5 | .25 | .19 | .125 | .09 | .06 | .05 | .04 |
| | **15db Attenuation (very severe)** | | | | | | | |
| 10cms (3GHz) S-Band | 30 | 15 | 11.3 | 7.5 | 5.5 | 3.8 | 3.3 | 2.9 |
| 3cms (10GHz) X-Band | 4.2 | 2.1 | 1.7 | 1.1 | .82 | .53 | .45 | .41 |
| 1cm (30GHz) Ka-Band | .75 | .37 | .29 | .19 | .14 | .09 | .08 | .07 |
| | **20db Attenuation (extreme)** | | | | | | | |
| 10cms (3GHz) S-Band | 40 | 20 | 15 | 10 | 7.5 | 5.0 | 4.4 | 3.8 |
| 3cms (10GHz) X-Band | 5.6 | 2.8 | 2.2 | 1.4 | 1.1 | .70 | .60 | .55 |
| 1cm (30GHz) Ka-Band | 1.0 | 0.5 | .38 | .25 | .18 | .125 | .10 | .09 |
| | | | Spacecraft | | | | | |
| | Aircraft | | | | | | | |

SOURCE: Based on the most conservative figures given in Medhurst (1965) hardly affects long wavelength (10cm.) radar at all. An X-band (about 3cm.) system will be down 10db only after penetrating a cloud mass precipitating at a rate of .25 inches per hour about 5 kilometers (two-way path length of 10km). In this case, objects which are highly reflective to X-band wavelengths (many man-made structures, certain crop patterns) may be detected. K-band systems (wavelength about 1cm) however, will suffer complete degradation. For these reasons the assumption that the number of hours during which precipitation intensities are equal to or greater than .25 inches per hour represents time lost to radar imaging systems was considered reasonable and conservative.

## GLOBAL AND REGIONAL CLOUD PATTERNS AND THE PHOTOGRAPHIC ENVIRONMENT

### Data Employed

In order to illustrate both qualitatively and quantitatively some of the major concepts and to show the geographic distributions of "easy," "moderate," and "difficult" photographic environments we have selected a number of maps and tables from the literature and devised some additional ones. Use is made of mean annual and mean monthly isoneph maps based on cloud cover in tenths for different parts of the world, especially for the U. S. and U.S.S.R. Since these maps are all based on estimates of cloud cover they inevitably have observer biases and errors of one sort or another.

A large part of the discussion of available radar and photographic time is derived from a series of ratios prepared by the U. S. Air Force Air Weather Service for a number of stations throughout the world. From this data we have prepared a series of station diagrams illustrating the monthly changes in time available to each sensor. Because of the original assumptions employed by the Air Weather Service in calculating the ratios, these data must be viewed with caution with respect to space applications. A more complete discussion of these assumptions is given in the section dealing with the interpretation of ratios.

General Results

Having commented on weather elements limiting the imaging potential of both radar and photography, the question arises as to where these various influences occur. The discussion which follows attempts to outline broad geographical patterns of cloud cover and precipitation rates as an aid in determining the location of problem areas in remote sensing with radar and photography.

On the average between 50 and 60 per cent of the earth experiences cloudy conditions every day. The distribution of cloud cover and the percent of actual sky cover for any locality, however, varies both with time of day and season. Figure 7 is a mosaic of Tiros weather pictures illustrating the pattern of global cloud cover on February 13, 1965. On it are revealed large areas of the continents that are obscured by clouds, especially the southeastern United States, and western Europe. In addition, high mountain areas such as the Himalayas, Andes, and portions of the Rockies are also hidden. Relatively clear skies seem to occur over most of Africa, Arabia, India, Australia, and Siberia, although the 5km resolution limitation inherent in Tiros imagery may actually underestimate true cloud amounts in areas of low percent cloud cover, and miss altogether regions of thick haze.

The location of apparently cloud-free areas interpreted from Tiros imagery agrees well with the world map of mean January cloudiness (Figure 8). During this month, regions with .1 (10%) or less cloud cover are found between 10° and 25° north latitude near the Bay of Bengal, the Thar and Nubian deserts of India and Africa respectively, and portions of the Sudan. Statistically these are the only areas where one could expect photographic conditions of .1 or less sky cover to exist in January, though most of the

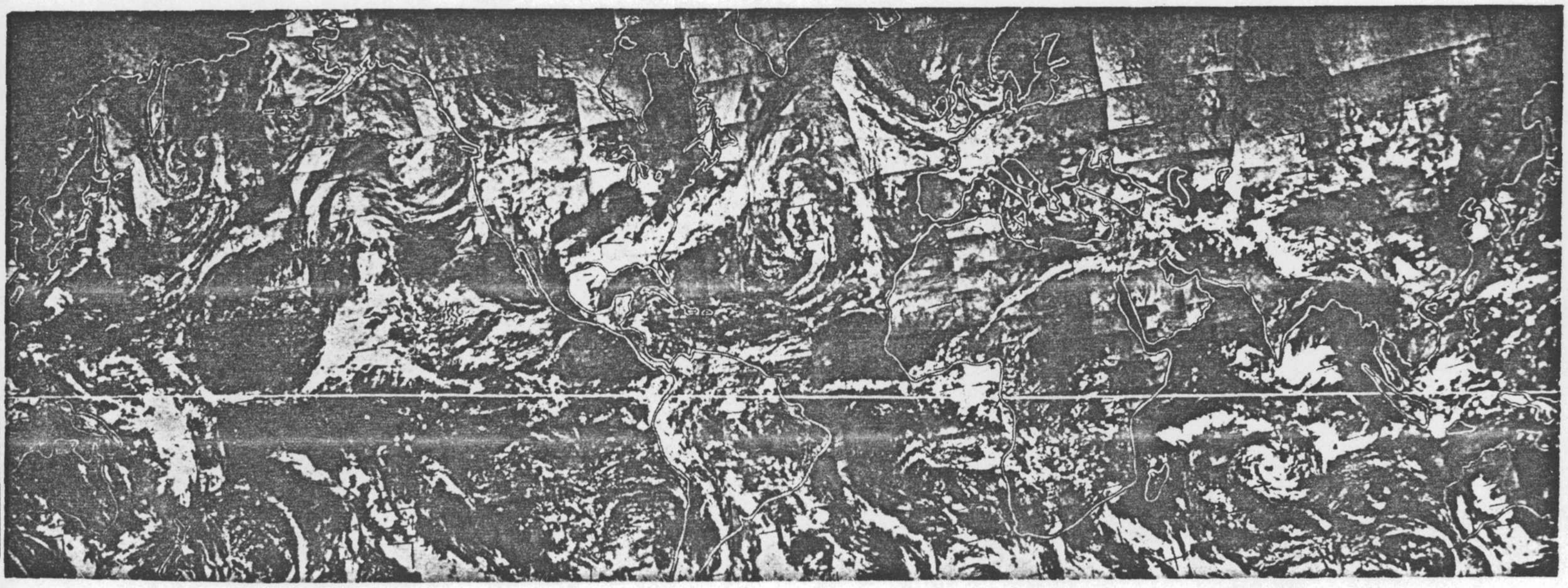

Figure 7. Photomosaic of global cloud cover as seen from Tiros IX weather satellite during a 24 hour period on February 13, 1965. Clouds appear as white patches, sworls, and streaks against the gray background of the earth and oceans. Superimposed in white. upon the mosaic are outlines of the major land masses. The horizontal white line marks the equator. On the average between 50 and 60% of the earth on any given day may be covered by clouds of varying types and thicknesses. Ocean areas tend to be cloudier than land masses, and coastal areas cloudier than inland regions. The coarse resolution (5 km.) of the Tiros imagery underestimates cloud cover in areas of small or scattered fair-weather cumuli and thin cirrus trails. After Manual of Photogrammetry, 1966, p. 996.

territory between these latitudes in the Eastern Hemisphere experience up to 30% cloud cover.

In contrast to cloud-free areas, vast stretches of the earth are almost totally (70%) cloud covered during January as exemplified in the high latitudes over Antarctica, the North Atlantic, and the North Pacific. Smaller, but equally significant, locations where January cloud cover exceeds .7 (70%) may also be found in such densly populated and highly industrialized areas as the Great Lakes region of North America, most of northern and western Europe, and Japan. Less densely populated areas which suffer high cloud amounts in January include a major part of Brazil and most of New Guinea -- precisely those areas for which little is known of distributional patterns of physical and cultural features, and which are most amenable for data collection via remote sensor techniques. All of these areas are regarded as exceedingly difficult environments for the acquisition of aerial photography, especially if missions have been critically timed and imagery is needed for precise time periods. Moreover, there is some question as to whether a delay of several weeks would improve the chances of obtaining photographic coverage.

Patterns of mean cloudiness in July (Figure 9) resemble those in January for most parts of the world with a few notable exceptions. Chief among these is represented by the Indian subcontinent. Although included in the relatively cloud-free area in January, India experiences greater than .8 (80%) cloudiness in July because of moist air pushed landward by the southwest monsoon. Aerial and space photography during the whole of this wet season is a hit and miss proposition, and radar is expected to achieve at least a complementary status. Conditions very similar to those which prevail in India during July exist at some time or other over most of the humid tropics, rendering these difficult to moderately difficult environments for photography.

More detailed patterns of regional cloud cover are illustrated in Figures 8 and 9 for the U. S. and U.S.S.R. It is apparent from Figure 10 that on the average only a small region near Yuma, Arizona is sufficiently

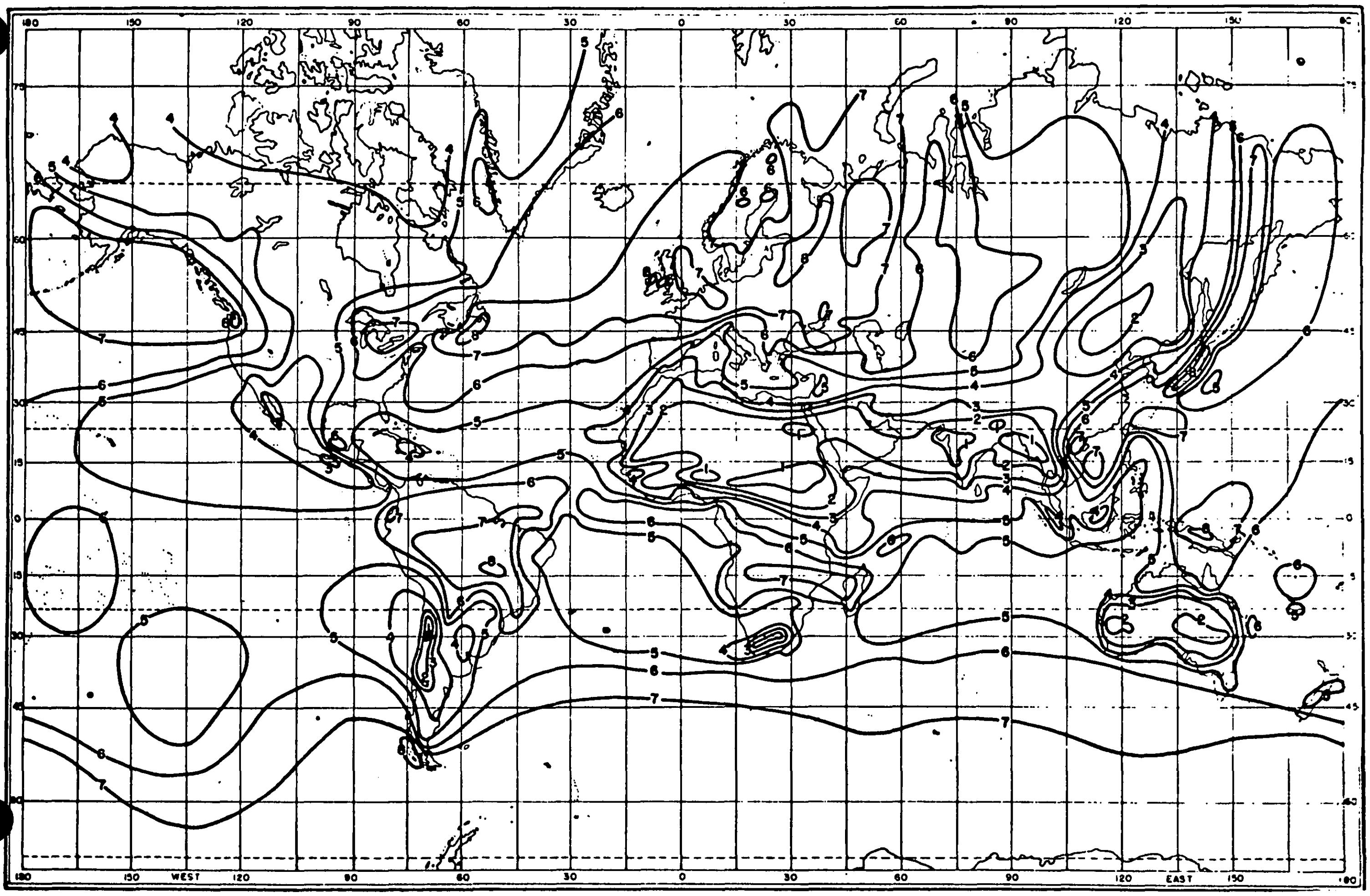

Figure 8. Mean cloudiness in January. After Haurwitz and Austin, 1944, Plate X

Figure 8 shows the average world distribution of isonephs in tenths cloud cover. If the sky is completely covered the value is 10, if completely clear it is 0. As might be expected, the areas of least cloud cover, say from 10-30%, occur primarily in arid and semi-arid areas such as Central Australia, North Africa and Saudi Arabia, South Africa, northern Chile, and the southwest U.S. Within these large areas, however, regions with 10% or less average cloud cover are few and small, as for example the Thar desert and Bay of Bengal areas of India, the Nubian desert and parts of the Sudan in Africa, and the heart of the Atacama desert in Chile. In contrast, coastal and insular localities may experience high percentages of cloud cover not only in January but throughout the year (see also Figure 9 — Mean Cloudiness in July). The south China coast, New Guinea, Great Britain, and Western Europe, southern Chile, the Gulf of Alaska and the Great Lakes region in the U.S.A. are cases in point. In general isonephs for January have a latitudinal arrangement with the major exception of Eurasia in which isonephs have a pronounced longitudinal orientation. For polar orbiting spacecraft this alignment indicates that extremely large areas of the Eastern Hemisphere on any given orbit for any given day in January might be cloud covered. The cloud penetration capabilities of radar would enable data to be obtained over these areas at critical times of dense cloud cover.

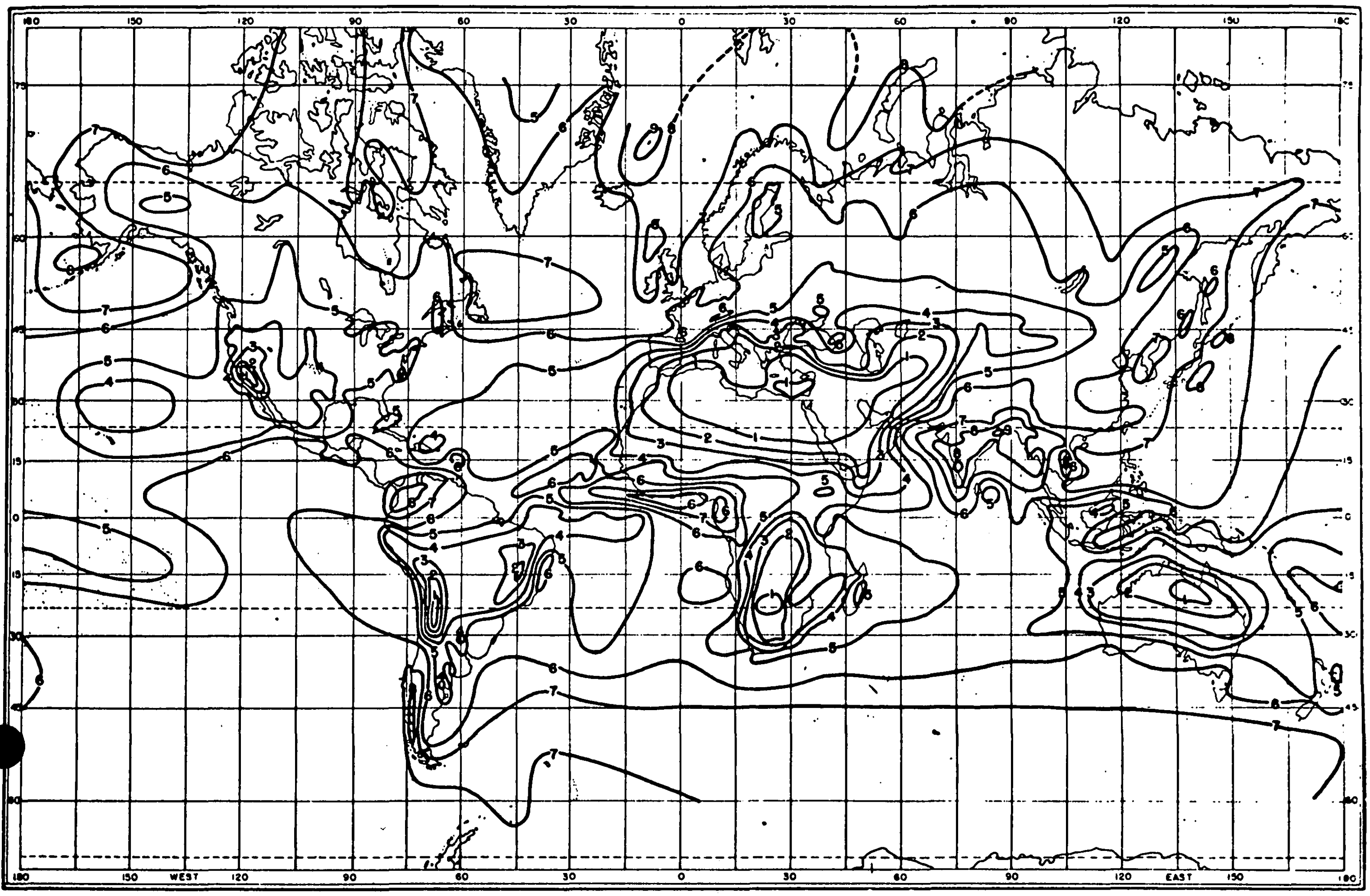


Figure 9. Mean Cloudiness in July. After Haurwitz and Austin, 1944, Plate XI

The distribution of isonephs for July are best described by comparison with those of January (Figure 8). Areas which, on the average, are essentially clear of cloud cover (10% or less) are located in roughly the same regions as described for January with a few notable exceptions. These include the appearance of cloud-free areas in the southwestern Gulf of Carpentaria in Australia, the Kalahari desert of southern Africa, the central valley of California, and a huge area stretching from North Africa to the Near East and Southwest Asia. Particularly cloudy areas (from 60-90% average July cover) are found along the Ivory Coast of Africa, on the Indian subcontinent, along the southern coast of Chile, and along the east coast of Honshu and Hokkaido. As indicated on the January isoneph map there is a general increase in average percent cloudiness in the higher latitudes, particularly over the oceans. It is notable that the arctic slopes of Alaska, the Scandinavian Countries and the Soviet Union have from 70-80% + average cover in the photographic (summer) season.

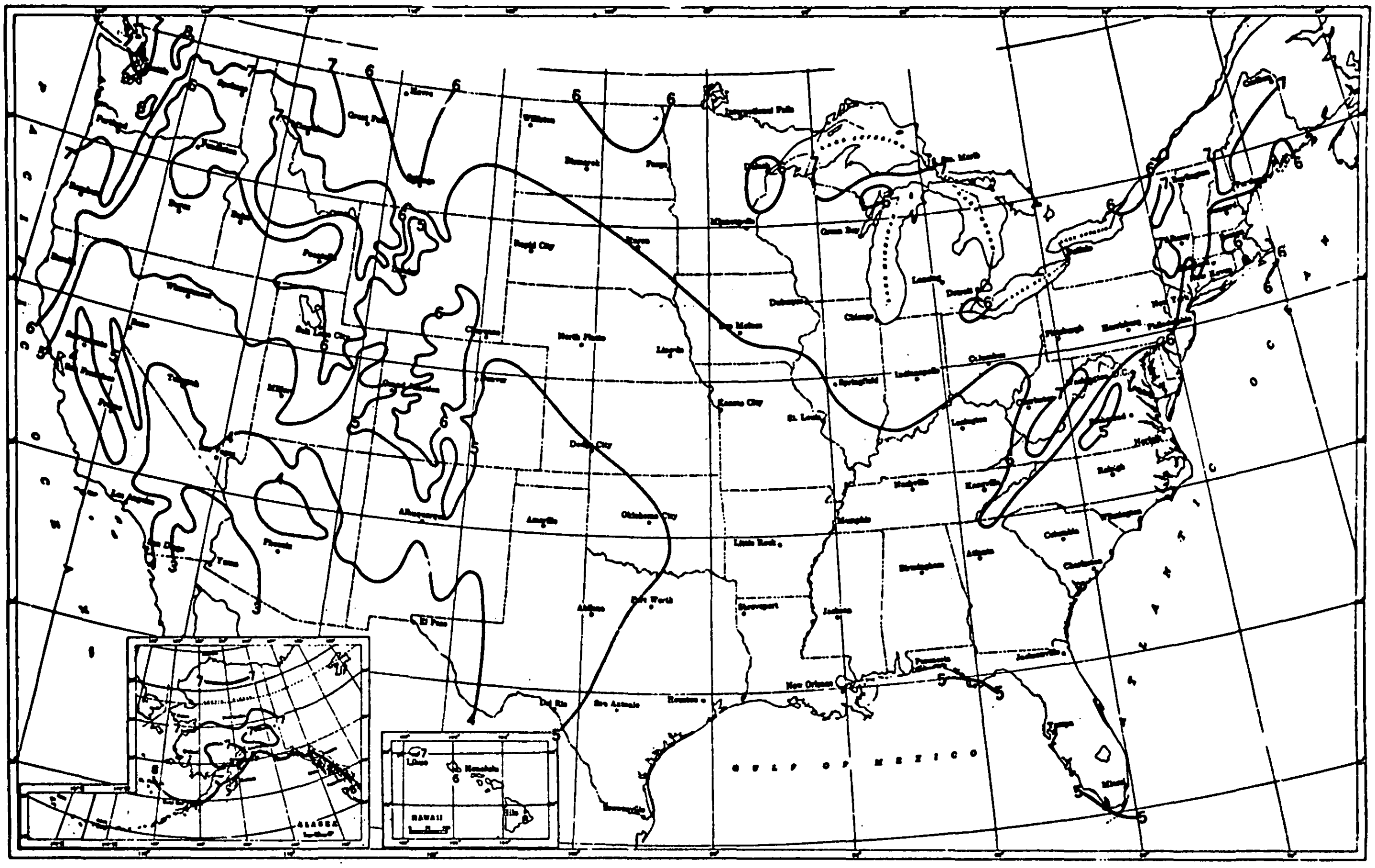

Figure 10. Mean sky cover from sunrise to sunset in tenths. Taken from The Weather Handbook, 1963, p. 246.

Mean sky cover is calculated as the average percent cloud cover during daylight hours. Since these are annual averages, they indicate nothing of seasonal or monthly variations. Kansas City, for example, lies between the .5 and .6 (50-60%) isonephs indicating that on the average between fifty and sixty per cent of the sky during daylight hours is cloud covered. Calculations based on the average number of days per month with cloud cover .1 or more (Figure 12) reveal that Kansas City can expect 24.5 days in May with more than .1 cloud cover (the least cloudy month). In other words about 79% of the daylight time in May is unsuitable for aerial photography (assuming a .1 cloud cover limitation), and about 65% of the daylight time of October is unsuitable. The ratio of available radar hours to available photographic hours for the X-band (3 cm) radar system proposed for spacecraft use at Kansas City is respectively 9.5 to 1 in May and 5.2 to 1 in October.

cloud free every day for photography. Most of the country averages 40-60 per cent cloudiness each day, and a few localities such as the Pacific Northwest, the Great Lakes, and northern New England experience greater than 70 per cent cloudiness. As will be shown in a later section these figures are of limited value, however, beyond merely suggesting areas of difficulty for photography. Figure 11 showing the average number of photographic days during the photographic season in the U.S.S.R. (Schloss, 1960) is much more revealing. Even during the photographic season there are usually only 5 days sufficiently cloud-free over northern Siberia to permit the collection of imagery. A greater number of photographic days usually occurs toward the drier, southwestern portions of U.S.S.R., suggesting once again that as one progresses from dry lands to more humid environments the amount of time available for photography drops off sharply.

Mean cloudiness maps for January and July as well as the regional maps for the U.S. and U.S.S.R. give only a qualitative approximation of average sky cover conditions from which inferences must be drawn for other times during the year. These maps cannot be utilized for estimating cloud conditions on a particular day. They do, however, indicate the location of typically cloudy or clear environments and from these conclusions may be drawn about regions where clouds will pose serious problems for space sensors. In general the dry land regions of the world pose few imaging problems for photography, and radar, it would appear, will provide alternative and supportive data in these regions. In seasonally cloudy parts of the tropics and mid latitudes, however, radar will perform at least a complementary service to photography by supplying data on a demand basis and during periods of unfavorable weather. Since seasonally or moderately cloudy environments occupy the greatest part of the earth, radar will doubtless serve as an overall supportive system to photography, the latter supplying high resolution imagery some of the time and radar supplying moderately high resolution, high contrast imagery nearly all the time. The various roles of radar have been summarized in the table below for different regions of the earth.

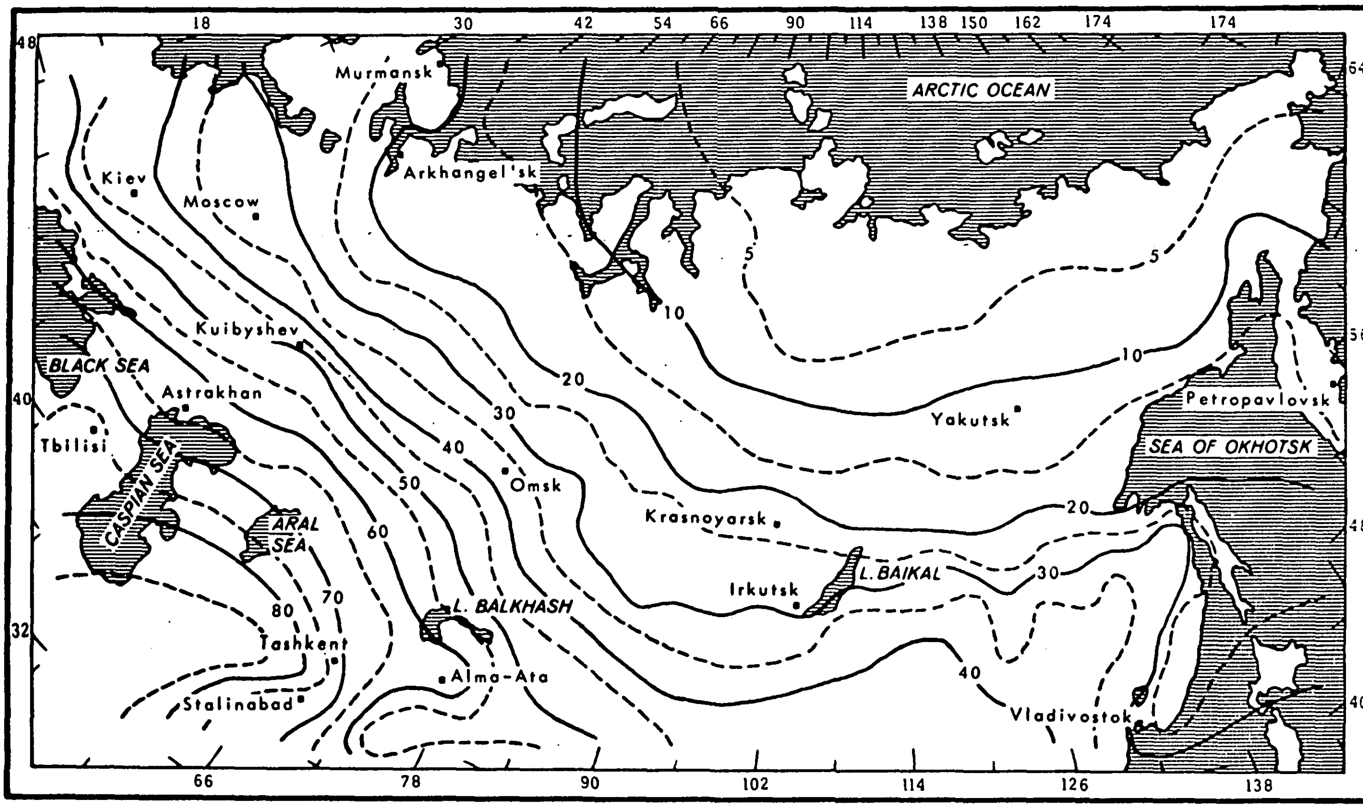


Figure 11. Average Number of Photographic Days During the Aerial Photographic Season in U.S.S.R. From Graham and Greer, et al., 1965.

During the six month aerial photography season there are as few as five days north of the Arctic Circle in Siberia which are suitable for aerial photography. This number increases considerably to about 85 days per season in the region of Kara Kum desert east of Caspian Sea. According to the data, suitable aerial photographic conditions of .1 or less cloud cover exist for only about 7-8% of the season north of Yakutsk, while north of Tashkent and Tbilisi at latitude 41-42°N almost 45% of the season is suitable for photographic missions (considering cloud conditions only). In terms of the entire year, however, 5 days accounts for only about 1.3% of the time and 85 days approaches only 23.3% of the time. Clearly, radar systems offer an imaging capability in the higher latitudes of Russia where photography would be slow, costly and more than likely piece-meal.

RADAR SUPPORTIVE TO PHOTOGRAPHY

| Role of Radar | Expected Regions of Occurrence | Examples of Regions |
|---|---|---|
| Ancillary ("easy" photographic environment) | Deserts; dry land savannahs during dry season; dry continental interior; regions of summer drought | North Africa; SW US; Interior Australia; Interior Eurasia during winter; South Africa Mediterranean region |
| Complementary ("moderate" photographic environment) | Humid, sub-humid regions; foggy or cloudy coasts; mid latitude insular areas | Japan; NW US; British Isles; coastal southeast Asia; northern and western Europe |

RADAR ALTERNATIVE TO PHOTOGRAPHY

| Role of Radar | Expected Regions of Occurrence | Examples of Regions |
|---|---|---|
| Primary ("difficult" photographic environment) | High latitude; tropical monsoon; high mountain | Arctic winter and spring; Indian sub-continent; Andes; Himalayas, etc. |

Techniques are available in the Manual of Photogrammetry for calculating somewhat more accurately the time available for photography in the United States (Figure 12). The number associated with each of the stations listed in Figure 12[4] is the average number of days per month with cloud cover .1 or less and, therefore, does not satisfy the type of data preferred for this type of study. At Yuma, Arizona one can expect 21.4 days of suitable weather for photography every month, while on Nantucket Island only 1.6 days per month meet the requirement of .1 or less sky cover. In order to determine the actual number of cloud-free days for a particular month, the number associated with each station must be multiplied by the percentage listed for that month in Table 2. To take an extreme

[4]Figure 12 is an earlier version of the series of monthly maps published in the Manual of Color Aerial Photography (1968). We use it here because it summarizes the annual data very well in one map.

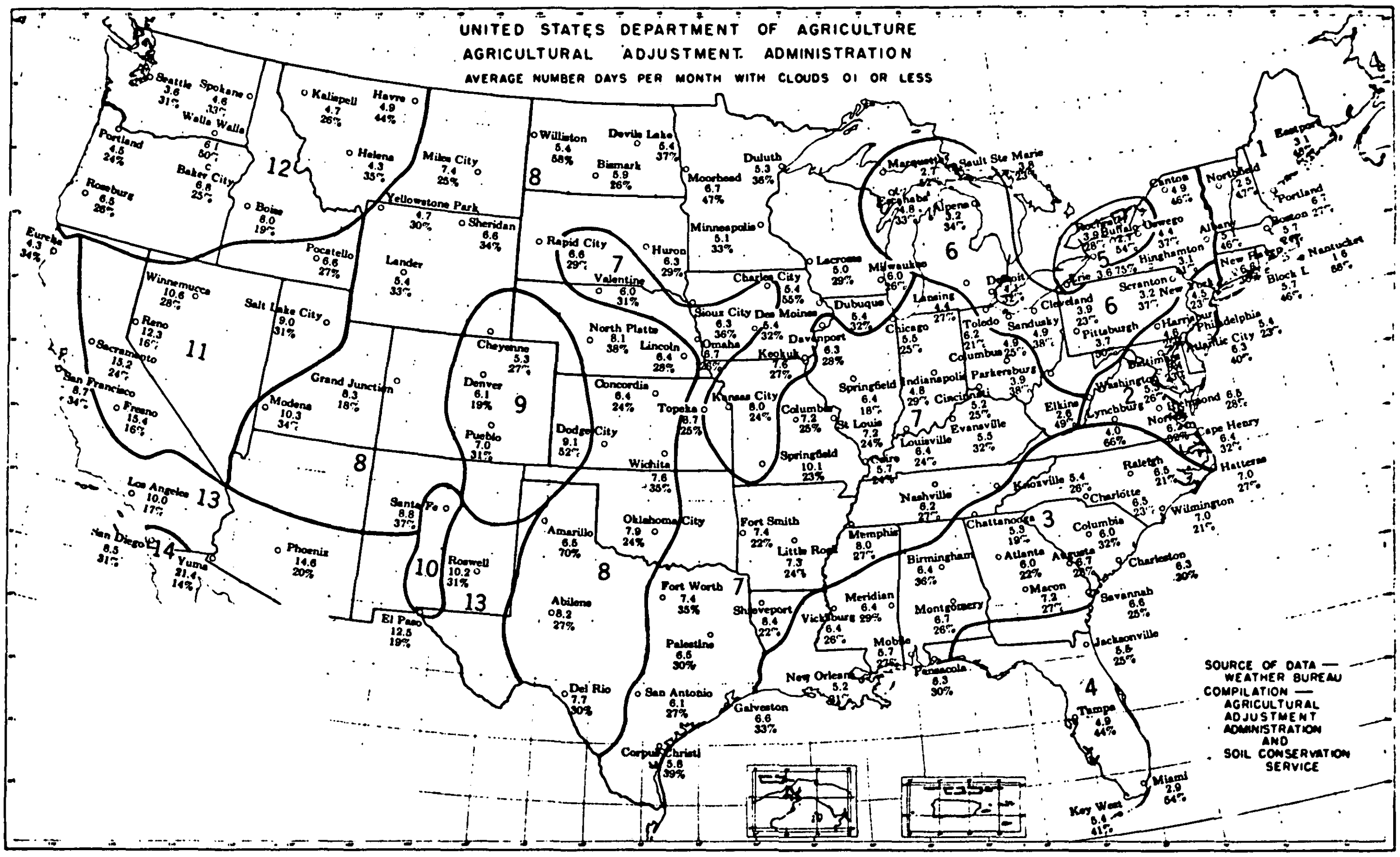


Figure 12. Map of U.S. showing expectancy of cloudless photographic days on an annual basis. The first figure under each station shows the number of days per month when the ground is 0.1 or less obstructed by clouds, based on a yearly average; to determine the average for any given month, multiply this figure by a factor obtained from table I. The second figure under each station is the percentage below average which can be expected 1 year in 10 (the worst year). (Diagram courtesy of U.S. Dept. of Agriculture). Manual of Photogrammetry (1966).

"Figure 12 is a map of the U.S., with zone lines delineated thereon in such a manner that the number of days in any given month on which the sky can be expected to be not more than 1/10 obscured by clouds can be estimated for a given area. The expectation is based on a study of the weather records for the 37 years prior to 1939. As an example, suppose the area to be photographed lies between Little Rock and Fort Smith, Ark., in region 7 on the map. The average number of days per month with clouds 1/10 or less is 7.3 for Little Rock and 7.4 for Fort Smith. Therefore, the average for the project area is 7.35. This figure is an average for a 12-month yearly period. For some months the figure will be higher, and for some less. Now, referring to Table I in the line for region 7 the percentage of the average for each month of the year is given. Thus, for June the figure is 80%. The number of days with 1/10 or less clouds in June would be 80% of 7.35 or 5.88 days. Referring again to the map, for 1 year in every 10, the number of days at Little Rock can be expected to be 24% less, and at Fort Smith 22% less. Thus, the worst expectation, as well as the average expectation is given. A day in which the sky is 1/10 or less covered is considered a photographic day.

In using this probability map, an estimate of actual expected photographic hours would be the product of the probable photographic days in any given period multiplied by the number of photographic hours per day (Figure 10, the Solar Altitude Diagram may be used in conjunction with the illustration above to obtain the probable number of photographic hours for a given location in the U.S.A.) for the average latitude of the project." (Manual of Photogrammetry, 1966, vol. 1, p. 211) example of the detrimental influence of cloud cover on photography, note that in December only 25 per cent of the average 2.7 photographic days available at Buffalo, New York (region 5) actually have cloud cover of .1 or less. This amounts to only half of one day, or .5 per cent of the total 744 hours in December. When solar altitude is accounted for according to methods described in the section on U.S. analysis which follows, one finds that there is no time available for photography at Buffalo in December because solar altitude is below the minimum requirement for "good" photography. The difference in time available for photography and radar therefore is very marked, for in December rainfall rates capable of attenuating radar signals are almost never limiting.

It may be noted from Figure 12 that throughout the humid and sub-humid regions of the United States the average number of photographic days per month is in the range from 2-10, and that even during optimum periods this figure rarely exceeds half the days in the month. Below in Table 2 are listed the month and place of the highest average time availabilities for photography within each region delineated. These have been determined by locating the station with the highest average number of days per month and multiplying this number by the corresponding percentage found in Table 3.

TABLE 2

| Region | Location | No. of Days Available for Photography During the Least Cloudy Month | |
|---|---|---|---|
| 1 | Portland, Maine | Oct. | 9.5 days |
| 2 | Hatteras, North Carolina | Oct. | 11.0 |
| 3 | Macon, Georgia | Oct. | 12.25 |
| 4 | Jacksonville, Fla. | March | 8.9 |
| 5 | Oswego, N.Y. | May | 6.8 |
| 6 | Sandusky, Ohio | Sept. | 6.4 |
| | Canton, N. Y. | | |
| 7 | Springfield, Mo. | Oct. | 16.3 |
| 8 | Modena, Utah | Oct. | 13.9 |
| 9 | Dodge City, Kansas | Oct. | 14.5 |
| 10 | El Paso, Texas | Oct. | 18.5 |
| 11 | Fresno, Calif. | Aug. | 24.6 |
| 12 | Boise, Idaho | July | 18.0 |
| 13 | Yuma, Arizona | Oct. | 27.6 |
| 14 | San Diego, Calif. | Nov. | 13.5 |

It is evident from the tabulation that October is the least cloudy month for most areas in the United States, and that there are wide regional contrasts in the amount of time actually available for photographic missions. This ranges from 9.5 days in region 1 to more than 27 days in region 13. More importantly, it is notable that October is not the best month for photography in all parts of the U.S. This fact suggests that attempts to optimize photographic quality precludes obtaining it at one time over the entire U.S., that is, obtaining it synoptically. On the other hand, if synoptic imagery is required at some predetermined or critical time, as for example in crop phenological or transportation studies, the user must be prepared to expect large gaps in coverage arising from cloud interference. Variations in cloud cover and duration of cloud-free conditions within the United States and throughout the world are so great that the probabilities of successfully photographing large continuous areas from space in a short time period would be small.

## TIME AVAILABLE FOR RADAR AND PHOTOGRAPHIC IMAGING: SOME GLOBAL COMPARISONS

Ratios of available radar to photographic hours have been calculated by the Air Force Air Weather Service (1964) for a number of stations throughout the tropics and high latitudes. Some of these ratios have been diagramed in Figures 14,15, but before they are interpreted the meaning of the ratios themselves must be evaluated. Assumptions employed by the Air Weather Service in constructing the ratios were that radar (wavelength unspecified) could map through all non-precipitating clouds both day and night, and that photographic systems could obtain data only when there was less than 20 per cent cloudiness below 10,000 feet. The following discussion demonstrates that these assumptions result in the generation of ratios which underestimate the time available for radar imaging from space and overestimate the time available for photography.

Space photography will suffer time degredations from cloud layers above 10,000 feet as well as from those below 10,000 feet. Serebreny and Blackmer (1961) have studied altitudinal variations in cloud amounts for five stations in the U.S. and have indicated the number of hours and the amount of sky cover that occurred in July and December (1958) for specific cloud types. Table 3 has been compiled from their data to show the percent of time during which high level cirrus, cirrostratus and cirrocumulus sky cover was equal to or exceeded .3 (30%). Since these calculations are based on only one year's observations, however, the data reveal only an order of magnitude and do not represent average conditions. Moreover, the percentages are for mid-latitude stations and may not be representative of more tropical or polar localities. Nevertheless the data indicate that overestimation of photographic time may be considerable depending upon the time and location.

TABLE 3

Percent of time in July and December, 1958 during which high altitude cloud types comprised >.3 cloud cover for five stations in the United States.

| Location | Total time with sky cover >.3 (hrs.) | # hrs. during which cloud cover >.3 was composed of high altitude clouds alone | % of time during which high altitude clouds compose the overcast |
|---|---|---|---|
| Red Bluff (July) | 178 | 31 | 17.41 |
| Red Bluff (Dec.) | 505 | 221 | 43.76 |
| Rapid City (July) | 486 | 41 | 8.43 |
| Omaha (July) | 537 | 77 | 14.33 |
| Omaha (Dec.) | 417 | 111 | 26.61 |
| San Antonio (July) | 367 | 56 | 15.25 |
| San Antonio (Dec.) | 426 | 68 | 15.96 |
| Charlotte, N.C. (July) | 584 | 55 | 9.41 |
| Charlotte, N.C. (Dec.) | 420 | 122 | 29.04 |

If the time available for photography represents an overstatement of space capabilities in the Air Weather Service ratios, the amount of time available for radar imaging has been understated. This is true mainly because in the construction of the ratios all precipitating clouds were assumed to be prohibitive to radar sensing, a point not without validity for aircraft operations and longer path lengths. Such is not the case from space, however, as already indicated in the discussion of Table I. For a two-way path length of 13km it can be calculated that for 10db attenuation a space-borne X-band system can penetrate up to .6 cm/hr precipitation. At shorter path lengths higher rates of precipitation can be penetrated, so that at a path length of 10km as much as .7 cm/hr precipitation may be penetrated by the same X-band system. As pointed out earlier a path length of 13.5km is roughly equivalent to a precipitating cumulo-nimbus cloud as viewed from a space look-angle of 42°. A 10km path length is equivalent to a cumulo-nimbus cloud at near range -- 22°.

To illustrate the degree of underestimation of available radar time incorporated in the Air Weather Service ratios, one may look at the data of Feldman (1964). Feldman has calculated the average time during the year when precipitation rates produce given one-way attenuations in an X-band radar for several world stations. Some of these have been reproduced in Figure 13. Colombo, Ceylon receives approximately 200cm annual precipitation with a slight bimodal distribution in the months April, May, and June, and again in October, and November. Despite these humid conditions in only about 100 hrs/yr (slightly more than 1% of the time) are rainfall intensities high enough to produce 5db one-way (10db 2-way) attenuation at viewing angles of 80-82°. The equivalent figure for a radar look angle of 32° would be about 16 hours. Similarly, Tokyo with about 150cm has a more or less even distribution of rain throughout the year and suffers 5db attenuation for only about 55 hours/year (.62% of the time). The equivalent time for a spacecraft pointing angle of 32° would be 9 hours (.1%). The curves shown in Figure 13 clearly demonstrate that the amount of time unavailable for radar imaging is extraordinarily small for most regions of

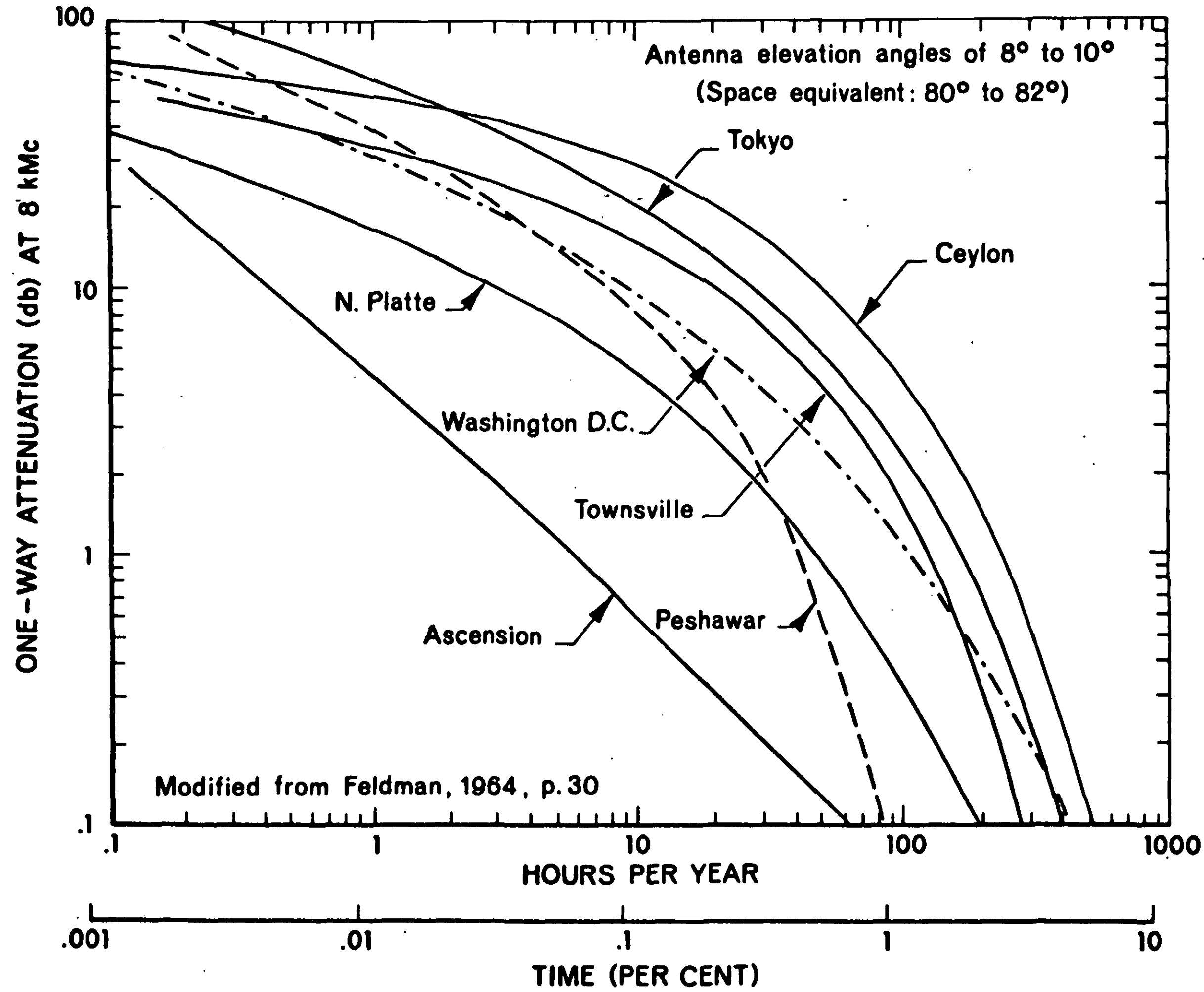


Figure 13. Average time during which precipitation produces given one-way attenuations in an X-band radar (8GHz) system for selected stations. 5db attenuation (10db 2-way) occurs only .1-2% of the time, even for very rainy areas (Modified from Feldman, 1964, p. 30).

the world. Cloudy coastal or insular areas such as Japan and the British Isles, which present genuine time limitations on photography, could be imaged virtually any time by radar. Less humid areas have correspondingly greater proportions of time available for radar and photographic imaging, so that at North Platte, Nebraska with 45cm annual precipitation, radar may successfully attain imagery 99.9 per cent of the time. As a general rule it appears that 10db 2-way attenuation occurs less than 2-3 per cent of the time regardless of how humid the region. Certainly from the chart it appears that most world stations record less than 2 per cent and in many cases less than 1 per cent radar time degradataion due to rain at the viewing angles used by Feldman. At the smaller angles proposed for spacecraft these percentages would lie in the range around 0.2 - 0.4% because the path lengths involved would be shorter.

To illustrate both the range in values of the ratios and the varied situations in which unsatisfactory conditions exist for photography, but not for radar, we may consult Figures 14 and 15. For each station in these figures the ratios of available radar to photographic hours are shown by month, so that each inflection on the curves represents a different month. At Eskimo Point, N.W.T., for example, the January ratio is about 75, the July and August ratios are about 10, and the December ratio is about 30. Above the chart for each station are listed the mean sky cover for July (approximately the time of maximum solar altitude in the northern hemisphere) the latitude, longitude, and the mean annual precipitation in centimeters.

As a reference against which to estimate the imaging potential of orbiting radar systems, Table 4 lists the average number of photographic hours (column 1) which may be expected in July at the stations presented in Figures 14 and 15. By multiplying this figure by the corresponding ratio for July (column 2), the number of hours considered available to radar may be determined (column 3) and expressed as a percent of the total time in July (column 4). The last column, percent of time available to radar in July, illustrates the very conservative (and in some cases even misleading) nature of the ratios. In most cases this figure should be above 95% (for

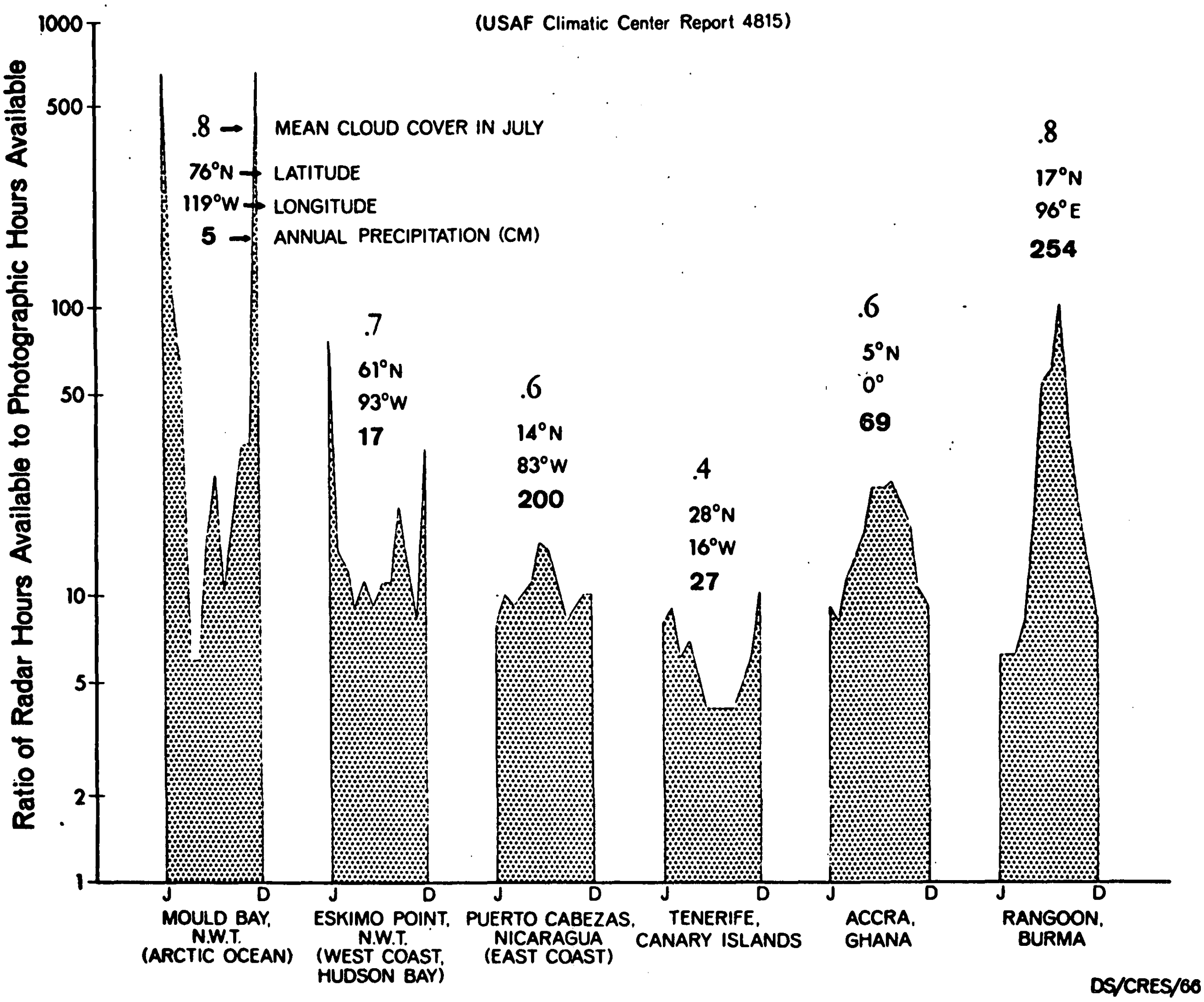


Figure 14. A comparison of hours available for radar and photography for selected high and low latitude stations. Comparison based on two rules; that radar sees through all non-precipitating clouds for at least 3 consecutive hours and for photography that there is no more than 20% cloud cover below 10,000 feet with greater than 5 miles visibility for 3 consecutive hours.

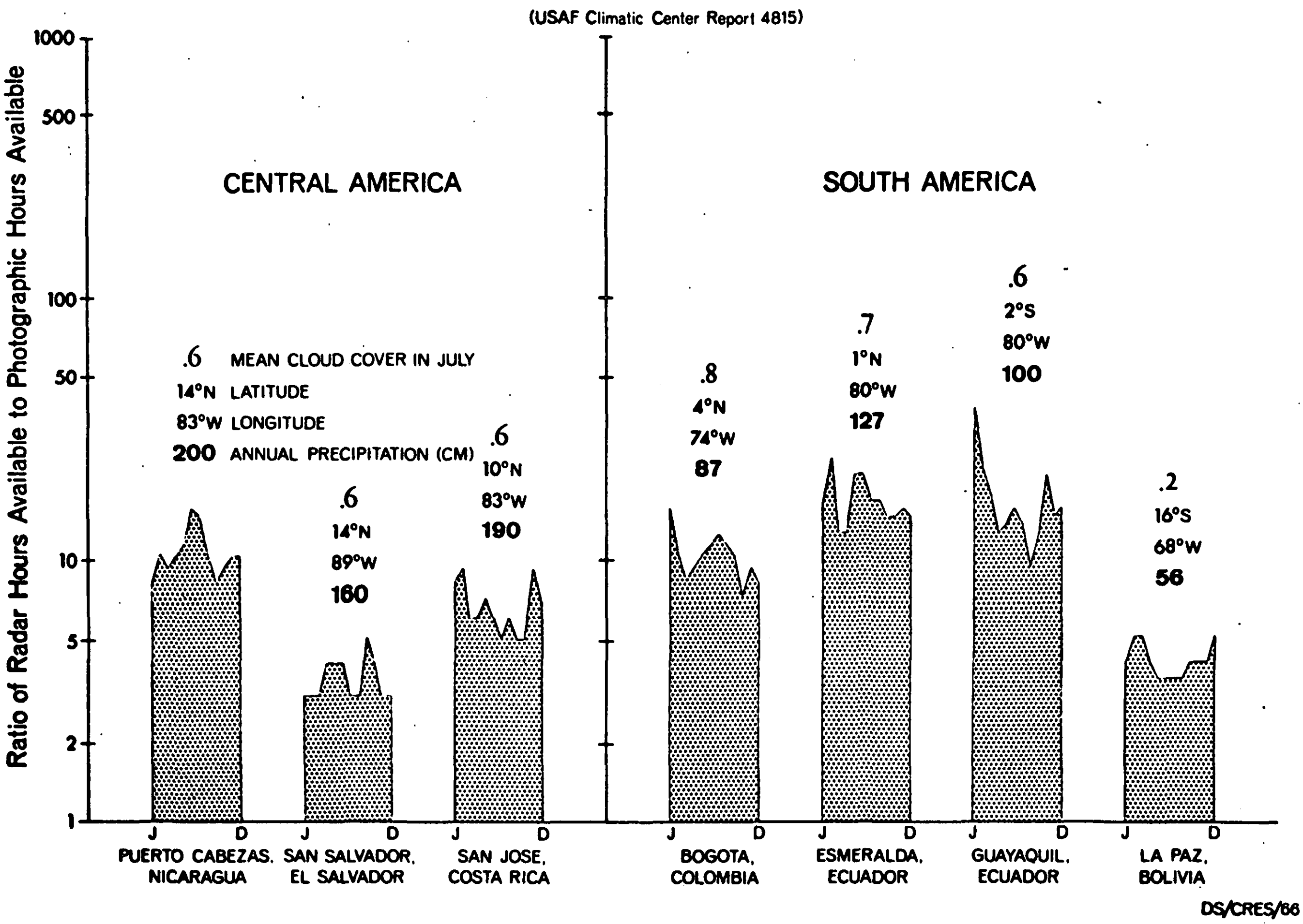


Figure 15. Comparison of hours available for radar and photography for stations in Central and South America. Comparison based on two rules; that radar sees through all non-precipitating clouds for at least 3 consecutive hours and for photography that there is no more than 20% cloud cover below 10,000 feet with greater than 5 miles visibility for 3 consecutive hours.

a 3 cm radar system) and in some instances (i.e. arctic stations with characteristically low rainfall intensities) should be near 100 per cent. Since data pertaining to the actual number of hours with specified rainfall intensities are not available for the stations presented we have utilized the data from Air Weather Service without alteration.

TABLE 4

(All data are average for July)

| Stations | (1) Photo Hrs. | (2) Ratio | (3) Radar Hrs. | (4) % Time in July Available to Radar |
|---|---|---|---|---|
| Mould Bay | 21 | 21 | 546 | 86 |
| Eskimo Point | 45 | 11 | 495 | 67 |
| Puerto Cabezas | 30 | 14 | 420 | 56 |
| Accra | 28 | 23 | 644 | 87 |
| Tenerife | 206 | 4 | 824* | 100 |
| Rangoon | 8 | 56 | 448 | 60 |
| San Salvador | 193 | 3 | 579 | 78 |
| San Jose | 100 | 5 | 500 | 67 |
| Bogota | 41 | 12 | 492 | 67 |
| Esmeralda | 41 | 16 | 656 | 88 |
| Guayaquil | 51 | 13 | 663 | 89 |
| La Paz | 237 | 3 | 711 | 96 |

*This number is impossible since there are only 744 hours in July. By recalculating using 744 hours as the base, a ratio of 3.6 results, indicating that the ratio of 4 may have been arrived at by rounding.

Source: USAF Air Weather Service (1964)

The chart for Mould Bay, Canadian Northwest Territory illustrates an extremely high capability for obtaining radar imagery during the polar night when normal photography is infeasible (November to March). In July at Mould Bay, the most favorable month for photography, a ratio of 26:1 exists in favor of radar. Although the calculated time availability for radar in July is only 86 per cent, average annual rainfall is so low (5 cm) that rainfall intensities seldom exceed .25 inches per hour (.635 cm). Correspondingly a 3-cm radar system probably would have a near 100 per cent time capability. Much the same situation exists for Eskimo Point farther south on the Coast of Hudson Bay.

Tenerife in the Canary Islands has comparatively low ratios for most months. Cloud amounts in this locality are low in July, and throughout most of the year, because of a persistent high pressure cell over the Atlantic, the influence of which combines with a cold water current adjacent to the Islands to prevent the formation of clouds. Photography is seldom hindered by low-level cloud systems, but may occasionally be degraded at space altitudes by thin, high-level cirrus formations. Even though the ratio for July is only 4, there is essentially a 100 per cent time availability for radar at Tenerife because of expected low rainfall intensities.

Accra, Ghana, has moderately high ratios of radar to photographic hours that probably result from a high frequency of cloudy but relatively rainless conditions during July. Calculations based on the number of photographic hours available (28) indicate that radar can map 87 per cent of the time during this month while photography is possible only 10 per cent of the daylight time. It may be concluded from this that cloudiness at Accra, and perhaps along most of the north coast of the Gulf of Guinea, is generally great enough to hamper space photography during the summer months by the creation of extensive gaps in the imagery.

Monsoon conditions at Rangoon, Burma, during the summer lead to a high incidence of cloud cover detrimental to space-borne photographic systems. The highest ratio (56:1) occurs in July when sky cover averages 80 per cent. Cloudy conditions often commence in the forenoon and persist until early evening. During part of this time precipitation may hinder the use of shorter wavelength radars (1-3 cm), but would not often influence longer wavelength systems (3cm plus). Exclusion of all precipitating clouds from the time available to radar has resulted in an apparent 60 per cent imaging potential, but the true figure is no doubt higher if cloud systems with precipitation intensity less than .25 inches/hr are included within the penetration capability of radar systems.

Puerto Cabezas, Nicaragua is a coastal station on the Atlantic side of Central America in a locality which annually receive 200 cm of rainfall. July cloud cover averages about 60 per cent and the average time expectancy for conventional photography has been calculated to be only about 30 hours. This low number of photographic hours suggests that cloudiness has a high daytime incidence, while the comparatively low ratio of radar to photographic time suggests a high frequency of rain-bearing clouds. As a consequence of subtracting all precipitation hours from the data, Air Weather Service figures yield a total time capability in July of only 56 per cent for radar (the lowest of any of the stations recorded); however, it is likely that a significant portion of the precipitation time yields rainfall rates below the .25 inches per hour necessary to cause 10db 2-way attenuated 3cm radar signals. We expect that an orbiting X-band radar would be able to image successfully during all but a small percentage of the time in this environment.

San Salvador, El Salvador lies on the Pacific side of Central America in a tropical savannah region. A rather low ratio of 3 is recorded for this station in July. Although mean cloudiness and precipitation are comparable to Puerto Cabezas, the number of hours available for obtaining photography varies by a factor of more than 6. If these figures are correct (see Table 3) the incidence of cloudiness at San Salvador must occur at a time non-detrimental to photography, and; even though radar imaging conditions are somewhat better than at Puerto Cabezas (579 hours vs. 420 hours in July), the resulting ratio is lower. For reasons already proposed, the 78 per cent time capability for radar in July probably should be increased.

Data for San Jose, Costa Rica, in July are very similar to those at San Salvador, and for many of the same reasons. Ratios throughout the year, however, are slightly higher then for San Salvador which may indicate a somewhat lower number of precipitation hours, though with greater rainfall intensities.

Bogota, Columbia is a comparatively dry mountain station which suffers about 80 per cent cloudiness in July. A ratio of radar to photographic hours of 12 is reported during this month, placing it roughly on a par with Puerto Cabezas. Although cloudiness is greater at Bogota than at Puerto Cabezas the number of photographic hours is greater (41 vs. 30). Moreover, the number of radar hours available at Bogota exceeds conditions at Puerto Cabezas by a margin of 72 hours, reflecting the lower number of rainfall hours in the Colombian Highlands. In general terms, however, these two stations are quite similar not only in July, but throughout most of the year.

July data for Esmeralda and Guayaquil, Equador may be expected to be similar by reason of geographic proximity. The former station has a higher July cloudiness (70% vs 60%) and correspondingly few hours available for photography (41 vs 51). Ratios of 16 and 13 respectively exist in July, but in terms of radar imagery this difference amounts to only a 7 hour advantage at Guayaquil. The total time available for radar is very close to 90 per cent in both cases. Of interest is the monthly pattern of change in the ratios. More often than not the ratios for Esmeralda are equal to or greater than those at Guayaquil. This trend is reversed, however, during January, March and October. The greatest single contributor to these variations may be the diurnal pattern of cloudiness, since there is only slight difference in rainfall averages and latitude. Whatever the causes, it is evident that very modest changes in the temporal occurrence of cloudiness or the number of rainfall hours recorded at a station may be sufficient to produce quite large fluctuations in the ratio of radar to photographic hours.

La Paz, Bolivia undergoes only minor variations in ratio from month to month primarily because of a relatively dry climate and the high probability for clear skies. In July, cloudiness averages only about 20 per cent, which is within the tolerance of urgent aerial photographic missions. That station approaches very closely the theoretically optimum ratio from the point of view of photography (that is, if photography were possible 8 hours/day and radar imagery could be obtained 24 hours/day, the ratio would be 3:1). In the case of La Paz, photography is obtainable during

237 of the 279 daylight hours and radar is obtainable during 711 of the 744 hours in July.

The fact that several stations may have similar ratios of radar to photographic hours available, but different amounts of actual time available, indicates that quick generalizations regarding the capabilities of these two systems are not easy to make on the basis of ratios alone. In each situation there are peculiarities in the temporal regimes of cloudiness as well as the number of rainfall hours exceeding critical rates, and for this reason the actual number of hours available to each sensor should be indicated along with the ratio. Evidently, from the types of ratios encountered, there are two quite distinctly different processes at work to produce low ratios. In the one case a low ratio may arise because there are many hours available for photography, as in desert areas, and a concomitant high number of hours available for radar. This condition would lead to the theoretically optimum ratio described above. The second type of low ratio results from the occurrence of a moderate to high number of photographic hours and an unusually low number of radar hours. In reality such a situation seldom arises as can be shown by looking at the actual number of hours per year with rainfall rates greater than critical radar penetration capabilities. The greatest incidence of this phenomenon would seem to occur in humid tropical regions where one could imagine a high probability of early evening and early morning clouds on the heels of consistently cloud-free days.

A practical demonstration of the utility of radar as a substitute for photography in cloudy environments in the Central American tropics has recently been given in the mapping of Darien Province, Panama. The radar imagery from which the accompanying mosaic (Figure 16) was constructed was obtained in 6 imaging hours of 17,000km$^2$, with an average of three passes over each area, i.e. the equivalent of 50,000km$^2$ of imagery. This, in an area of notorious cloudiness where photographic missions have a very low success rate (MacDonald, 1969).

Figure 16. A practical application of radars all-weather capability is shown by the radar mosaic of Darien Province, Panama. In 1967, a side-scan radar system imaged approximately 10,000 sq. km. in six days of operation, which included only six hours of flying time. Most points were imaged from at least four different look-directions, In the 15 years prior to the radar coverage, continuous effort has resulted in coverage of only about 40% of this province by aerial photographs, because of the nearly continuous cloud cover. Mosaic prepared by Raytheon/Autometric for the United States Army Engineer Topographic Laboratories. Imagery obtained by Westinghouse Corporation.

# COMPARISON OF HOURS AVAILABLE FOR RADAR AND PHOTOGRAPHIC IMAGING IN THE UNITED STATES

## Data Source and Analysis

The basic data used in this part of the study were taken from Tables C and E of the U.S. Weather Bureau's Monthly Summary of 10-Year Weather Observations. A sample page of these data is shown in Figure 17. Table C, Occurrences of Precipitation Amounts, was available for 118 first-order stations in the contiguous forty-eight states. Table E, Percentage Frequencies of Sky Cover, Wind and Relative Humidity, was available for 129 stations. Each table gives the total number of occurrences or the percent frequency of occurrence of each phenomenon observed during the ten year period for every hour of the day for each month.

Computer tapes of the data contained in Tables C and E were obtained from the National Weather Records Center, Ashville, North Carolina. These tapes as originally supplied were not useable on the General Electric 625 computer operated by the Computation Center of the University of Kansas. Several unusual characters had to be translated before the computer could even read the tapes. After a print-out of the data was obtained it was necessary to sort and rearrange the data into a format which could be conveniently manipulated. This done, computer programs were written and the necessary quantities for each weather station were calculated. These were then submitted to the computer for mapping by Harvard University's SYMAP Program. This program generates isopleth maps by finding the contours at specified intervals.

## Computation of Time Available to Aerial Photography

For the purposes of this study, time was considered available to aerial photography when the altitude of the sun was equal to or greater

## C OCCURRENCES OF PRECIPITATION AMOUNTS:

| INTENSITIES | FREQUENCY OF OCCURRENCE FOR EACH HOUR OF THE DAY | | | | | | | | | | | | | | | | | | | | | | | | NO OF DAYS WITH |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | A.M. HOUR ENDING AT | | | | | | | | | | | | P.M. HOUR ENDING AT | | | | | | | | | | | | |
| | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | NOON | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | MID. | |
| TRACE | 32 | 30 | 37 | 30 | 31 | 40 | 40 | 39 | 41 | 35 | 33 | 38 | 33 | 26 | 24 | 24 | 26 | 30 | 27 | 26 | 24 | 28 | 25 | 30 | 64 |
| .01 IN. | 7 | 6 | 6 | 6 | 6 | 6 | 6 | 7 | 6 | 4 | 9 | 6 | 6 | 5 | 3 | 5 | 5 | 2 | 4 | 6 | 5 | 3 | 5 | 8 | 14 |
| .02 TO .09 IN. | 1 | 4 | 4 | 5 | 4 | 4 | 3 | 4 | 3 | 4 | 4 | 2 | 4 | 2 | 3 | 2 | 3 | 4 | 3 | 1 | 2 | 4 | 6 | 5 | 27 |
| .10 TO .24 IN. | | | 1 | 1 | 3 | 1 | 1 | 1 | | | | | | | | | | | | | | | | | 8 |
| .25 TO .49 IN. | | 1 | | 1 | | | | | | | | | | | | | | | | | | | | | 4 |
| .50 TO .99 IN. | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| 1.00 TO 1.99 IN. | | | | | | | | | | | | | | | | | | | | | | | | | 1 |
| 2.00 IN AND OVER | | | | | | | | | | | | | | | | | | | | | | | | | |
| TOTAL | 40 | 41 | 48 | 43 | 44 | 51 | 50 | 51 | 50 | 43 | 46 | 46 | 43 | 33 | 30 | 31 | 34 | 36 | 34 | 33 | 31 | 35 | 36 | 43 | 119 |

## E PERCENTAGE FREQUENCIES OF SKY COVER, WIND, AND RELATIVE HUMIDITY:

| HOUR OF DAY | CLOUDS SCALE 0-10 | | | WIND SPEED (M. P. H.) | | | | RELATIVE HUMIDITY (%) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 0-3 | 4-7 | 8-10 | 0-3 | 4-12 | 13-24 | 25-& OVER | 0-29 | 30-49 | 50-69 | 70-79 | 80-89 | 90-100 |
| 00 | 49 | 8 | 44 | 7 | 46 | 45 | 3 | | 5 | 27 | 23 | 25 | 20 |
| 01 | 51 | 6 | 43 | 6 | 48 | 42 | 4 | | 5 | 27 | 20 | 28 | 20 |
| 02 | 49 | 9 | 42 | 4 | 49 | 44 | 4 | | 3 | 24 | 24 | 27 | 22 |
| 03 | 51 | 6 | 43 | 6 | 45 | 43 | 6 | | 3 | 22 | 23 | 27 | 25 |
| 04 | 51 | 7 | 42 | 7 | 45 | 42 | 6 | | 3 | 21 | 24 | 28 | 24 |
| 05 | 48 | 8 | 44 | 5 | 48 | 41 | 5 | | 2 | 21 | 22 | 31 | 25 |
| 06 | 45 | 10 | 46 | 6 | 47 | 42 | 5 | | 2 | 20 | 20 | 32 | 25 |
| 07 | 37 | 12 | 52 | 5 | 50 | 40 | 5 | | 1 | 21 | 20 | 32 | 25 |
| 08 | 32 | 10 | 58 | 6 | 47 | 42 | 4 | | 2 | 22 | 23 | 30 | 23 |
| 09 | 33 | 11 | 56 | 6 | 42 | 46 | 6 | | 4 | 29 | 24 | 24 | 19 |
| 10 | 34 | 12 | 54 | 4 | 37 | 52 | 7 | + | 7 | 42 | 20 | 14 | 17 |
| 11 | 35 | 11 | 54 | 4 | 37 | 51 | 8 | 1 | 18 | 41 | 15 | 12 | 13 |
| 12 | 36 | 13 | 52 | 4 | 34 | 51 | 11 | 2 | 22 | 38 | 16 | 11 | 10 |
| 13 | 34 | 12 | 54 | 5 | 30 | 57 | 9 | 6 | 27 | 35 | 14 | 8 | 9 |
| 14 | 34 | 10 | 56 | 3 | 30 | 58 | 9 | 7 | 32 | 34 | 11 | 8 | 8 |
| 15 | 35 | 9 | 56 | 4 | 31 | 55 | 11 | 10 | 32 | 34 | 9 | 8 | 7 |
| 16 | 32 | 12 | 56 | 4 | 33 | 55 | 8 | 8 | 33 | 32 | 10 | 9 | 8 |
| 17 | 32 | 13 | 55 | 3 | 43 | 51 | 4 | 2 | 31 | 35 | 13 | 9 | 9 |
| 18 | 36 | 13 | 51 | 6 | 51 | 39 | 4 | 2 | 22 | 33 | 20 | 15 | 8 |
| 19 | 41 | 12 | 47 | 5 | 53 | 38 | 4 | 1 | 15 | 34 | 23 | 19 | 8 |
| 20 | 43 | 13 | 44 | 6 | 47 | 44 | 3 | 1 | 12 | 34 | 20 | 22 | 12 |
| 21 | 45 | 11 | 44 | 5 | 45 | 47 | 3 | 1 | 10 | 31 | 21 | 23 | 14 |
| 22 | 48 | 9 | 43 | 4 | 51 | 43 | 3 | + | 9 | 30 | 22 | 24 | 15 |
| 23 | 48 | 10 | 42 | 5 | 52 | 40 | 2 | | 7 | 28 | 21 | 26 | 18 |
| AVG | 41 | 10 | 49 | 5 | 43 | 46 | 6 | 2 | 13 | 30 | 19 | 20 | 16 |

Figure 17. Data format for Tables C and E in Climatography of the United States, Decennial Census of United States Climate: Summary of Hourly Observations, 1951-1960.

than 30° and the cloud cover was equal to or less than 30 per cent. Therefore, in order to compute the total time which was suitable for aerial photography it was necessary to compute these two quantities for each station for each month. The first quantity to be determined was the average number of hours each day (of a specified month) that the sun had an altitude of more than 30° ($\Delta h$). Knowing this, the next step was to extract from the data the average percent frequency of cloud cover equal to or less than 30 per cent during these hours ($\bar{B}$). Both variables were used to compute the average number of hours in a given month available to aerial photography ($T_p$) over a given station.

Computation of hours with solar altitude greater than 30° ($\Delta h$).

If the Earth had no atmosphere the time available to aerial photography would be a function of the declination of the sun and latitude. A map showing average time available per day for a specified month would appear as a series of lines parallel to the equator.

The meridian angle (t) of any heavenly body is "the distance measured eastward or westward (whichever is shorter) on the equator from the intersection of the meridian and equator to the foot of the hour circle through the body."[5]

The meridian angle (t) of the sun (or any other celestial body) at any altitude is given by:

$$1.\quad \cos t = \frac{\sin h - \sin\phi \sin\delta}{\cos\phi \cos\delta}$$

where h is the angular distance of the sun above the horizon (equal to 30°), $\delta$ is the declination of the sun on a specified day, and $\phi$ is the latitude of a particular place.[6]

[5] J. J. Nassau, Practical Astronomy (2nd Edition; New York: McGraw-Hill, 1959), p. 242.

[6] Nassau, p. 242.

The amount of time that the altitude of the sun will be greater than some specified angle can be defined as twice the meridian angle (t) of the sun when it attains that altitude. This definition is only slightly in error since the declination of the sun only changes by about 20 minutes of arc per day.

Note that when the sun is on the meridian it is local apparent noon. That is, t (in hours) is the time that it takes the sun to go from the specified minimum altitude to noon. If we assume that the declination of the sun is constant for any particular day and that the ending minimum altitude is the same as the beginning minimum altitude, then the time it takes the sun to go from noon to the minimum altitude will be exactly the same as the time from the minimum altitude to noon. Thus the meridian angle, whether measuring eastward or westward, will be identical and the desired time is just twice the meridian angle (2t). This means that the time during which the sun will be suitably located for aerial photography is divided evenly on either side of noon. The importance of this point will become apparent when discussing the computation of average cloud cover.

In order to generate average monthly values, 2t (the amount of time the sun has an altitude greater than 30°) was computed for each station for every day of each month.[7] The daily values were summed and the average taken.

$$2.\quad h = \sum_{I=1}^{I=30} 2t/30$$

This procedure reduces the error arising from the diurnal variations of the declination of the sun and gives a mean daily value of $\Delta h$ good to about $\pm$ 0.1 hour.

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[7]For convenience in computing, the year was divided into 12 months of 30 days each.

Computation of the average percent frequency of cloud cover less than 30% ($\bar{B}$).

As pointed out in the previous section, half of the time the sun has an altitude greater than 30° occurs before local noon and half occurs after noon. By rounding $\Delta h$ to the nearest even number of hours, it was possible to average the percent frequency of cloud cover equal to or less than 30% for an equal number of hours in each side of noon because the data was tabulated for every hour of the day. This determines $\bar{B}$ (the average percent frequency of cloud cover $\leq$ 30% during photographic hours) for the station and month in question (see Figure 17, Table E).

Determination of time available to aerial photography

The equation for the time available to aerial photography ($T_p$) is:

3. $T_p = N \Delta h \bar{B}$ (hours)

where N is the number of days in the month, $\Delta h$ is the average number of hours in each day of the month when the altitude of the sun $\geq$ 30°, and $\bar{B}$ is the average percent frequency of cloud cover $\leq$ 30% during the hours defined by $\Delta h$.

Thus, $T_p$ is the average number of hours per month available to aerial photography for the month and station specified. The details of the computations are contained in the computer program, Appendix D. $T_p$ was computed for 129 stations of which 94 had ten years record of average cloud cover $\leq$ 30% for every month. The 129 values obtained for each month were divided into 7 classes, and maps for the mid-season months are presented in the next section. The calculated values for each station are tabulated in Appendix B.

Calculation of Time Lost for Radar Imaging

As previously discussed, the ability of radar to "see through" a precipitating cloud mass depends on the wave-length at which the radar system is operating, as well as the size and number of the raindrops. While useful images can be obtained through precipitation, it has been found that images obtained through a cloud mass precipitating at a rate of .25 inches per hour or more are sufficiently degraded with most radar systems to be of distinctly less value than the undegraded image. It can be assumed, therefore, for purposes of comparison that a precipitation intensity equal to or exceeding .25 inches per hour would be sufficient to restrict the use of radar for imaging.

Table E of the Summary of Hourly Observations gives the number of times that each category of precipitation intensity was observed during each hour of the day for every month. The categories define the amount of precipitation that was actually observed to fall during the specified hour converted to an equivalent intensity per hour. Thus, while the actual precipitation intensity may be quite variable, the ranges define a lower limit that would produce the observed precipitation amounts. For example, if one-fourth inch of precipitation was observed during some hour, a precipitation intensity of .25 inches per hour is the lowest intensity that could have produced it. If it had rained at the rate of one inch per hour for fifteen minutes the result would have been the same. This provides another element of conservatism in the determination of the number of hours that precipitation intensity was .25 inches per hour or more.

In order to determine the time lost to radar (Tr), the number of hours the precipitation intensity was equal to or exceeded .25 inches per hour (x) were summed and divided by the number of years for which records were kept (five or ten years, depending on the station)!

4. $Tr = \frac{X}{\text{YEARS}}$

where x is the number of hours precipitation intensity was .25 inches per hour or more. The solution to the equation yields the average number of hours that precipitation intensity was equal to or greater than .25 inches per hour for the station and month specified. The above equation for Tr was evaluated by the computer program in Appendix E. The results of this analysis are discussed in the following section.

After equations 3 and 4 were evaluated, the results were divided into categories suitable for mapping. The decision to use seven classes was made quite arbitrarily. Seven classes is small enough to prevent confusion in interpreting the maps and large enough to show the spatial variations in the occurrence of the parameters.

Several statistical methods of data grouping were tried. A computer program which divides data into classes by four different methods was used. Briefly, the methods are:

1. Grouping around the means. After specifying seven initial classes, this technique shuffles stations between groups until every individual is closer to the mean of its group than to the mean of any other group.
2. Average deviation. This method reduces the deviations around the means of the classes to a minimum by shifting stations to different classes.
3. Analysis of variance. The class sizes are adjusted until the sums of the squares of the deviations from the means of the classes are minimized.
4. Blanket of error. This method shifts stations in an attempt to arrive at groupings with the largest numerical break between the classes.

The object of these techniques is to generate classes which have the least amount of internal variation and have maximum distinctiveness. When applied to these data, the resulting classes varied so much that maps with these derived classes would not be comparable from one month to another. For comparability it was decided that it would be more appropriate to have the same categories on every map. The statistical methods did indicate that in the case of time lost to radar, so few stations ever experienced more than six hours lost that this value was a convenient lower limit for the highest category. As a result, the categories chosen for the Time

Lost to Radar maps were 1) 0-1 hour per month, 2) 1-2 hours per month, 3) 2-3 hours per month, 4) 3-4 hours per month, 5) 4-5 hours per month, 6) 5-6 hours per month, and 7) 6-12.8 hours per month. 12.8 hours was the maximum amount of time lost to radar found for any station in the continental United States in any month. In some months, the highest categories did not appear.

By a similar procedure the Time Available to Aerial Photography categories were selected as follows: 1) 0-30 hours per month, 2) 30-60 hours per month, 3) 60-90 hours per month, 4) 90-120 hours per month, 5) 120-150 hours per month, 6) 150-180 hours per month, and 7) 180-210 hours per month. As before, the higher categories did not appear every month, particularly when suitable conditions for aerial photography were limited by a low solar altitude during the winter months.

## Results of the Analysis

The results of these calculations and classifications are shown in Figures 18-23 for aerial photography and Figures 24-27 for radar.

Figure 18 for January shows that the time available to aerial photography is contained within the first two categories for most of the United States. Southern Florida is in a third category. The southern third of the nation has from 30-60 hours available while the northern two-thirds has 30 hours or less. Over 60 hours are available for the southern tip of Florida or about 10 per cent of the total time in the month. In January, north of latitude 39° (approximately the latitude of Kansas City), the sun never attains an altitude of 30°, hence the time available for aerial photography is zero.

Figure 19 for April shows that everywhere in the U. S. the sun's altitude is greater than 30° for at least a part of each day. The patterns show east-west banding due to sun angle and variations within each band due to cloud cover. The amount of time available to aerial photography generally increased from north to south except around the Gulf Coast and Peninsular Florida. The southwestern states show up clearly as an area of high photographic time: around Tucson 120-150 hours (~20% of the month) are available.

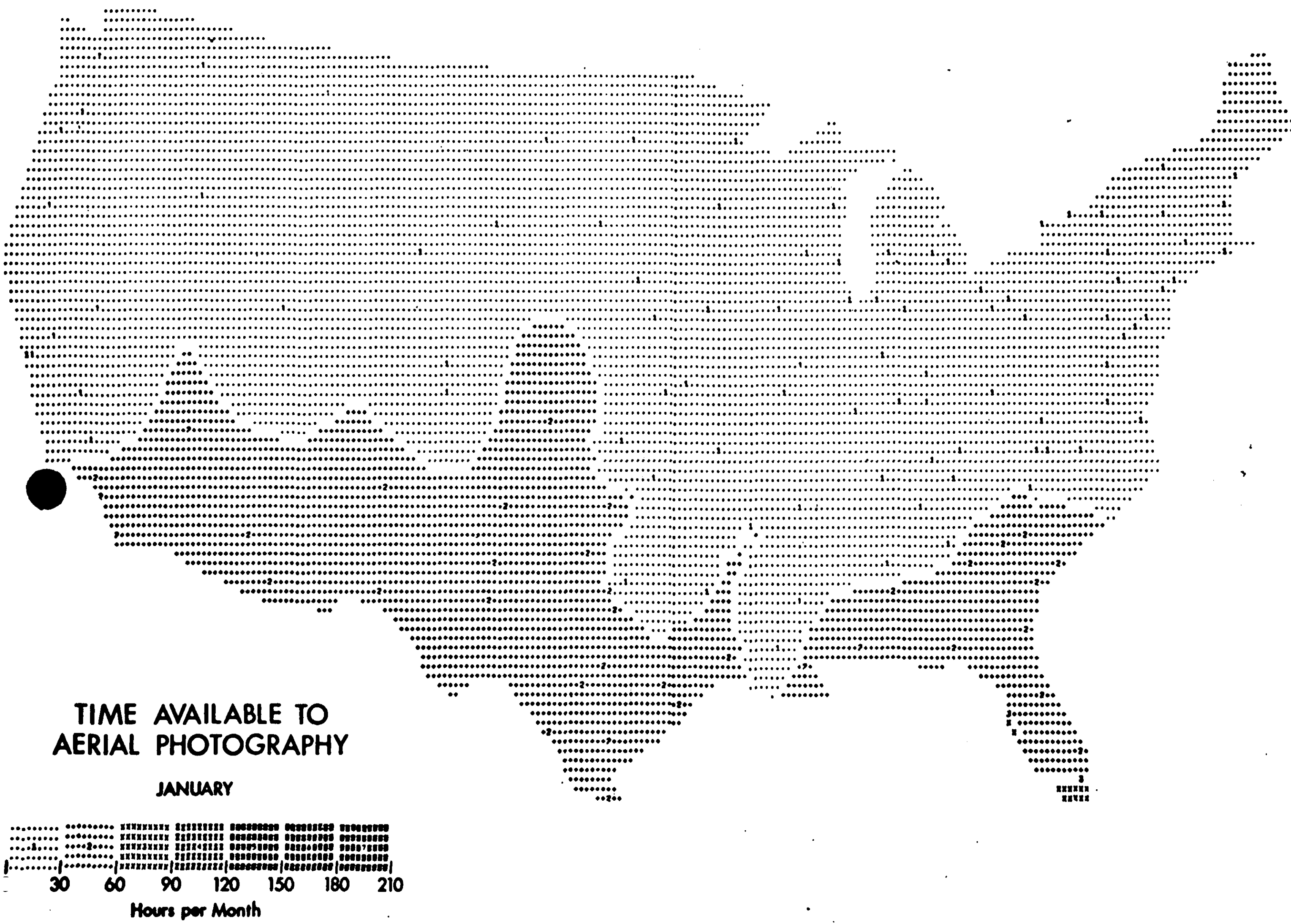


Figure 18. Time available for aerial photography in January.

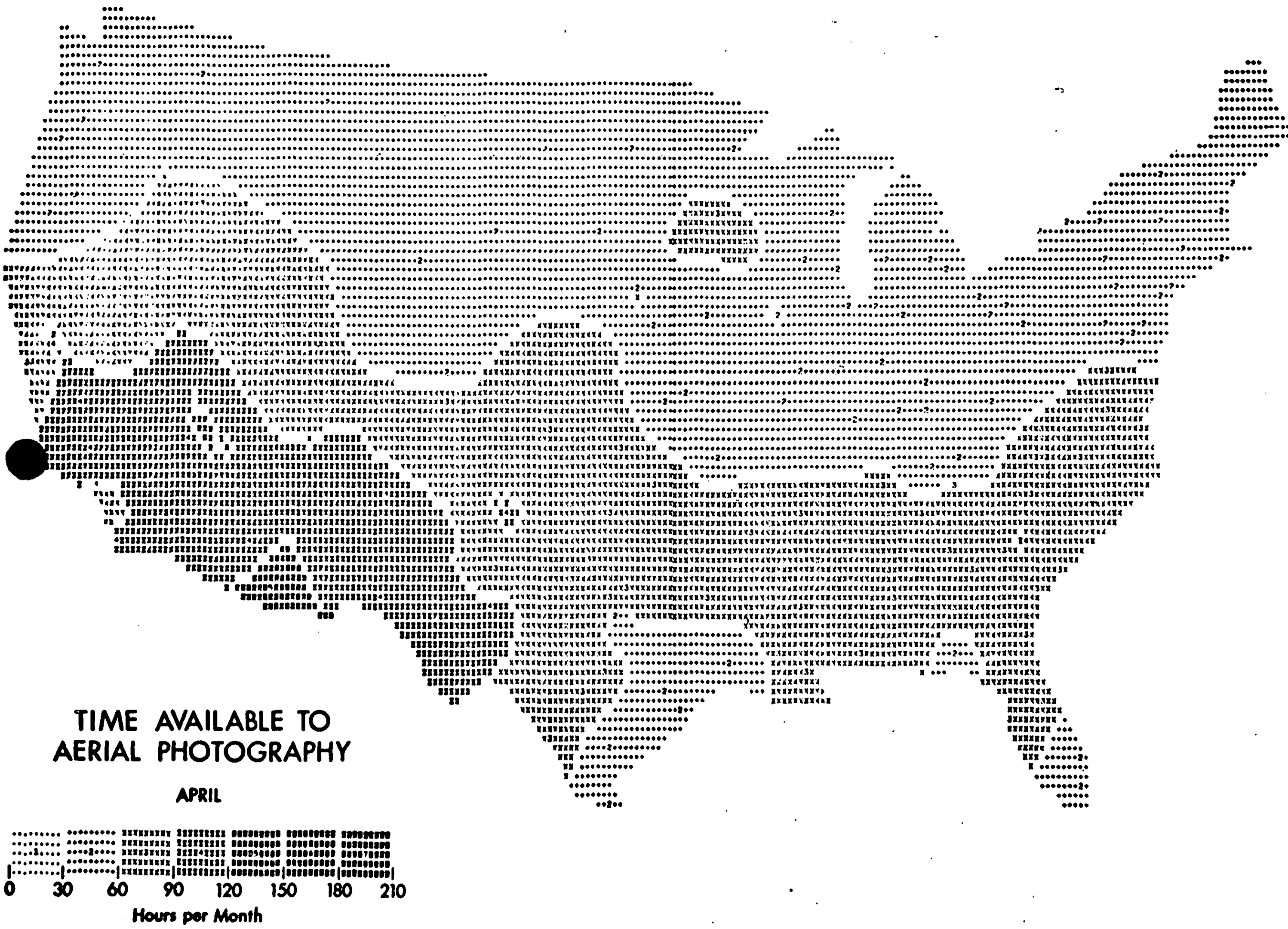


Figure 19. Time available for aerial photography in April.

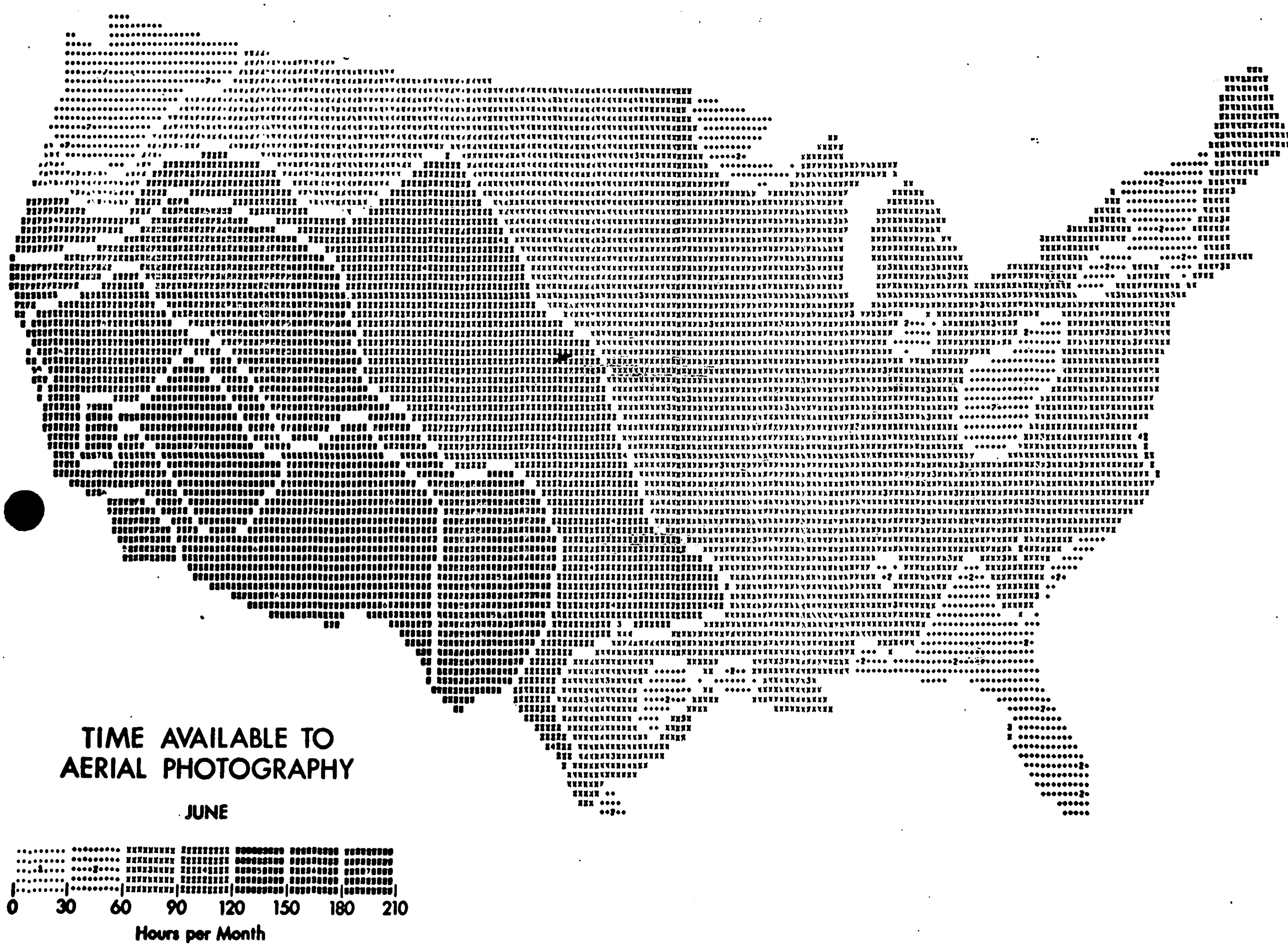


Figure 20. Time available for aerial photography in June.

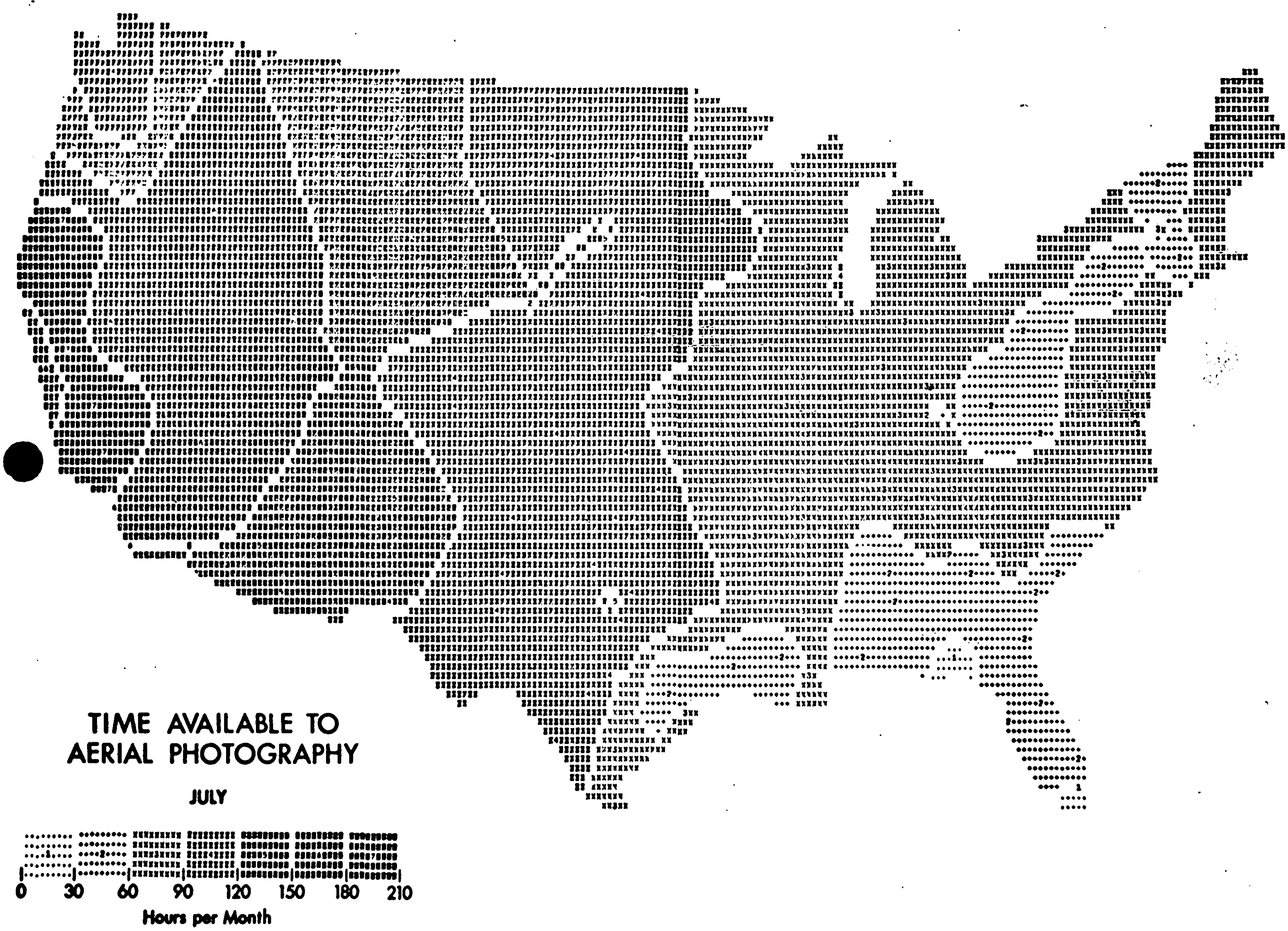


Figure 21. Time available for aerial photography in July.

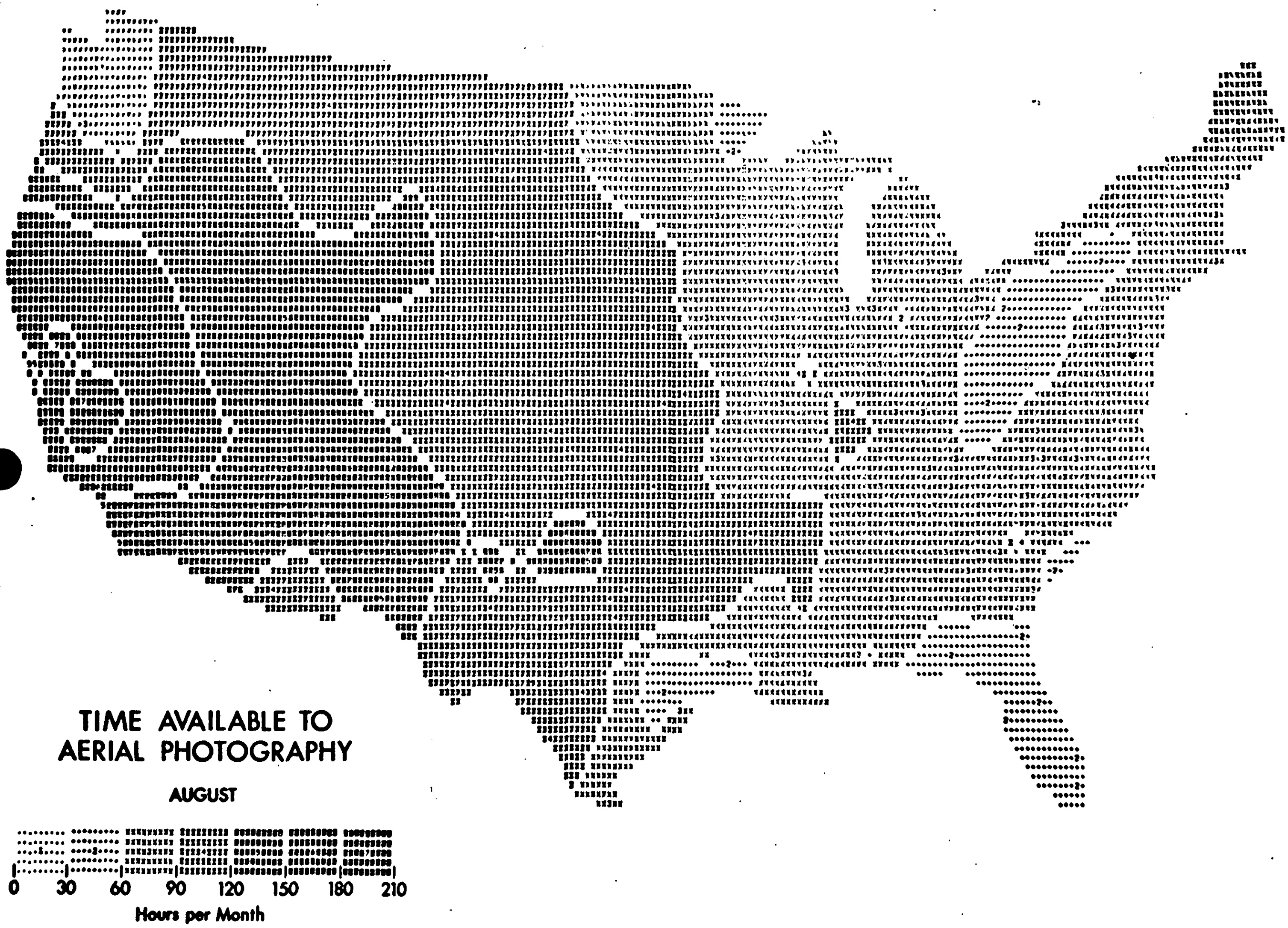


Figure 22. Time available for aerial photography in August.

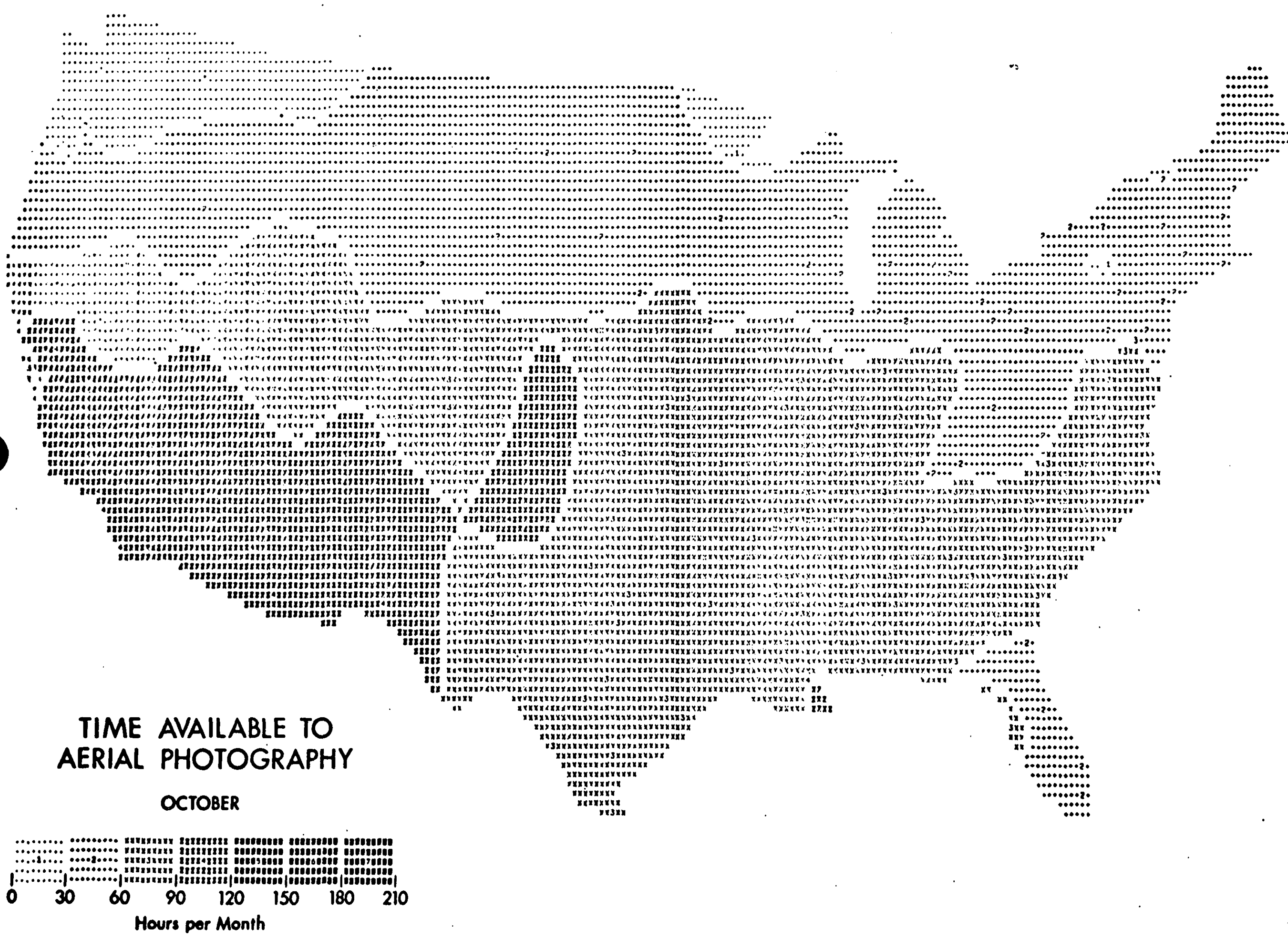


Figure 23. Time available for aerial photography in October.

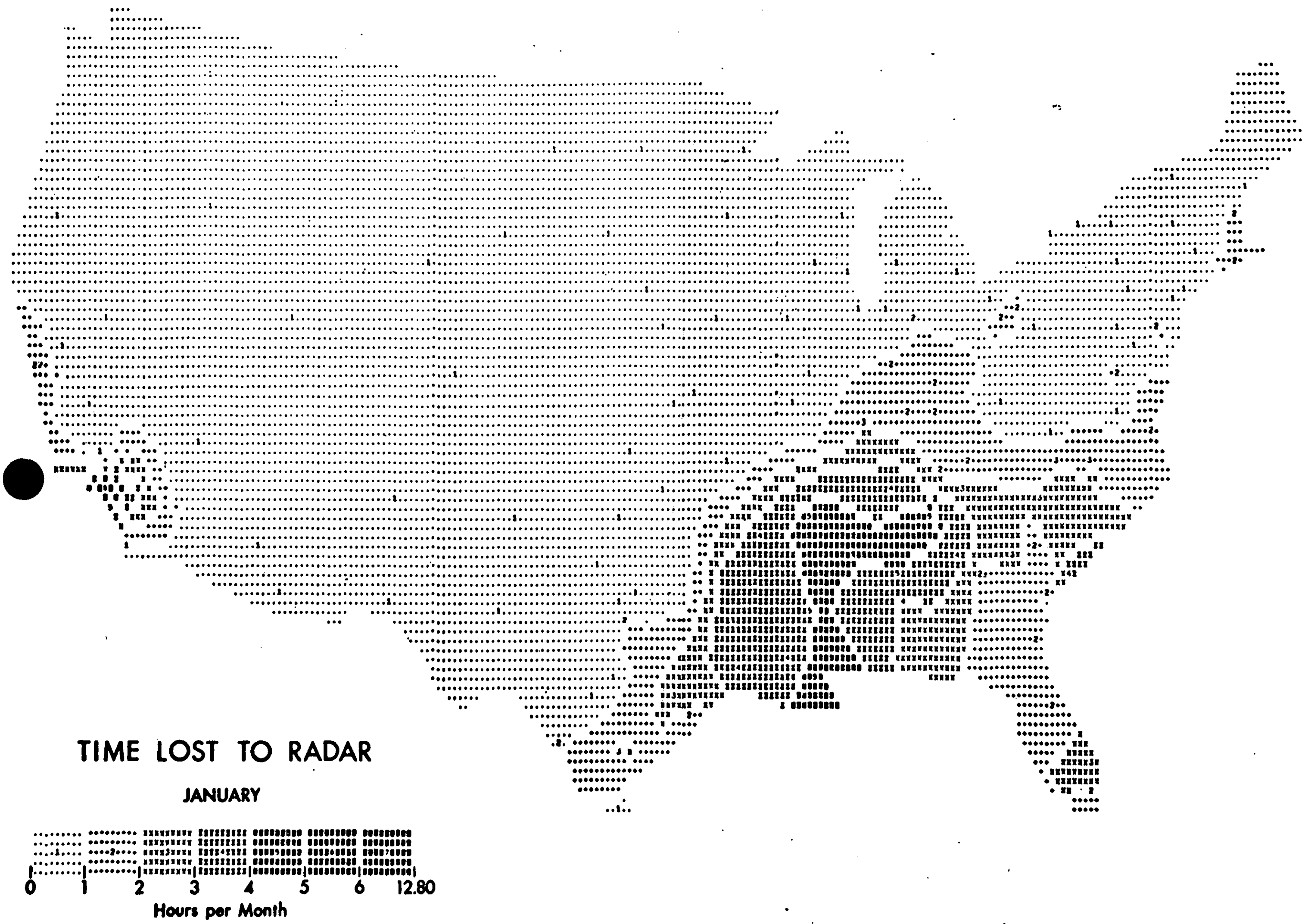


Figure 24. Time lost to radar in January.

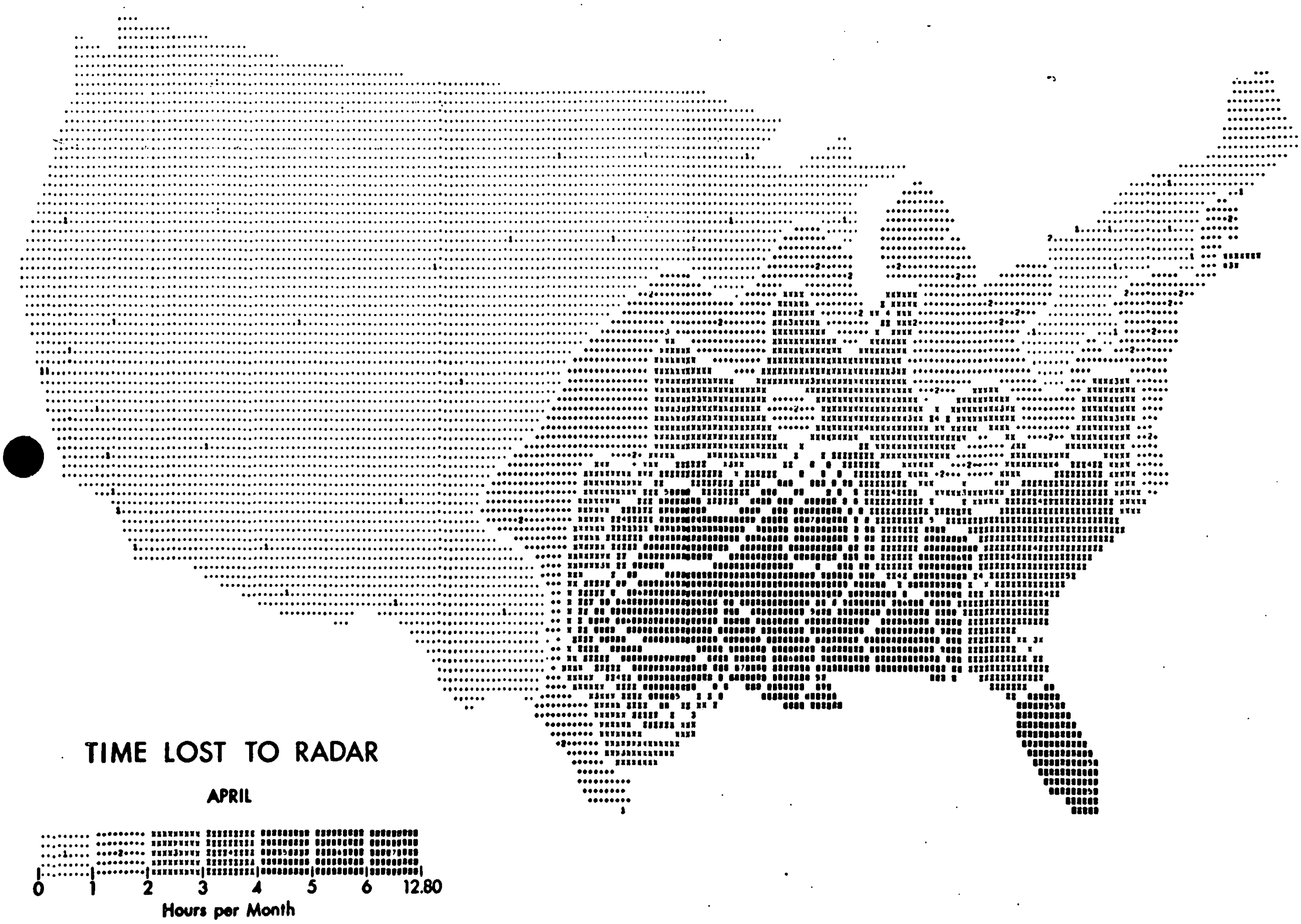


Figure 25. Time lost to radar in April.

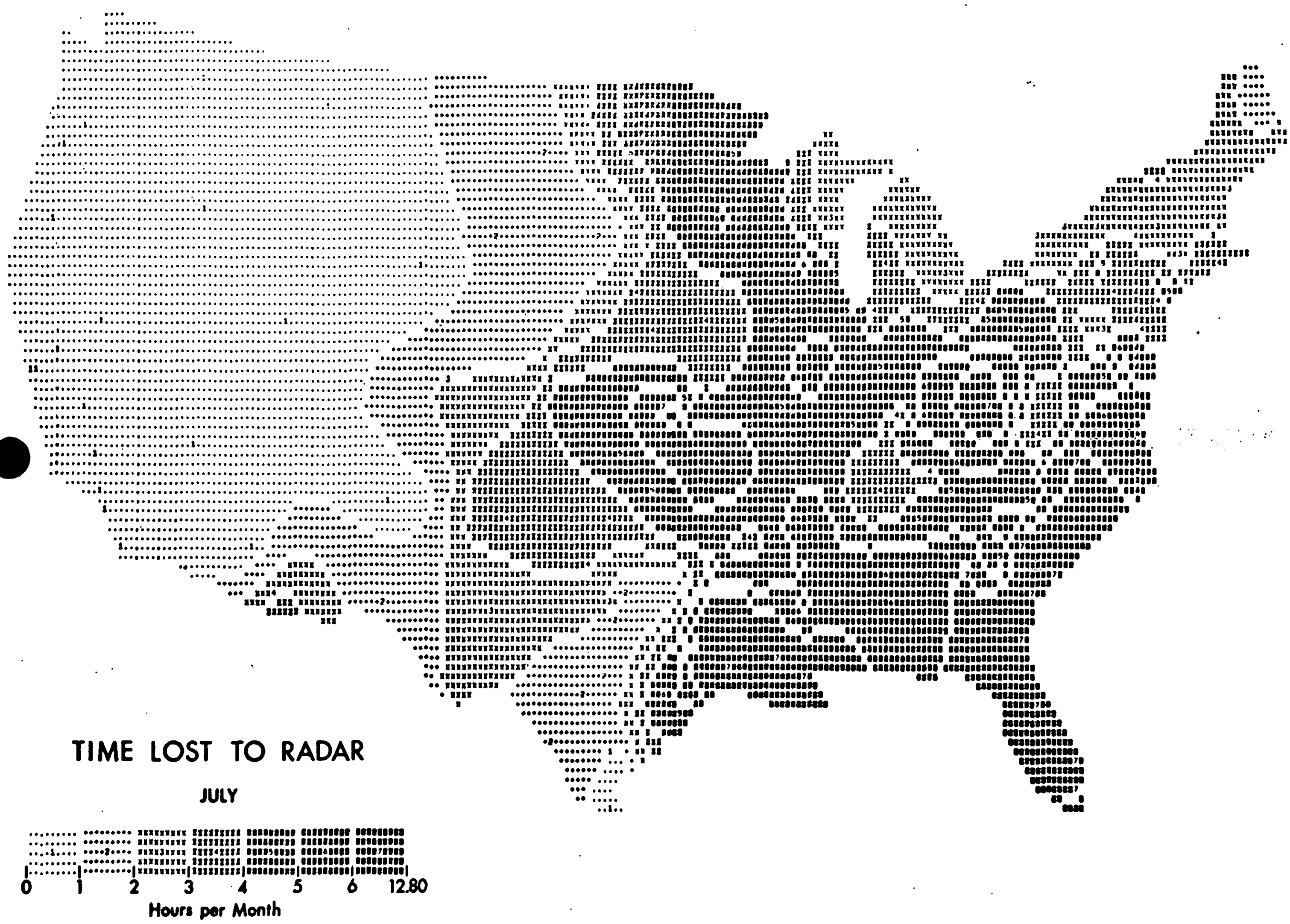


Figure 26. Time lost to radar in July.

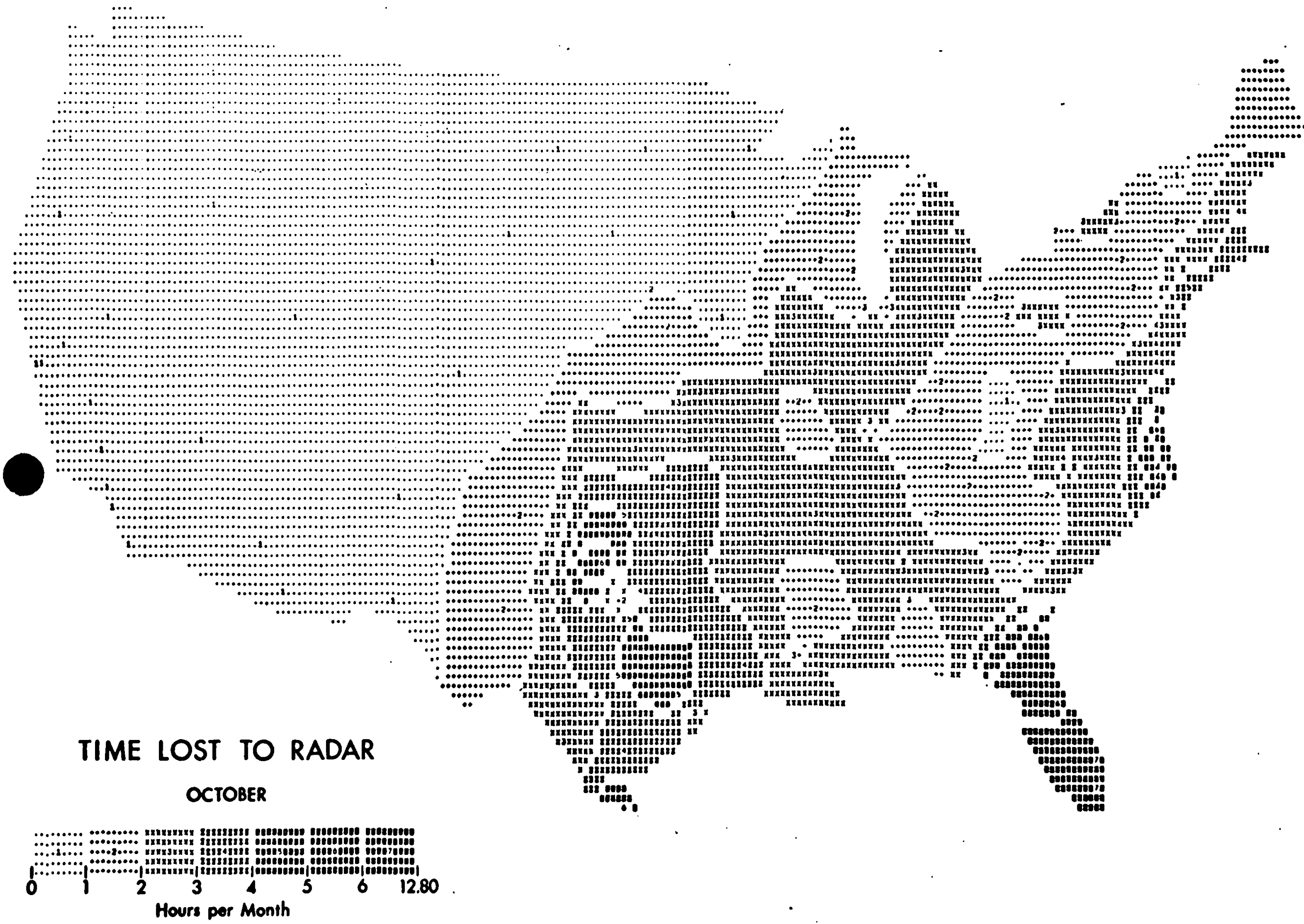


Figure 27. Time lost to radar in October.

Figure 20 for June was included to show, together with Figure 22 for August, the seasonal tilting of the bands representing regions of similar time available for aerial photography. The bands show distinct tilting from a winter pattern of east-west bands to a summer pattern of north-south bands.

Figures 21 gives the photographic hours for July. In the mid-latitudes of the northern hemisphere this is the month when the temperature at the earth-atmosphere interface is at a maximum. Except for the west coast, thunderstorm activity over the U.S. is also at a maximum. Total cloud cover, however, appears to be at a minimum. Note that the eastern half of the U.S. has the least time available to aerial photography and contains most of the heavy precipitation. Total variation of time available is at a maximum in July. Parts of the Gulf Coastal states have less than 5 per cent of the time available whereas the interior of California has 180-210 hours available which is about 30 per cent of the time.

Figure 23 for October is similar to the map for April. It is interesting that this is the clearest month in the Mississippi Delta area.

Figure 24 is the number of hours lost to radar for the month of January. Heavy precipitation activity and, therefore, time lost to radar imaging are confined to the lower Mississippi valley and the west coast of California. Nowhere in the U.S. can more than 6 hours (less than 1% of the time) be expected to be lost due to heavy precipitation.

Figure 25 for April indicates that precipitation intensities greater than .25 inch per hour have disappeared from the west coast. The heavy precipitation activity in the lower Mississippi valley has increased both in quantity and areal coverage. Maritime tropical air from the Gulf of Mexico is penetrating deep into the interior of the U.S. with attendant increase in precipitation amounts and intensities. The maximum computed time lost is 7.2 hours (exactly 1%) at Memphis, Tennessee.

Figure 26 is for July when the U.S. has the maximum development of precipitation intensities greater than .25 inches per hour. The maximum absolute value of 12.8 hours (<2%) was observed at Charleston, South Carolina. The whole eastern half of the United States is in the higher categories. The entire east coast from Florida to North Carolina appears in the highest (6 to 12.8 hours) category of hours lost. Several small nodes of this category appear in the interior of the U. S. (Topeka, Kansas and Charleston, West Virginia) as does the lower Mississippi valley. An unexpected area of high intensity rainfall appears in Arizona around Tucson where there are more than 4 hours unavailable for radar.

The last of this series, Figure 27, is for the month of October. For the first time the Mississippi valley does not dominate the map. Southern Florida and Texas are clearly the areas of the heaviest precipitation activity. The explanation probably lies in coastal penetration by hurricanes in October. The U. S. is in general experiencing a withdrawal of maritime tropical air and a decrease in thunderstorm and heavy precipitation activity.

The general patterns shown by these maps are the result of several factors. In general, the summer maps show a north-south banding. The western half is more favorable to both aerial photography and airborne radar imaging. This result was not unexpected, however, since clear skies and low precipitation are generally associated with increasing aridity. More thunderstorm activity might have been expected in the western U.S. but, at any one point, they occur only infrequently. In the southwest heavy precipitation has been observed which does not reach the ground. This phenomenon generally occurs in relatively arid regions and covers small areas. It can be expected, therefore, that occasionally, when flying long traverses over arid regions, a small portion of the ground may not be seen by radar.

The sequence of maps showing the number of hours per month available to aerial photography strongly reflect, in turn, the two variables used in the computation. The maps for January, April, and October show east-west banding which is a result of the low maximum altitude of the sun attained during the late fall to early spring part of the year. The non-parallelism of the bands is due to cloudiness but other than that the extent of freedom from clouds cannot be determined from the maps.

In the summer the amount of time the sun has an altitude of 30° or more is nearly a constant over the whole U.S. In fact, the sun has an altitude greater than 30° for about a half hour longer in the northern part of the U. S. than it does in the southern. This "constant solar illumination" means that the patterns on the maps are exclusively an indication of the occurrence of cloud covers of less than 30 per cent.

The sun actually attains its maximum altitude above the horizon at the time of summer solstice (June 21-22). The map for June shows a series of bands tilting generally southeast-northwest with the amount of time favorable for aerial photography increasing to the west. On the July map these bands are nearly north-south and by August they are again tilted southeast-northwest. The presence of this pattern in August as well as June suggests that freedom from clouds is at a maximum when the earth's surface and lower atmosphere are at the highest temperature rather than at the time of maximum insolation.

This series of maps shows, not unexpectedly, that over the United States more time is available to aerial photography in the summer than in the winter. Consequently, using the criteria for obtaining good aerial photographs as defined in this paper, and all other factors being equal, the summer is the preferred season for planning aerial photographic missions.

Conversely, since most of the U. S. receives its maximum precipitation both in amount and intensity in the summer, the winter is the best time for planning airborne radar imaging missions. However, this conclusion cannot be considered significant from a practical point of view, since no less than 98 per cent of the time is available for radar imaging for any month of the year.

## CONCLUSIONS

1. Many imaging missions involving both radar and photography will utilize the supportive capacities of each. In some instances photo-

graphy will be obtained over most of a project area, but more likely photography and radar together will generate the image base.

2. Synthetic aperture, X-band radar systems have a near all-weather capability for obtaining high contrast, high resolution imagery from space. The most severe weather limitation for these systems is precipitation intensity greater than .25 in/hr.

3. At viewing angles proposed for space-borne radar systems (22°-42°) 2-way path lengths through most cloud systems are between 7.5 and 15km. At shorter path lengths higher rainfall intensities are required for moderate to severe attenuation than longer path lengths.

4. Detailed comparisons of hours available to photography and radar by months have been made for the United States based on a sample of 129 stations. These indicate that little time is lost to an X-band radar over most of the U.S., except along the lower Mississippi valley. However, the ratios of time available are about 25:1 in favor of radar over photography in this region during July.

5. The amount of time during which precipitation intensities are high enough to cause 10db 2-way attenuation is on the order of a few per cent for very wet environments and as low as a few hundredths per cent for dry environments. Thus the time unavailable for radar is almost negligible.

6. Space photography is limited by cloud cover and by solar altitude. Average hourly observations of sky cover on a world scale are not readily obtainable. However, the study of United States data may be representative of much of the rest of the world between 30 and 50° latitude. These data show much more time available to photography during the summer than during the winter months.

7. In dry, cloud-free environments radar imagery is expected to be ancillary to photography because of the relatively high probability of obtaining high quality photographs.

8. In moderately cloudy environments throughout the world we anticipate that photography will complement imagery obtained by radar over large project areas simply because radar can obtain continuous coverage nearly all of the time. Also, when continental or comparable coverage is desired it is reasonable to regard photography as supplementary to radar because it will supply the necessary basis for extending inferences to radar imagery collected through continuous cloud.

9. In particularly difficult environments such as exist during the polar spring and tropical monsoon, radar doubtless will serve as the only reliable imaging system for either long range or critically timed studies. Photography has a very limited capability for obtaining acceptable imagery in these regions regardless of whether it is piece meal or synoptic, and the long delays in completing missions may render some of the imagery useless for comparative purposes.

## REFERENCES


American Society of Photogrammetry (1968), Manual of Color Aerial Photography. Washington, D. C.

American Society of Photogrammetry (1966), Manual of Photogrammetry, 3rd ed. Washington, D. C.

Austin, P. M. (1966), Frequency of occurrence of rain attenuation of 10db or greater at 10GC, Massachusetts Institute of Technology, Department of Meteorology, Defense Documentation Center, Defense Supply Agency, DDC No. AD 652-498.

Bird, J. B. and A. Morrison (1964), Space photography and its geographical applications, Geographical Review, 54(4), 463-486.

Bogachkov, N. I. (1962), The Effect of Haze on Aerial Color Photography. Translation, Foreign Technology Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

Bullock, P. (1956), Atmospheric haze in aerial photography, Photogrammetric Engineering, 22(5), 967-972.

Conway, H. M., S. L. May, and E. Armstrong (1963), The Weather Handbook. Conway Publications, Atlanta.

Çravet, H. R. (1968), Planning and operation of a color aerial photographic mission, in Manual of Color Aerial Photography, American Society of Photogrammetry, Washington, D. C.

Feldman, N. E. (1964), Estimates of communication satellite system degradation due to rain. Rand Corporation, Santa Monica, California.

Graham, L. C., et al. (1965), Coherent high-resolution radar interpretation and analysis techniques study, unclassified pages (26-29) in a classified report, Goodyear Aerospace Corp., DDC No. AD 355 237.

Greaves, J. R., P. E. Sherr, and A. H. Glaser (1969), Cloud cover statistics and their use in the planning of remote sensing missions, Remote Sensing of Environment, in press.

Harman, W. E. (1966), Aerial photography, in Manual of Photogrammetry, (M. M. Thompson, ed.), American Society of Photogrammetry, Falls Church, Virginia, vol. I and II, 195-242.

Haurwitz, B. and J. M. Austin (1944), Climatology. McGraw-Hill, New York.

Horvath, R., J. G. Braithwaite, and F. C. Polcyn (1969), Effects of atmospheric path on airborne multispectral sensors. Infrared and Optical Sensor Laboratory, Willow Run Laboratories, Institute of Science and Technology, University of Michigan, Ann Arbor, Michigan.

MacDonald, H. C. (1969), Geologic evaluation of radar imagery for Darien Province, Unpublished Ph. D. dissertation, University of Kansas. To be published as CRES Technical Report No. 133-7, Center for Research in Engineering Science, University of Kansas.

Medhurst, R. G. (1965), Rainfall attenuation of centimeter waves: Comparison of theory and measurement, in Transactions on Antennas and Propagation, IEEE, pp. 550-564.

Middleton, W. E. K. (1950), The attenuation of contrast by the atmosphere, Photogrammetric Engineering, 16(5), 663-672.

Moore, R. K. and D. S. Simonett (1967), Potential research and earth resource studies with orbiting radars: Result of recent studies. American Institute of Aeronautics and Astronautics Paper No. 67-767.

Moore, R. K. and D. S. Simonett (1967), Radar remote sensing in biology, Bioscience 7, 386.

Nassaw, J. J. (1959), Practical Astronomy, 2nd ed. McGraw-Hill, New York.

Pierson, W. J., B. B. Scheps, and D. S. Simonett (1965), Some applications of radar return data to the study of terrestrial and oceanic phenomena, in Scientific Experiments for Manned Orbital Flight, vol. 4, Am. Astronautical Society, pp. 87-137. NASA Contract NSR 17-004-003.

Schloss, M. (1962), Cloud cover of the USSR, Geographic Review, 52(3), 389-99.

Serebreny, S. M. and R. H. Blackmer, Jr. (1961), An investigation to establish the true nature of cloud cover, Stanford Research Institute, Contract No. AF19(604)-7312, AD 262 949.

Tupper, J. L. (1956), The influence of atmospheric haze on the quality of aerial photographs, Photogrammetric Engineering, 22(5), 907-911.

USAF Climatic Center (1964), Feasibility study for radar in a RACOM system, Report 4815, Air Weather Service (MATS), Washington, D. C.

U.S. Department of Commerce, Weather Bureau (1951-60), Climatology of the United States No. 82-40. Decennial Census of United States Climate - Summary of Hourly Observations. Government Printing Office, Washington, D. C.

## APPENDIX A

| Station Number | Station |
|---|---|
| 03813 | Macon, Georgia |
| 03820 | Augusta, Georgia |
| 03822 | Savannah, Georgia |
| 03927 | Fort Worth, Texas |
| 03928 | Wichita, Kansas |
| 04725 | Binghamton, New York |
| 12839 | Miami, Florida |
| 12841 | Orlando, Florida |
| 12842 | Tampa, Florida |
| 12844 | West Palm Beach, Florida |
| 12916 | New Orleans, Louisiana |
| 12918 | Houston, Texas |
| 12919 | Brownsville, Texas |
| 12920 | Laredo, Texas |
| 12921 | San Antonio, Texas |
| 12923 | Galveston, Texas |
| 12924 | Corpus Christi, Texas |
| 12944 | Galveston, Texas |
| 13722 | Raleigh, North Carolina |
| 13723 | Greensboro, North Carolina |
| 13737 | Norfolk, Virginia |
| 13739 | Philadelphia, Pennsylvania |
| 13740 | Richmond, Virginia |
| 13741 | Roanoke, Virginia |
| 13743 | Washington, D. C. |
| 13781 | Wilmington, Delaware |
| 13866 | Charleston, West Virginia |
| 13874 | Atlanta, Georgia |
| 13876 | Birmingham, Alabama |
| 13880 | Charleston, South Carolina |

| Station Number | Station |
|---|---|
| 13881 | Charlotte, North Carolina |
| 13882 | Chattanooga, Tennessee |
| 13883 | Columbia, South Carolina |
| 13889 | Jacksonville, Florida |
| 13891 | Knoxville, Tennessee |
| 13893 | Memphis, Tennessee |
| 13894 | Mobile, Alabama |
| 13895 | Montgomery, Alabama |
| 13897 | Nashville, Tennessee |
| 13941 | Lake Charles, Louisiana |
| 13956 | Jackson, Mississippi |
| 13957 | Shreveport, Louisiana |
| 13958 | Austin, Texas |
| 13959 | Waco, Texas |
| 13960 | Dallas, Texas |
| 13963 | Little Rock, Arkansas |
| 13966 | Wichita Falls, Texas |
| 13967 | Oklahoma City, Oklahoma |
| 13968 | Tulsa, Oklahoma |
| 13970 | Baton Rouge, Louisiana |
| 13988 | Kansas City, Missouri |
| 13994 | St. Louis, Missouri |
| 13995 | Springfield, Missouri |
| 13996 | Topeka, Kansas |
| 14732 | New York, New York |
| 14733 | Buffalo, New York |
| 14735 | Albany, New York |
| 14739 | Boston, Massachusetts |
| 14740 | Windsor Locks, Connecticut |
| 14742 | Burlington, Vermont |
| 14751 | Harrisburg, Pennsylvania |

| Station Number | Station |
|---|---|
| 14764 | Portland, Maine |
| 14765 | Providence, Rhode Island |
| 14768 | Rochester, New York |
| 14771 | Syracuse, New York |
| 14777 | Wilkes Barre, Pennsylvania |
| 14819 | Chicago, Illinois |
| 14820 | Cleveland, Ohio |
| 14821 | Columbus, Ohio |
| 14822 | Detroit, Michigan |
| 14826 | Flint, Michigan |
| 14827 | Fort Wayne, Indiana |
| 14830 | Grand Rapids, Michigan |
| 14837 | Madison, Wisconsin |
| 14839 | Milwaukee, Wisconsin |
| 14848 | South Bend, Indiana |
| 14852 | Youngstown, Ohio |
| 14895 | Akron, Ohio |
| 14898 | Green Bay, Wisconsin |
| 14913 | Duluth, Minnesota |
| 14914 | Fargo, North Dakota |
| 14922 | Minneapolis, Minnesota |
| 14923 | Moline, Illinois |
| 14933 | Des Moines, Iowa |
| 14936 | Huron, South Dakota |
| 14942 | Omaha, Nebraska |
| 14943 | Sioux City, Iowa |
| 23023 | Midland, Texas |
| 23042 | Lubbock, Texas |
| 23044 | El Paso, Texas |
| 23047 | Amarillo, Texas |
| 23050 | Albuquerque, New Mexico |

| Station Number | Station |
|---|---|
| 23062 | Denver, Colorado |
| 23152 | Burbank, California |
| 23155 | Bakersfield, California |
| 23160 | Tucson, Arizona |
| 23169 | Las Vegas, Nevada |
| 23174 | Los Angeles, California |
| 23183 | Phoenix, Arizona |
| 23185 | Reno, Nevada |
| 23188 | San Diego, California |
| 23230 | Oakland, California |
| 23232 | Sacramento, California |
| 23234 | San Francisco, California |
| 24011 | Bismarck, North Dakota |
| 24089 | Casper, Wyoming |
| 24090 | Rapid City, South Dakota |
| 24104 | Spokane, Washington |
| 24127 | Salt Lake City, Utah |
| 24131 | Boise, Idaho |
| 24143 | Great Falls, Montana |
| 24157 | Spokane, Washington |
| 24225 | Medford, Oregon |
| 24229 | Portland, Oregon |
| 24232 | Salem, Oregon |
| 24233 | Seattle, Washington |
| 93037 | Colorado Springs, Colorado |
| 93193 | Fresno, California |
| 93721 | Baltimore, Maryland |
| 93805 | Tallahassee, Florida |
| 93807 | Winston Salem, North Carolina |
| 93814 | Covington, Kentucky |
| 93815 | Dayton, Ohio |

| Station Number | Station |
|---|---|
| 93817 | Evansville, Indiana |
| 93819 | Indianapolis, Indiana |
| 93820 | Lexington, Kentucky |
| 93821 | Louisville, Kentucky |
| 93822 | Springfield, Illinois |
| 94789 | New York, New York |
| 94823 | Pittsburgh, Pennsylvania |
| 94846 | Chicago, Illinois |

## APPENDIX B
## TIME AVAILABLE TO AERIAL PHOTOGRAPHY

The numbers listed under each month are the average number of hours for that month during which the altitude of the sun is equal to or greater than 30° and the cloud cover is equal to or less than 30%.

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 3813 | 37.8 | 75.5 | 52.3 | 64.2 |
| 3820 | 35.3 | 80.7 | 64.0 | 73.8 |
| 3822 | 42.9 | 76.2 | 49.5 | 65.9 |
| 3927 | 31.9 | 63.7 | 121.3 | 79.3 |
| 3928 | 17.9 | 64.3 | 98.4 | 73.5 |
| 4725 | 0.1 | 38.8 | 39.1 | 29.6 |
| 12839 | 62.7 | 52.3 | 25.2 | 34.5 |
| 12841 | 58.8 | 64.9 | 58.4 | 54.9 |
| 12842 | 60.3 | 71.4 | 45.6 | 64.4 |
| 12844 | 50.1 | 48.6 | 44.0 | 34.3 |
| 12916 | 37.9 | 70.3 | 69.9 | 91.6 |
| 12918 | 34.2 | 49.4 | 37.1 | 70.6 |
| 12919 | 43.2 | 47.0 | 74.8 | 63.5 |
| 12920 | 51.1 | 67.2 | 118.1 | 76.6 |
| 12921 | 43.9 | 66.0 | 102.3 | 80.4 |
| 12923 | 37.5 | 56.2 | 69.2 | 82.4 |
| 12924 | 41.3 | 47.8 | 70.9 | 69.9 |
| 13722 | 28.5 | 75.4 | 77.3 | 71.0 |
| 13723 | 26.1 | 76.1 | 73.3 | 72.7 |
| 13737 | 19.7 | 74.0 | 80.0 | 64.3 |
| 13739 | 3.7 | 52.9 | 63.9 | 58.4 |
| 13740 | 15.1 | 61.2 | 72.4 | 64.0 |
| 13741 | 16.0 | 63.5 | 53.1 | 55.0 |
| 13743 | 7.4 | 63.6 | 79.8 | 66.3 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 13781 | 4.0 | 58.4 | 72.5 | 60.2 |
| 13866 | 5.1 | 41.7 | 37.1 | 47.4 |
| 13874 | 28.9 | 73.9 | 59.6 | 78.8 |
| 13876 | 25.8 | 66.3 | 47.0 | 73.7 |
| 13880 | 35.6 | 70.8 | 36.4 | 61.6 |
| 13881 | 29.4 | 77.0 | 61.5 | 73.8 |
| 13882 | 22.3 | 70.7 | 70.6 | 74.3 |
| 13883 | 37.0 | 90.9 | 74.7 | 79.6 |
| 13889 | 44.6 | 72.4 | 45.6 | 57.6 |
| 13891 | 18.0 | 68.6 | 75.5 | 69.7 |
| 13893 | 22.3 | 64.7 | 70.3 | 78.0 |
| 13894 | 39.3 | 71.7 | 36.8 | 86.4 |
| 13895 | 33.7 | 82.7 | 55.4 | 82.7 |
| 13897 | 16.6 | 62.6 | 67.0 | 72.4 |
| 13941 | 33.1 | 53.8 | 39.1 | 78.0 |
| 13956 | 27.6 | 73.5 | 68.5 | 81.4 |
| 13957 | 29.9 | 63.2 | 92.4 | 86.9 |
| 13958 | 39.1 | 64.6 | 90.4 | 82.7 |
| 13959 | 34.4 | 56.0 | 110.9 | 72.3 |
| 13960 | 17.8 | 67.3 | 117.7 | 83.5 |
| 13963 | 29.9 | 66.1 | 75.0 | 81.3 |
| 13966 | 30.9 | 79.7 | 117.9 | 75.7 |
| 13967 | 34.4 | 72.7 | 113.2 | 85.3 |
| 13968 | 25.6 | 65.3 | 95.7 | 78.8 |
| 13970 | 22.6 | 62.0 | 48.9 | 75.7 |
| 13985 | 50.1 | 78.3 | 113.0 | 94.5 |
| 13988 | 8.3 | 54.5 | 82.2 | 71.4 |
| 13994 | 7.0 | 50.4 | 72.7 | 68.8 |
| 13995 | 15.6 | 57.6 | 73.3 | 75.3 |
| 13996 | 8.2 | 54.7 | 83.3 | 71.0 |
| 14732 | 2.9 | 54.4 | 72.8 | 55.2 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 14733 | 0.0 | 43.5 | 83.3 | 38.1 |
| 14734 | 1.9 | 53.5 | 71.4 | 57.3 |
| 14735 | 0.0 | 40.0 | 61.1 | 38.9 |
| 14739 | 0.0 | 55.7 | 72.5 | 46.9 |
| 14740 | 0.2 | 52.2 | 45.4 | 47.3 |
| 14742 | 0.0 | 48.0 | 51.7 | 30.6 |
| 14751 | 3.9 | 49.4 | 73.4 | 56.7 |
| 14764 | 0.0 | 52.3 | 72.1 | 47.3 |
| 14765 | 1.1 | 58.4 | 72.8 | 54.3 |
| 14768 | 0.0 | 46.7 | 76.9 | 33.9 |
| 14771 | 0.0 | 42.5 | 72.9 | 36.4 |
| 14777 | 1.0 | 48.0 | 57.1 | 48.2 |
| 14819 | 0.2 | 52.6 | 80.5 | 53.5 |
| 14820 | 0.4 | 42.4 | 84.0 | 49.0 |
| 14821 | 2.2 | 42.7 | 68.3 | 58.2 |
| 14822 | 0.0 | 47.7 | 87.4 | 52.8 |
| 14826 | 0.0 | 39.9 | 76.6 | 41.3 |
| 14827 | 1.1 | 40.3 | 69.4 | 58.3 |
| 14830 | 0.0 | 46.3 | 80.0 | 43.6 |
| 14837 | 0.0 | 56.5 | 76.5 | 51.4 |
| 14839 | 0.0 | 55.3 | 97.2 | 51.4 |
| 14848 | 0.5 | 42.6 | 74.7 | 56.1 |
| 14852 | 0.8 | 40.5 | 69.9 | 50.8 |
| 14895 | 0.8 | 37.6 | 72.3 | 52.4 |
| 14898 | 0.0 | 54.0 | 80.3 | 41.0 |
| 14913 | 0.0 | 51.2 | 74.4 | 27.9 |
| 14914 | 0.0 | 51.5 | 100.4 | 35.7 |
| 14922 | 0.0 | 64.1 | 100.7 | 48.0 |
| 14923 | 1.0 | 59.9 | 82.9 | 62.4 |
| 14933 | 0.9 | 51.3 | 79.5 | 59.8 |
| 14936 | 0.0 | 53.3 | 120.2 | 54.8 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 14942 | 0.9 | 59.7 | 105.3 | 65.4 |
| 14943 | 0.0 | 59.9 | 102.9 | 59.3 |
| 23023 | 48.8 | 91.8 | 105.4 | 80.3 |
| 23042 | 42.6 | 87.6 | 114.4 | 81.9 |
| 23044 | 55.2 | 117.8 | 119.9 | 108.7 |
| 23047 | 40.0 | 90.5 | 114.2 | 97.9 |
| 23050 | 41.6 | 96.7 | 134.0 | 103.0 |
| 23062 | 6.2 | 57.8 | 115.3 | 74.3 |
| 23152 | 41.0 | 88.4 | 182.5 | 101.5 |
| 23155 | 21.2 | 95.2 | 193.6 | 103.4 |
| 23160 | 52.2 | 122.5 | 127.8 | 112.7 |
| 23169 | 34.0 | 119.1 | 159.2 | 103.9 |
| 23174 | 39.0 | 87.5 | 156.5 | 91.7 |
| 23183 | 46.5 | 118.2 | 146.4 | 115.0 |
| 23185 | 6.6 | 80.3 | 161.9 | 80.6 |
| 23188 | 46.4 | 91.6 | 150.4 | 102.5 |
| 23230 | 9.6 | 84.7 | 151.8 | 85.5 |
| 23232 | 7.0 | 90.8 | 204.4 | 101.1 |
| 23234 | 12.2 | 82.9 | 168.7 | 89.1 |
| 24011 | 0.0 | 49.9 | 111.8 | 33.3 |
| 24089 | 0.0 | 47.1 | 126.2 | 53.6 |
| 24090 | 0.0 | 47.7 | 120.1 | 55.0 |
| 24127 | 1.3 | 63.8 | 151.5 | 77.2 |
| 24131 | 0.0 | 63.0 | 174.0 | 53.8 |
| 24143 | 0.0 | 44.5 | 145.1 | 30.0 |
| 24157 | 0.0 | 45.5 | 150.5 | 25.3 |
| 24225 | 0.0 | 51.1 | 192.7 | 50.6 |
| 24229 | 0.0 | 39.7 | 119.2 | 30.3 |
| 24232 | 0.0 | 34.7 | 144.2 | 29.0 |
| 24233 | 0.0 | 36.4 | 108.8 | 16.3 |
| 93037 | 12.1 | 62.9 | 110.1 | 69.1 |
| 93193 | 12.3 | 99.6 | 205.3 | 110.8 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 93721 | 7.0 | 59.1 | 76.2 | 61.5 |
| 93805 | 40.2 | 54.7 | 25.4 | 60.2 |
| 93807 | 28.7 | 78.4 | 67.2 | 61.4 |
| 93814 | 4.7 | 45.6 | 77.2 | 65.9 |
| 93815 | 2.4 | 41.3 | 76.0 | 57.2 |
| 93817 | 9.4 | 54.4 | 78.1 | 77.2 |
| 93819 | 4.2 | 43.0 | 69.1 | 63.7 |
| 93820 | 9.6 | 44.6 | 59.7 | 61.9 |
| 93821 | 8.3 | 54.9 | 79.8 | 71.6 |
| 93822 | 3.7 | 54.7 | 79.2 | 69.8 |
| 94789 | 3.0 | 54.1 | 77.2 | 58.0 |
| 94823 | 1.5 | 32.9 | 41.7 | 44.7 |
| 94846 | 0.2 | 48.9 | 69.2 | 51.6 |

APPENDIX C

HOURS LOST TO RADAR

The numbers listed under each month are the average number of hours for that month that precipitation intensity equaled or exceeded .25 inches per hour.

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 3813 | 1.6 | 3.0 | 6.2 | 2.2 |
| 3820 | 2.2 | 3.6 | 4.1 | 1.0 |
| 3822 | 1.0 | 3.9 | 8.7 | 2.8 |
| 3927 | 0.4 | 5.6 | 2.4 | 1.6 |
| 3928 | 0.2 | 1.7 | 4.4 | 2.2 |
| 4725 | 0.0 | 0.2 | 4.2 | 1.8 |
| 12839 | 1.9 | 4.8 | 6.0 | 8.7 |
| 12841 | 1.2 | 4.8 | 7.2 | 5.8 |
| 12844 | 2.8 | 4.6 | 7.4 | 8.2 |
| 12916 | 4.6 | 4.7 | 8.0 | 2.6 |
| 12918 | 2.3 | 4.5 | 5.0 | 4.1 |
| 12919 | 0.6 | 0.9 | 0.7 | 5.3 |
| 12920 | 1.0 | 1.2 | 1.8 | 2.4 |
| 12921 | 0.7 | 2.1 | 1.8 | 2.9 |
| 12924 | 2.0 | 2.3 | 0.9 | 3.5 |
| 12944 | 1.8 | 2.1 | 4.5 | 2.8 |
| 13722 | 2.0 | 3.4 | 6.3 | 2.4 |
| 13723 | 2.0 | 3.3 | 5.3 | 3.3 |
| 13737 | 1.8 | 1.4 | 5.6 | 5.2 |
| 13739 | 1.0 | 1.2 | 3.9 | 2.2 |
| 13740 | 0.7 | 2.5 | 5.5 | 2.9 |
| 13741 | 0.6 | 1.4 | 3.0 | 2.4 |
| 13743 | 1.0 | 2.4 | 4.5 | 2.2 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 13866 | 0.8 | 2.2 | 7.0 | 0.8 |
| 13874 | 3.5 | 5.0 | 5.7 | 2.1 |
| 13876 | 4.0 | 3.6 | 5.5 | 2.9 |
| 13880 | 3.4 | 4.0 | 12.8 | 2.4 |
| 13881 | 2.1 | 3.8 | 4.6 | 1.7 |
| 13882 | 4.4 | 4.2 | 4.5 | 1.8 |
| 13883 | 1.8 | 3.6 | 7.6 | 1.8 |
| 13889 | 1.4 | 2.8 | 8.9 | 5.9 |
| 13891 | 2.7 | 2.9 | 4.3 | 1.4 |
| 13893 | 4.3 | 7.1 | 5.3 | 2.2 |
| 13895 | 3.0 | 5.5 | 5.2 | 2.0 |
| 13897 | 3.8 | 3.4 | 3.3 | 2.1 |
| 13941 | 3.7 | 6.6 | 8.5 | 3.5 |
| 13956 | 4.0 | 4.9 | 5.1 | 1.6 |
| 13958 | 0.8 | 3.5 | 1.5 | 4.1 |
| 13959 | 1.2 | 5.4 | 1.4 | 4.4 |
| 13960 | 0.7 | 5.4 | 1.3 | 3.2 |
| 13963 | 3.5 | 5.4 | 3.9 | 2.1 |
| 13966 | 0.2 | 2.6 | 3.0 | 5.8 |
| 13967 | 0.4 | 3.2 | 3.6 | 4.0 |
| 13968 | 0.6 | 4.6 | 4.6 | 3.9 |
| 13970 | 3.6 | 5.5 | 7.7 | 2.0 |
| 13988 | 0.1 | 2.6 | 4.2 | 2.5 |
| 13994 | 0.4 | 1.6 | 4.3 | 1.8 |
| 13995 | 0.5 | 2.9 | 5.8 | 2.9 |
| 13996 | 0.3 | 2.2 | 6.1 | 2.1 |
| 14732 | 0.4 | 1.6 | 4.4 | 4.1 |
| 14733 | 0.4 | 1.0 | 2.2 | 1.5 |
| 14734 | 0.5 | 1.5 | 3.6 | 2.6 |
| 14735 | 0.1 | 0.5 | 2.6 | 1.6 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 14739 | 1.1 | 1.8 | 2.9 | 3.0 |
| 14740 | 0.6 | 0.8 | 2.8 | 2.4 |
| 14742 | 0.0 | 0.2 | 3.0 | 0.8 |
| 14751 | 0.4 | 0.8 | 2.5 | 1.4 |
| 14764 | 0.6 | 0.8 | 2.2 | 2.2 |
| 14765 | 1.3 | 2.5 | 3.8 | 3.7 |
| 14768 | 0.0 | 0.5 | 2.1 | 2.1 |
| 14771 | 0.0 | 0.9 | 2.5 | 2.0 |
| 14777 | 0.6 | 1.4 | 3.2 | 1.2 |
| 14819 | 0.3 | 1.7 | 4.9 | 2.0 |
| 14820 | 0.7 | 1.6 | 3.6 | 1.7 |
| 14821 | 1.7 | 1.5 | 5.0 | 1.0 |
| 14822 | 0.1 | 1.7 | 2.5 | 2.1 |
| 14827 | 1.0 | 1.7 | 4.3 | 2.2 |
| 14830 | 0.0 | 1.8 | 3.1 | 2.2 |
| 14837 | 0.1 | 1.8 | 5.0 | 1.6 |
| 14839 | 0.1 | 1.4 | 4.0 | 1.7 |
| 14848 | 0.6 | 3.4 | 3.6 | 2.0 |
| 14852 | 1.1 | 1.8 | 4.9 | 2.1 |
| 14895 | 1.2 | 1.3 | 4.6 | 1.4 |
| 14898 | 0.0 | 0.6 | 2.6 | 1.2 |
| 14913 | 0.0 | 0.7 | 4.9 | 0.3 |
| 14914 | 0.0 | 0.5 | 4.1 | 0.1 |
| 14922 | 0.0 | 0.1 | 5.0 | 0.7 |
| 14923 | 0.3 | 2.4 | 4.5 | 2.6 |
| 14933 | 0.6 | 1.1 | 3.2 | 0.6 |
| 14936 | 0.1 | 0.1 | 1.4 | 0.4 |
| 14942 | 0.0 | 2.1 | 3.2 | 1.2 |
| 14943 | 0.0 | 1.2 | 3.3 | 1.0 |
| 23023 | 0.0 | 0.0 | 2.2 | 1.8 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 23044 | 0.0 | 0.0 | 1.8 | 0.5 |
| 23047 | 0.1 | 1.2 | 3.4 | 1.5 |
| 23050 | 0.0 | 0.0 | 0.8 | 0.7 |
| 23062 | 0.0 | 0.1 | 2.0 | 0.3 |
| 23152 | 5.5 | 0.2 | 0.0 | 0.3 |
| 23155 | 0.2 | 0.6 | 0.0 | 0.4 |
| 23160 | 0.4 | 0.0 | 3.0 | 0.2 |
| 23169 | 0.0 | 0.0 | 0.6 | 0.2 |
| 23174 | 4.6 | 0.8 | 0.0 | 0.0 |
| 23183 | 0.0 | 0.2 | 0.6 | 0.6 |
| 23185 | 0.0 | 0.0 | 0.2 | 0.0 |
| 23188 | 0.7 | 0.5 | 0.0 | 0.0 |
| 23230 | 1.3 | 0.5 | 0.0 | 0.1 |
| 23232 | 0.6 | 0.8 | 0.0 | 0.0 |
| 23234 | 1.8 | 0.5 | 0.0 | 0.2 |
| 24011 | 0.0 | 0.1 | 1.7 | 0.0 |
| 24089 | 0.0 | 0.4 | 0.2 | 0.0 |
| 24090 | 0.0 | 0.0 | 1.4 | 0.0 |
| 24104 | 0.0 | 0.0 | 0.4 | 0.1 |
| 24127 | 0.0 | 0.3 | 0.4 | 0.0 |
| 24131 | 0.0 | 0.2 | 0.2 | 0.0 |
| 24143 | 0.0 | 0.2 | 0.8 | 0.0 |
| 24225 | 0.1 | 0.1 | 0.2 | 0.6 |
| 24229 | 0.3 | 0.1 | 0.1 | 0.8 |
| 24232 | 1.0 | 0.2 | 0.0 | 0.6 |
| 93193 | 0.3 | 0.5 | 0.0 | 0.0 |
| 93721 | 0.7 | 1.8 | 5.4 | 2.3 |
| 93814 | 1.3 | 1.7 | 5.2 | 1.8 |
| 93815 | 1.9 | 1.5 | 3.8 | 1.2 |
| 93817 | 2.0 | 3.0 | 4.3 | 2.0 |

| Station Number | January | April | July | October |
|---|---|---|---|---|
| 93819 | 1.1 | 2.1 | 4.3 | 2.6 |
| 93820 | 1.2 | 3.2 | 5.4 | 1.6 |
| 93821 | 1.7 | 2.0 | 3.9 | 1.8 |
| 93822 | 0.3 | 2.4 | 5.3 | 2.4 |
| 94823 | 0.4 | 0.6 | 4.8 | 2.0 |

# APPENDIX D

## FORTRAN IV COMPUTER PROGRAM

```
C       TIME AVAILABLE FOR AERIAL PHOTOGRAPHY
C       SUN ALTITUDE GREATER THAN 30 DEGREES
        DIMENSION HRS(30), DES(30,12), DESM(30,12), CLD(24)
        DOUBLE  PRECISION CSOT, ACSOT
        CSUNA = .50
        READ (5,2) ((DES(I,J),DESM(I,J), I = 1,30), J = 1,12
      1 FORMAT (F4.1)
      2 FORMAT (2F3.0)
        DO 3 I = 1,30
        DO 3 JJ = 1,12
        DESG = DESM(I,JJ)/60.
      3 DES(I,JJ) = (DES(I,JJ) + DESG) * 0.01745329252
        DO 15 N=1,140
        READ (5,1) DLAT
        ALAT = DLAT * 0.01745329252
        DO 15 J = 1,12
        IF ( J.EQ. 1) HRMO = 7.44
        IF ( J .EQ. 2) HRMO = 6.78
        IF ( J .EQ. 3) HRMO = 7.44
        IF ( J .EQ. 4) HRMO = 7.20
        IF ( J .EQ. 5) HRMO = 7.44
        IF ( J .EQ. 6) HRMO = 7.20
        IF ( J .EQ. 7) HRMO = 7.44
        IF ( J.EQ. 8) HRMO = 7.44
        IF ( J .EQ. 9) HRMO = 7.20
        IF ( J.EQ. 10) HRMO = 7.44
        IF (J.EQ. 11) HRMO = 7.20
        IF (J.EQ. 12) HRMO = 7.44
```

```
      DO 4 I = 1,30
      CSOT = (CSUNA - SIN(ALAT)*SIN(DES(I,J)))/COS(ALAT)*COS(DES(I,J)))
      IF (CSOT.GT. 1.0) CSOT = 1.0
      ACSOT = (1.-CSOT*CSOT)/CSOT
      HANGLE = ATAN(SQRT(ABS(ACSOT)))
      ANGLE = HANGLE * 2. * 57.295779513
      IF (ACSOT .LT. 0.) ANGLE = ( 360.-ANGLE)
    4 HRS(I) = ANGLE/15.
      SUMHRS = 0.
      DO 5 I = 1,30
    5 SUMHRS = SUMHRS + HRS(I)
      AVEHRS = SUMHRS/30.
      NHRS = AVEHRS
      IF (NHRS.LE. 1) NHRS = 2
      IF (NHRS .EQ. 3) NHRS = 4
      IF ( NHRS .EQ. 5) NHRS = 6
      IF ( NHRS .EQ. 7) NHRS = 8
      IF ( NHRS .EQ. 9) NHRS = 10
      IEND = (24-NHRS)/2
      DO 6 I = 1,IEND
    6 READ (1,7) NOSTA
    7 FORMAT (I5)
      IF(NHRS .EQ. 0) GO TO 14
      DO 8 I = 1, NHRS
    8 READ (1,9) NOSTA, TOBS, CLD(I)
    9 FORMAT (I5,4X,F3.0,F3.0)
      SCLD = 0.
      DO 10 I = 1, NHRS
   10 SCLD = SCLD + CLD(I)
      PCTIME = (SCLD/(TOBS * FLOAT(NHRS)))*100.
      GO TO 17
   14 PCTIME = 0.
   17 DO 11 I = 1,IEND
```

```
11 READ (1,7) NOSTA
   PCTPH = 0.0416666667 * PCTIME * AVEHRS
   HRSPH = PCTPH * HRMO
   WRITE (43,12) J , NOSTA, HRSPH
12 FORMAT (I2, 1X, I7, F10.1)
   WRITE(6,13) J, NOSTA, PCTPH, HRSPH, NHRS, AVEHRS
13 FORMAT (I5, 5X, I7, 2F20.1, I20, F20.1)
15 CONTINUE
16 STOP
   END
```

## APPENDIX E
## FORTRAN IV COMPUTER PROGRAM

```
C         TIME LOST TO RADAR IMAGING
C         PRECIPITATION INTENSITIES GREATER THAN .25 INCHES / HOUR
          DIMENSION FREP(96), YRS(141), DUMMY (232)
          READ (5,5) (YRS(I), I = 1,124
        5 FORMAT (40F2.0)
          REWIND 1
          DO 10 M = 1,12
          IF (M.EQ.1) IR = 8
          READ (1,2) (DUMMY(I), I = 1,IR)
          HRS = 744.0
          IF (M.EQ.2) HRS = 678
          IF (M.EQ. 4) HRS = 720
          IF (M.EQ. 6) HRS = 720
          IF (M.EQ. 9) HRS = 720
          IF (M.EQ.11) HRS = 720
        2 FORMAT (9X,F1.0)
          DO 1 N = 1,124
          READ (1,3) NOSTA, (FREP(J), J = 1,12)
        3 FORMAT (I6, 7X, 12F3.0)
          READ (1,6) (FREP(J), J = 13,96)
        6 FORMAT (13X, 12F3.0)
          IF (NOSTA.EQ.94823)GO TO 9
          READ (1,2) (DUMMY(I), I = 1,226
        9 SUMFP = 0.
          DO 4 I = 1,96
        4 SUMFP = SUMFP + FREP(I)
          X = SUMFP / YRS(N)
          TRPC = ((HRS = X) / HRS) * 100.
```

```
      TRHR = HRS = X
    7 FORMAT (4X, I5, F11.1)
      WRITE (43,7) NOSTA, X
      WRITE (6,8) NOSTA, TRPC, TRHR, X
    8 FORMAT (I10, 3F20.1)
    1 CONTINUE
      IR = IR + 18
      REWIND 1
   10 CONTINUE
      STOP
      END
```

APPENDIX 5

# CROP-TYPE DISCRIMINATION WITH COLOR INFRA RED PHOTOGRAPHY: PRELIMINARY RESULTS IN DOUGLAS COUNTY, KANSAS

IA-NASA-174

# CROP-TYPE DISCRIMINATION WITH COLOR INFRA RED PHOTOGRAPHY: PRELIMINARY RESULTS IN DOUGLAS COUNTY, KANSAS

by

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TABLE OF CONTENTS

## INTRODUCTION

The feasibility of producing crop distribution maps, along with other types of thematic land use maps from spacecraft is under active study at the University of Kansas. These studies resemble, in part, those underway on a much larger scale at Purdue University. However, we are concerned primarily with defining and analyzing: 1) the nature of geographic decay functions for crop identification with distance from a training set; 2) the local and regional character of time-dependencies in training and prediction studies; 3) the problems of map production using either a three-layer color infrared photography or a three-channel return-beam vidicon system comparable to that proposed for an early ERS or EROS type satellite. There are many constraints in producing thematic maps with false color photographs or, indeed, with <u>any</u> sensor. These include determining whether consistently detectable, and usable, differences exist between the crops being studied in order to discriminate between them. Time of planting, varieties planted, crop conditions as a function of time of planting, soil type, and irrigation practices, are only a few of the complexities one encounters which make for imperfect predictions and inconsistencies of various types. No two areas, however closely spaced, are identical in all of these respects. Further, it is already well known that not all months during the growing cycle enable acceptable discrimination to be made between crops. The study reported takes only one month during the growing season (July) for analysis. Samples earlier and later in the growing season will be investigated in due course, so that the annual cycle of detectability and discrimination between crops becomes evident.

The present study involves a simulation of detectability and discrimination using resolutions obtained with a coarse-spot densitometer which are closely akin to those to be obtained with spacecraft photography. In addition the aerial ektachrome infrared photography is the same as that flown in the recent SO 65 experiment on Apollo 9 and covers essentially the same wavelength bands as that of the three-channel system proposed for EROS. The study area includes portions of Douglas County, Kansas as shown in Figure 1. Color infrared photography (Kodak Type 8443) was obtained by NASA/MSC Mission 54, July 31, 1967.

## DATA AVAILABLE

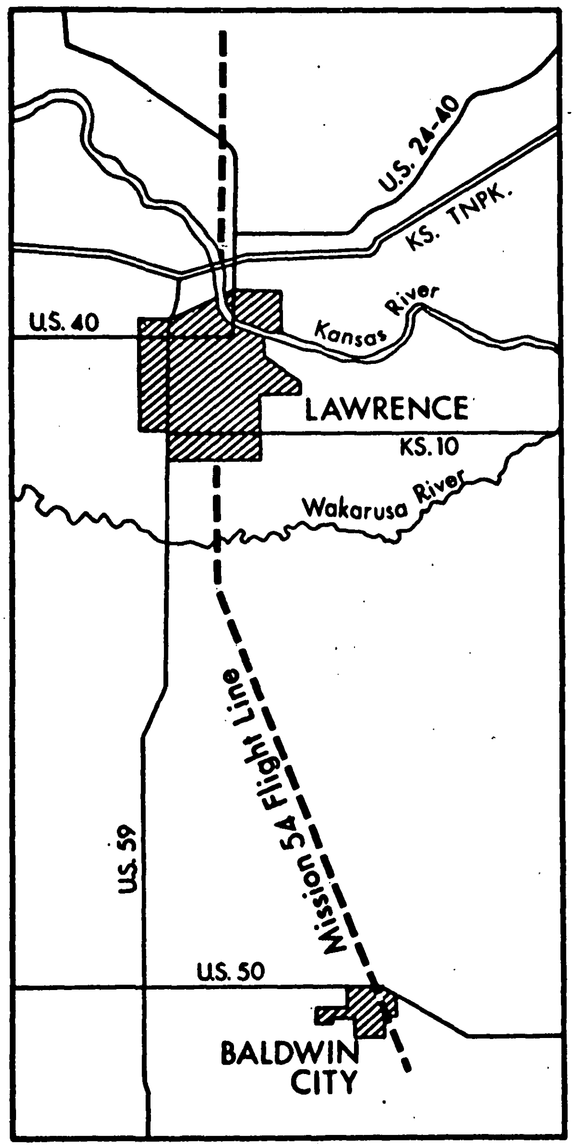
To obtain quantitative results with the 9 x 9 color infrared photograph transparencies, several steps are involved. Since each is both time and labor consuming, they are briefly discussed with their inherent problems.

### Ground Truth

Ground truth data is available for approximately 550 fields. Of these some 212 are used as a basis for the present report. Densitometer readings are being made on the remaining fields. Since many of the fields overlap frames of photography, and there were two flight altitudes of 7,000 and 11,000 feet the number of fields available is at least double for training and prediction. By the end of June 1969, all fields will have been processed providing a considerably larger data set than is presently available.

### Densitometry

Transmittance for the three dye layers of the Ektrachrome infrared film is being measured for each field for which crop-type data is available, using a standard spot-reading densitometer (MacBeth Quantalog model EP-1000) with a 1 millimeter aperture. Readings were made using standard Wratten 47 B, 92 and 99 filters in the densitometer, which correspond closely with the spectral response of the three color emulsion layers of normal Ektachrome color photographic film. By using these filters developed with Ektachrome infrared film we can very crudely, but acceptably for our purposes here "simulate" multi-band photography employing discrete bands in the green, red, and near infrared regions.




Scale 1:250,000

Figure 1. The study area lies along the Mission 54 Flight Line between Baldwin City and Lawrence, and north of Lawrence.

We originally intended to use a scanning densitometer in these studies. However, the scanning densitometer being built at CRES is not yet operational. Consequently, our densitometry with the Quantalog, consists of five spot readings in each color band (blue, green, red, corresponding crudely to the response in the green, red and near infrared regions) for each field, with the spots distributed fairly evenly across the field. This distribution is random, yet subjective to the densitometer operator.

At present, 212 fields have been processed with the densitometer. Our preliminary results are based on this set of data.

The ground resolution in these experiments using the spot-densitometer is comparable to that expected from spacecraft photography. Using a 1 millimeter aperture in the spot-densitometer, the ground area illuminated on the film of 1:14,000 scale is approximately 46 feet; on the film of 1:22,000 scale, this area is approximately 72 feet.

Land Use Categories

All crops in this study have been grouped into 10 preliminary categories as follows: corn, sorghum, wheat, soybeans, oats, alfalfa, red clover, brome, pasture, and hay. Hay is a "catch-all", covering a number of crops planted for hay-making. Pasture also is a catch-all, which includes both natural grasslands, such as bluestem, and cultivated and improved brome and other grasses.

This classification has several problems, the most important of which is the lumping of all varieties of a given crop together. At least three varieties of corn, half a dozen of sorghum, and several of wheat, are only examples of the diversity of crop varieties as well as crop types found in the study area. When a number of varieties of several crops are present, each with their own phenology which produces hastening or delay of important stages in growth it is naturally more difficult to discriminate between crops when there is built in, through varietal differences, substantial within-class variance. To put this in another way, wheat in Texas is NOT the same as wheat in Kansas both because the varieties are different, and the total milieu and phenology is different. It is also true that wheat at one end of a small study transect is not the same as wheat at the other end, let alone 10 to 20 miles away. This study, however, considers all varieties of a given crop as the same and it is thus assumed that substantial differences between varieties of a single crop do not exist. To the degree that this assumption is invalid it will be reflected in our ability to discriminate given crop categories accurately.

### Other Factors

There are many other factors which can and will be considered more specifically in later analysis of the data. These include: (a) sun angle: sun altitude and azimuth calculations have already been made for each frame of photography; (b) distance of field from center of photograph -- uneven illumination is present with increasing distance from the center of the photograph partly as a consequence of foreshadowing and backshadowing of reflected light on the illuminated photographs, and partly as a consequence of some unremoved vignetting.

## PRELIMINARY RESULTS

Preliminary results of identifying agricultural crop-types have been obtained using 1060 data points, or 212 fields. Although detailed analysis has not been made, these results are summarized in the following comments and summary table (Table 1).

Pattern recognitions were made by Baye's decision rules on this data. Robert Haralick wrote the necessary computer program and processed the data for us.

### Experiment 1

The first experiment to distinguish crop-types quantized the data in 10 categories, thus accounting for the probability distribution of observations in each category of crop-type (wheat, oats, soybean, corn, milo, pasture, alfalfa, brome, red clover, and hay). Half of the data (530 data points) were taken, and these data were used both to train and then classify crop-types into the 10 given categories. A level of correct identification of .51 was obtained indicating that there is considerable overlap in the three-dimensional probability distributions. By collapsing this data into four categories (wheat and oats; soybeans; corn and milo; pasture, alfalfa, brome, red clover and hay) based on considerations of crop generic similarities and not how the sensor would have grouped them based on spectral reflectance, the resulting probability of correct crop-group classification was .66 .

In the same experiment, half (530) of the data points were used to train and the other half to classify into 10 crop-type categories; the result was correct classification of 76 data points out of 530, or a probability of .12 . At four levels of categorization using this process, the resulting probability for correct classification was .38 .

Experiment 2

The second experiment normalized the 10 crop-type categories so that each category had an equal probability distribution regardless of the number of data points per crop-type category. In other words, all crop-type categories were weighted equally. There were 90 unique points in this quantized data. Using the same data to train and classify (530 data points) the resulting probability of classifying 10 normalized crop-type categories was .44 . Collapsing these 10 categories to four, as in Experiment 1, resulted in a probability of .58 . When half the data was used to train for classification on the other half at 10 levels of categorization, 64 out of 530 fields were correctly classified, or a probability of .12; at four levels of categorization, the probability was .39 .

Experiment 3

The third experiment of preliminary crop-type classification normalized the data for each observation in addition to normalizing the 10 crop-type categories in order to account for variations in luminous intensity along the aircraft flight line and between the two runs of data. This process normalized the intensities of the three different color bands as read through the three different densitometric filters, so that each color intensity reading ($B_i$, $G_i$, $R_i$) is normalized with respect to intensity so that the values used are the ratios

$$\frac{B_i}{B_i + G_1 + R_1}, \quad \frac{G_i}{B_i + G_1 + R_1}, \quad \frac{R_i}{B_i + G_1 + R_1}$$

Using the same normalized data to train and classify, (530 data points), the resulting probability of correctly classifying 10 normalized crop-type categories was .30 . Collapsing to four levels of categorization, resulted in a probability of .55 . When half of the data was used to train for classification on the other half, at 10 levels, 47 out of 530 fields were correctly classified, or a probability of .10; at four levels this probability was .43 .

Experiment 4

The fourth and final experiment employed unnormalized crop-type categories and normalized data. Using the same normalized data to train and classify (530 data points), the resulting probability of correctly classifying 10 unnormalized crop-type categories was .38 . Collapsing to four levels of categorization, as in the above experiments, resulted in a probability of .60 . The most significant aspect of this experiment compared to the three previous experiments is that when half the data was used to train for classification on the other half, 100 out of 530 fields were correctly classified at the 10 crop-type category level, or a probability of .19, and at the four category level 238 fields were classified correctly, a probability of .49. This suggests that there is important information in the proportional return from each wavelength band, independent of intensity, and that we can generalize best (with this data) using normalized data and unnormalized categories. When 530 data points in the fourth experiment were quantized to the 10 category levels, there were only 50 unique points. This is 40 less than the number of unique points in the second experiment, allowing for a better probability distribution with normalized quantized data.

## FURTHER STUDIES

These preliminary simulation experiments are of interest for spacecraft crop-type mapping in that they indicate clearly that a three channel ERTS satellite system will find the end of July to be decidely an undesirable time of the year to discriminate crop-types near Lawrence, Kansas: the accuracy of classification is poor for both 10 classes and four class categories. Obviously other months will need to be evaluated.

Immediate future efforts with the enlarged data set include a study of distance decay functions such as would apply when training in the southern portions of the study area and predicting with increasing distances toward the northern portions of the study area.

Since the study area is dissected by two rivers and their adjoining lowland valleys, we will compare results when training in the lowlands for prediction in the uplands, and vice versa. We will also train on the low altitude (7,000) data and predict for the high altitude (11,000) data.

When the 530 data points were quantized to 10 levels of categorization, several categories appear to group together. Since this grouping is based on how the sensor views the categories and not as we have grouped them in functional categories, these groups need further investigation.

Problems of variation in across-field-of-view reflectance need to be investigated further in order to decide how we normalize our data in the future.

In addition to discriminating crop-types on the basis of spectral reflection using automatic processing techniques, comparative tests will be made using human interpreters. These interpreters will be "trained" on a color-infrared photograph in which crop-types for given fields are known to them, and they will then be asked to predict crop types in adjacent fields, and to distant areas.

TABLE I. SUMMARY OF PRELIMINARY EXPERIMENTS**

| | A* (530 Data Points) | | | | B* (Different 530 Data Points) | | | |
|---|---|---|---|---|---|---|---|---|
| Experiment | Number Correct | Probability for 10 Categories | Number Correct | Probability for 4 Categories | Number Correct | Probability for 10 Categories | Number Correct | Probability for 4 Categories |
| 1 | 272 | .5132 | 349 | .6584 | 76 | .1245 | 203 | .3830 |
| 2 | 234 | .4415 | 307 | .5792 | 64 | .1207 | 208 | .3924 |
| 3 | 157 | .2962 | 289 | .5452 | 53 | .1000 | 227 | .4283 |
| 4 | 202 | .3811 | 317 | .5981 | 100 | .1886 | 258 | .4867 |

*A = Train and classify on same data (530 data points).

B = Train on one-half of data (530 points), classify on other half (530 data points).

**The preliminary nature of these experiments, using a limited amount of the total data which will be available, precluded testing of statistical significance of difference among the experiments.